A HISTORY OF GAS ENGINES

1791 - 1900

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DECLARATION

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning.

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ABSTRACT

The internal combustion engine has become an indispensible part of our present-day life, but surprisingly, its evolution has received an almost negligible consideration by either engineers or historians of technology. The work contained in this thesis is an attempt to remedy this situation and so fill a gap in our technological heritage.

The presentation is one in which there is a blend of technical appraisal, historical association and social implication concerned with the development of the internal combustion engine. Detailed technical descriptions are given only where it is felt necessary to do so and pains have been taken to identify any general trends towards a particular goal that took place during the whole period under review.

In a work of this kind, it is impossible to ignore the influence of individuals whose contributions, for better or worse, shaped the course of later developments; the lives and work of the principal characters involved have, therefore, been incorporated. Included also is a consideration of the effect upon the technological development of the internal combustion engine of events in associated technologies, in particular, those of the gas industry and the ability of the latter to supply an acceptable fuel.

The work presented here has been greatly enhanced by the discovery of a hitherto quite unknown source of information, consisting of a collection of letters written by Mr. F.W. Crossley, of the Crossley Brothers, Manchester between the

years 1880 and 1885. This collection entitled 'Letters to Abel and Imray' has come into the author's possession. Enormous use has been made of this source which reveals a great deal about the extent and influence of scientific thinking and experimentation that took place during these years, which technologically were very eventful. A substantial gap in knowledge regarding the development of the present-day form of the internal combustion engine, therefore, has been filled.

In carrying out the searches, numerous primary sources of information have been used. These include the archives of the Klöckner Humboldt Werkmuseum, Deutz, Cologne, (a direct descendant of the firm N.A. Otto and Co. 1864); the archives of Crossley Brothers, Manchester; the Marks and Clerk Collection, Science Museum, London and the Deutsches Museum, Munich. The material contained in these sources is not generally accessible and partly for this reason and partly to make the work more meaningful, a large number of illustrations has been included.

The completed work is a substantial account of how the internal combustion engine came to be; of the part it played in industry as a prime mover and the contribution that it made to the economic and social life of the nations during the nineteenth century.

PREFACE

The potential advantages of internal combustion as opposed to external combustion, were appreciated in the late seventeenth century and in chapter one, these very early attempts are outlined. The various possible arrangements of engines are given and a form of classification has been devised to assist the reader in identifying particular patterns of development. Factors, which made it necessary during this early period to consider alternative means for motive power to that of the steam engine are considered and the role of the gas engine is briefly mentioned in order to provide an appreciation of its contribution to industry.

Chapter two is devoted entirely to the more significant ideas and proposals for engines that were suggested between the years 1791 and 1860. This has been termed the formative period and proves to be one in which countless ideas were either proposed or tried. Although a small number of engines were made to run, none of them became commercially acceptable and possible reasons for this are discussed in chapter three, in which also the effects of progress in the gas industry and the technology of gas making are related to those that were taking place in engine technology.

The first commercially acceptable engines were produced in the 1860's and in chapter four, the events that led to these engines becoming a saleable product are related. Erroneous ideas with regard to combustion arose about this time, which influenced subsequent work for many years. These are discussed along with the difficult technical problems that were encountered which at one stage, threatened to cause the abandonment of any further work related to internal combustion engines.

A consequence of these difficulties was the appearance of an engine which employed a totally different - but not new - mode of action. This was the 'free piston' or 'atmospheric engine'. Chapter five discusses this engine, which was so outstandingly successful in industry and the ancestor of today's engine. Many thousand of them were produced and it was this particular engine that was introduced into England to begin a major national industry. The circumstances surrounding its introduction are also given in this chapter.

Chapter six deals with the four-stroke engine which was produced by N.A. Otto in 1876. This was a significant milestone in the evolution of the internal combustion engine. Almost overnight, after a good deal of secret preparatory work, many of the difficulties which for a number of years had plagued inventors, disappeared. It was a highly successful innovation, but the theories on which it was believed to work were based on false concepts. In this chapter, the events leading up to actual production are related, the causes and effects of patent litigation cases are discussed and the claims of prior contenders to have invented the four-stroke engine are evaluated.

Chapter seven is concerned with the period post 1876 and reveals the enormous energy that was expended on improving the four-stroke engine. Some difficulties concerned with ignition, design and operation still existed and the attempts that were made to overcome them are related. Various conflicting ideas with regard to design, operation and power output are discussed and the effect of the expiry of the Otto patent in 1890 is stated. A list of the principal manufacturers of gas engines in Great Britain during the 1890's is given with an accompanying description of their engines and the contribution they made. The results of a highly successful merger between the electrical and engine technologies, which has been discovered to have taken place during the 1880's, are also related.

The restrictive effect of the Otto patent to a large extent was responsible for a great many individuals producing engines which operated on alternative cycles, such as the two-stroke, three-stroke and six-stroke versions. Tremendous ingenuity was displayed by their inventors as they broke new ground and such work has been shown to have had a complementary effect upon that which was taking place on the four-stroke engine. In chapter nine, the benefit to society, resulting from this work and the various uses and applications of gas engines, is examined. The various branches of industry that used them and the numbers and sizes of engines used are assessed, and the contribution which resulted from the provision of cheap gas generators permitting the use of large power gas engines, is studied.

A resumé is given in chapter ten, in which particular trends and events during the period 1791-1900 are identified. Conclusions are drawn and a general pattern of development is presented.

A technical appendix is presented in Volume Two. Appendix One is a report of experimental work that has been carried out by the author on three historic gas engines displayed in the North Western Museum of Science and Industry, Manchester. The report described the tests and modifications made to enable the engines to run on natural gas and thus be presented as working exhibits. Appendix Two contains copies of the various original agreements that were made between Langen, Otto and Roosen of Cologne(formerly N.A. Otto and Co.) and Crossley Brothers of Manchester and also those between Louis Simon and Co. of Nottingham and the German firm, all between 1868 and 1870. These agreements have been translated from the German language and describe the arrangements and conditions that existed when the internal combustion engine was introduced into England from Germany. Appendix Three is a reproduction of a recently discovered source which illustrates the extensive use of the gas engine during the 1880's. Appendix Four is a copy, in full, of the English patent 2081 of the four-stroke engine of 1876.

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CHAPTER ONE

INTRODUCTION

1.1 The various forms of engine

The word 'engine' has an extensive historic association. In its various forms - engin, engynne, ingyn(n)e, ingen - it has been in use since the early fourteenth century, appearing in a variety of contexts[1]. There is an obvious relationship between 'ingen' and the latin 'ingenium', hence the word ingenious, and this appears to be the origin of the word, but up to the middle of the seventeenth century, there seems to have been little regard for consistent spelling; all of the above forms being used to describe a variety of situations. Two fairly distinct applications, however, can be detected. One is that associated with a native talent such as of wit or genius: 'A man hath sapiences*, thre, Memorie, engine, and intellect also' (Chaucer - Second Nun's Tale 1386). 'If thy master be angrie with thee, I shall suspect his ingine, while I know him for't' (B. Johnson - Evolution of Man in Humanity 1598). The second application is that concerned with mechanical contrivances, namely instruments of war, also used from the early fourteenth century. The antiquated English usage given, however, makes the sentences containing the word almost unintelligible.

The path, towards the now generally accepted meaning of the word engine, began about the middle of the seventeenth century at which time it would seem to have acquired a quite distinct meaning from its former associations, 'ingine' and

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* Sapiences - possessing profound wisdom or knowledge

'ingynne'. The first indications of a prefix to describe a particular application can also be found about this time. Examples of those that still survive are: beer engine, fire engine, mill engine, carding engine, winding engine, traction engine, rose engine - an attachment to a lathe which produces on the work a variety of curved lines resembling a rosette - and dividing engine - an accurate and delicate form of ruling machine. Later came railway engine and blowing engine. At this particular time, the word 'engine', together with its prefix, became a way of expressing, or generally defining, any kind of machine in which physical power was applied to produce some desired physical effect.

A more restrictive use of the prefix began during the nineteenth century and, in addition, it took on a more especial meaning. The physical force applied was assumed to be heat (or caloric) and its conversion was later (after Joule) understood to be to mechanical power. It then became possible to be more specific about the engine referred to; for example, steam engine, reciprocating engine, four-stroke engine, single-acting engine, internal combustion engine, horizontal engine and so on. In this context, a prefix could then be used respectively, either to define the working substance that was used, the type of motion performed by the principal parts, the number of working strokes necessary to complete the cycle, the manner in which the working stroke was used by the engine, the place where the heat was produced or the physical disposition of the engine. These various definitions will now be more fully explained.

Faced with the problem of how to describe an engine, it seems natural enough to use a prefix which is directly related to the working substance that is being used. In the course of time, a variety of working substances have been tried and have consequently given rise to such terms as air engine, vapour engine, gas engine, diesel engine, ammonia engine, water engine and ether engine. Gunpowder was one of the first flammable substances to be used in attempts to produce engines in the late seventeenth century and references to 'gunpowder engine' can be found then and, indeed, during the eighty years or so following, to the 1860's. The cannon would thus be referred to as an engine, but it suffers from the disadvantage of dispensing with its piston at each firing stroke.

One of the first rotative devices was that by Hero of Alexandria who, at some time during his life between 150 B.C. to A.D. 250* suggested how a hollow sphere on which were mounted two 'nozzles', through which steam would issue, could be used to produce a rotary motion, but no evidence exists that Hero's Aeolipile was ever constructed. In 1619 Giovanni Branca put forward his ideas for an impulse turbine, but it was not until 1884, when Charles A. Parsons successfully produced his impulse turbine which is so widely used at the present time.[2]

The term 'reciprocating engine' is used to distinguish those engines in which there is a to and fro action of the piston, from those which execute a purely rotative motion such as that just described. Early reciprocating engines - the

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* Scholars differ widely in their opinion of Hero's lifespan. He is reported to have observed and given an account of a moon eclipse in A.D. 62. Dictionary of Scientific Biography Vol. VI p.310

steam engine by Newcomen in 1712 and the gas engine by Samuel Brown in 1824 - produced a power stroke at a more or less regular interval, but this intermittent nature of working, and slow, ponderous actions, was a great spur to producing something better.

The four-stroke engine is the most commonly used cycle of operation in modern-day engines and the use of this particular prefix appears to have begun c.1880 when engines that operated on quite a different cycle looked like being successful. These latter engines used only two-strokes of the piston to complete the working cycle and very early in the 1880's, engines of three stroke and six-strokes were made. There arose an obvious need, therefore, to distinguish between these various cycles of operation. A similar necessity arose with respect to the term, 'single acting engine'.

As steam engine technology progressed, it became common practice to admit steam alternately to each end of the cylinder so that each stroke of the piston became a useful one. The practice was tried in the early stages with gas and vapour engines, but numerous practical difficulties eventually caused its abandonment. The manner in which the working substance is used by an engine is not confined solely to the terms 'single' or double' acting; in steam engines for instance, the steam, after passing from the cylinder, is sometimes passed into a condenser and the engine would then be referred to as a 'condensing engine'. This results in improved efficiency and a further improvement in operation can be made when successive expansions are used, the principle is then known as compounding and a compound engine may employ two, three, or even four expansions, thus extracting more of the available work from the steam. Many attempts were made to compound gas engines, but were never successful for reasons discussed in chapter seven.

The prefix 'internal', as in internal combustion, describes those engines in which the fuel used is burned within the working cylinder, such as in gas engines, diesel engines, and inflammable vapour engines. The opposing term is external combustion engines, in which the fuel necessary to produce the high temperatures required is burned at some point remote from the working cylinder, such as the boiler of a steam engine or the furnace of a hot-air engine.

1.2 The heat engine

The various prefixes listed previously, although perplexing to the layman, have nowadays become explicit, but during the formative years of the internal combustion engine, beginning c.1790, there was a good deal of uncertainty with regard to the names that were given to engines. Patent specifications show that inventors were never quite sure what to call their newly-created devices. John Barber in 1791 proposed using 'inflammable air for the purpose of producing motion'[3]; Robert Street in 1794 described 'A method of producing inflammable vapour force by means of fire, flame, etc.'[4] Erskine Hazard, in a communication from Samuel Morey of America in 1826 'prepared a mixture of vapours with air and exploded them to obtain motive power'[5]. Uncertainty in terminology was quite common up to the 1860's and 1870's at which time the expression 'gas engine' became more frequently used. A popular phrase used by inventors at this time was 'Improvements in Motive Power'. Prior to this, hopeful inventors, partly from a desire to make their patent claims as comprehensive as possible and partly as a result of their uncertainty with regard to the physical properties of the substances involved, would make extensive claims such as 'Improvements in gas, caloric or air engines', or 'Improvements in gas, vapour and explosion engines'. Gradually, this generalised terminology took on a more definite meaning: the term 'gas engine' being used to define those engines that used gas such as hydrogen or coal gas;* 'vapour

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* In 1826, various attempts to use the vapour pressure of CO_2 were made. These also were referred to as 'Gas Engines'. A full discussion of these is given in Chapter Two.

engines' were those which used spirits or turpentine or resins; air engines were those in which air only was alternately heated and cooled to produce motive power. The reference to caloric engine, indicates that there was an appreciation that 'heat energy' to use the modern equivalent, was the agent responsible for the power that was produced. The term 'heat engine', however, did not come into general usage until much later, probably about 1870.

Heat engines are those in which a hydro-carbon fuel such as wood, gas or oil is used to raise the temperature of the working substance. Thus, the steam engine as an external combustion engine and the gas engine as an internal combustion engine, are both heat engines. In the former, the working substance is steam and in the latter, it is air. The work in this thesis is concerned with the technological development of internal combustion engines, but it is worthwhile at this juncture to outline the differences in operation of both steam and air engines. This proves helpful in attempting to establish why, c.1791, serious attempts began to obtain motive power using internal combustion, at a time when steam engines were apparently so much in favour.

The situation with regard to motive power at the beginning of the nineteenth century, was that the steam engine was in wide use with much thought being given to its improvement. Cetain defects inherent in its working, however, had become apparent. It was realised, for instance, that with a steam engine, a large amount of the available fuel was spent in producing the necessary change of state from liquid to vapour* and, furthermore, that the energy required to do

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* Joseph Black's concept of 'latent heat' was known by this time 6.

this was not utilised by the engine since, after using the steam, it was rejected still as steam. If the temperature of the steam before admission could be raised, the loss referred to above would be comparatively small, but it is here that the real difficulty and disadvantage of the steam engine lies.

High temperature steam cannot be obtained without extraordinary high pressures occurring, which, at that time, would have been quite unmanageable. So-called 'high pressure' steam engines were in use, but in 1826, pressures of fifty pounds to the square inch were thought formidable. Boiler explosions were thus a frequent occurrence in the steam engine plant up to the mid-nineteenth century and presented an obvious disadvantage to their use. The high latent property that water possessed led to other liquids such as ammonia and ether being tried, but because of their toxicity, they required a leak-proof regenerative cycle, which added considerably to the initial cost without sufficiently proving their worth.

The steam engine also possessed a number of practical disadvantages. When starting from cold, a period of at least a half hour was required to raise steam - with large engines it was as much as two hours. The boiler had to be stoked continuously, even when power was required only intermittently and, at the close of the day, the hot coals had to be 'drawn' from beneath the boiler. The ash, grit and smoke that seemed to be ever-present when steam engines were used was another inconvenience and, in addition, an attendant was required to supply the lubricant to the engine and the coal and water to the boiler. With difficulties of this nature present, it is hardly surprising that thoughts should be given to some alternative means for motive power, the employment of air being a popular choice. Benjamin Cheverton's letter of 1826 gives us some indication of the situation that existed at that time[7].

> 'It has long been a desideratum in practical mechanics to possess a power engine which shall be ready for use at any time, capable of being put into motion without any extra consumption of means and without the loss of time in its preparation. These qualities would make it applicable in cases where but a small power is wanted and only occasionally required. They are so numerous and the consequent saving of human strength so great that the advantages accruing to society would be immense, even if the current expense were greater than that of steam. Such an engine should also be actuated by a force so concentrated and so compendiously appropriated, as to occupy but little space and be but of little weight, by which it would become applicable to locomotive purpose' .... 'it is well known that the common steam engine satisfies none of these conditions' ....

1.2.1 Air engines. The gas engine method and essential requirements

When air is used as a working agent in an engine, there are two possible ways of utilising its properties. One is by causing it to be alternately heated and cooled, its temperature previously having been raised considerably in a separate furnace and, secondly, by arranging for a quantity of air to be heated by a combustible fuel that is intermingled with it. The latter is what may be described as the gas engine method, which eventually proved superior to any other which used air. Subsequent chapters are concerned with the technological development of this type of engine and, in order to assist the reader to appreciate the progress that was made, the basic principles involved in the working of such engines will shortly be outlined. An example of the first method of using air is the hot air external combustion engine and some mention will now be made of work that was done in this field, since it had a marked effect upon the ideas that arose for internal combustion engines.

Work with hot air engines began at the same time as, and proceeded simultaneously with, that on internal combustion engines. Indeed, hot air engines were thought to be a much more attractive proposition. Potential advantages included an avoidance of the need to change the state of the working fluids; no boiler was needed, hence no risk of explosion; no exhaust pipe from the engine was necessary and a water jacket was often dispensed with*, so the heat loss should be minimised; and further, when working, the hot air engine is almost silent, smooth in operation and shock-free. These considerably appealing features of the hot air engine attracted the attention of many of the eminent scientists in the first half of the nineteenth century, among them, J. P. Joule, Professor W. Thomson (Lord Kelvin) and, in 1854, Professor W. J. M. Rankine, who was sufficiently moved to prepare and read a paper on the subject to the British Association[8]. Several engineers, eminent in their own right, of the calibre of Stirling, Ericsson and Sir C. W. Siemens, devoted a good deal of their energies and studies to the practice and theory of hot air engines. But thirty years after Rankine's paper, even with numerous efforts by scores of less able inventors[9], hot air engines had made no real advances.

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* Larger power hot air engines (of 5 horse-power and above) would incorporate a water jacket

The factors responsible for this lack of success were mainly of a practical nature. Air is a difficult substance to heat and in order to produce in it a significantly high temperature, a large surface area of metal had to be heated to something like 600°C; even so, the maximum temperature of the air attainable was only 350°C. High maximum pressures - up to 200 pounds to the square inch resulted, but the mean effective pressure, largely because of the considerable volume expansion ratio used, was often less than ten pounds per square inch.

The combination of high temperatures and pressures, placed heavy demands on the material used for the heating chamber and frequent replacements were necessary due to its having burned away. A further disadvantage of hot air engines lay in the fact that they were bulky in comparison with the power generated; Wenham's hot air engine for instance, used a particular method of internal firing, which reduced the size of heating chamber required[10], but even then the cylinder diameter was twenty-four inches, stroke was twelve inches and it had an output power of only four-horse power.

The chief disadvantages of hot air engines, therefore, were the need for frequent hot chamber replacement and an enforcement to work at lower temperatures than would otherwise be desirable for an efficient cycle. In addition, the fuel consumption of hot air engines was up to five times that of a comparable steam engine. The Wenham used eight pounds of coal per brake horse-power per hour whilst the Bailey engine, it was claimed, used just under ten pounds of coal per hour[11]. (A Boulton and Watt Compound Steam engine would use about 2.7 pounds in 1863 and the average consumption of marine engines was about 4.25 pounds per brake horse-power, per hour).

In the gas engine method, the method of heating of the air is quite different and takes place within the working cylinder. Many of the practical disadvantages associated with the hot-air engines are thus eliminated. The temperature limits of operation are widened immensely and, consequently, a large mass of air can be heated in a fraction of a second. The combination of a boiler and furnace, or heat exchanger in the working cylinder enables a much more compact and simpler unit to be built; no preliminary warming-up period is required and it can be stopped and started very conveniently. These potential advantages of internal combustion engines over any other form appear to have been recognised as early as the 1670's, when attempts with gunpowder began, but their successful application was not achieved until nearly two hundred years later.

There are a number of ways, or cycles of working, by which an internal combustion engine can be made to work and these are given and discussed in Section 1.4 of this chapter, but having just outlined the advantages presented by such engines, it will be helpful at this point to define their theoretical requirements. The following are the essential points to be aimed at in practice.

1) The ingoing charge should experience a minimum restriction to flow. The passage conveying the charge should be of ample area to reduce frictional losses and short in length, so that the charge will not become unduly heated by the walls.

2) To reduce 'throttling' of the charge as it enters the

cylinder, the cut-off should be rapid and ignition should occur as soon as possible thereafter.

3) After ignition, the expansion of the burning gases must be rapid so that heat loss to the cylinder walls is reduced. The extent of the expansion should be such as to realise the maximum amount of work.

4) The exhaust gases should be released quickly by arranging for a rapid opening of the exhaust ports. The passages to be of a sufficient area to reduce restriction.

Depending on the particular cycle that is used, other requirements may arise, but by about the year 1885, these had come to be fully appreciated[12].

1.3 Three periods of progress

The technological progress of the internal combustion engine can be seen as taking place in three phases: the experimental period to 1860, followed by a development period to 1880 and lastly, an improvement period from then to the present time. As mentioned previously, the earliest recorded suggestions and attempts to obtain motive power using inflammable substances took place in the late seventeenth century[13]. These apparently follow the discovery of atmospheric pressure and the power of a vacuum by Evangelista Torricelli, Blaise Pascal and Otto Von Guericke. In 1673, Christiaan Huygens (1629-95) carried out experiments using gunpowder with a device constructed mainly of wood and leather. Huygens sought to utilise the vacuum* that resulted on cooling after an explosion had taken place[14]. Huygen's assistant, Denis Papin, continued in these attempts to ob-

* Precisely the same idea was used in the 1820's and very successfully in 1861. See Chapters Two and Three

tain a more peacable application of gunpowder, but apart from the obvious dangers, the difficulty of procuring a good vacuum and that of obtaining continuous motion, could not be overcome. It was the failure of these experiments which led Papin to experiment with steam[15] and after that, apart from a claim in 1729 by an Englishman, John Allen, to have used gunpowder in propelling a ship, the attempts with inflammable fuels - such as they were - ceased until 1791. During this period, attention was almost wholly occupied in using steam.

When John Barber once more revived the ideas for internal combustion engines in 1791, the experimental period thereafter gathered momentum with an ever-increasing interest in internal combustion. But almost seventy years were to pass before a successful version of such an engine appeared, designed by J.J.E. Lenoir who, at the time, was living in Paris. The Lenoir engine came after the lengthy succession of failures by other inventors and gave practical proof that the idea of internal combustion was possible. It signalled the beginning of the development period, but success was not easily achieved. The Lenoir engine itself went through a difficult proving period but it was, nonetheless, a notable landmark by which others sought guidance as they experimented themselves. Progress was slow and one can detect a feeling of exasperation by engineers and inventors during the 1860's at the failure to overcome the practical difficulties that still remained. As this particular period progressed, an understanding, first of the practical limitations of engines arose, to be followed by an appreciation of the theoretical considerations underlying their operation, the latter occurring in the late 1880's. It was during this particular decade that the rate of advancement in engine technology was probably greater than at any other time in its history, with events in associated technologies, such as in steel-making and gas production, greatly contributing. Scientific interest was roused also during the 1880's and the continuous demand by industry for mechanical power was further responsible for generating additional impetus.

By the early part of the 1880's a sufficient experience in the technology of engine making, coupled with a moderate degree of scientific understanding, had established the basic principles necessary to ensure an economical and efficient engine. From then on, the problem became one of improvement, of increasing the economy, the efficiency and the power of engines. For the first time, research projects to investigate the effect of varying parameters associated with engine performance were initiated and from these, improvements in combustion chamber design resulted from an appreciation of the value of compression ratio and an understanding of heat energy distribution that took place in the engine.

1.4 A classification of gas engines

From the vast number of ideas that were put forward for internal combustion engines during the three periods just mentioned, it is possible to distinguish three principal methods of working. These will now be described since it will assist the reader to obtain a more meaningful understanding of the progress that was made and to identify particular ideas that were popular at any one time. A classification of this nature also simplifies the task of comparison, a number of engines, for instance, of quite dissimilar appearance, often prove to have identical modes of operation.

The three classifications based on the method of working and the working cycle of each is as follows:

Type 1 Engines without prior compression of the charge. Ignition occurring at constant volume.

Type 2 Engines in which the charge, having previously been compressed, is ignited as it enters the working cylinder, giving rise to a constant pressure cycle.

Type 3 Engines with prior compression of the charge. Ignition occurring at constant volume.

Type 1	Type 2	Type 3
Admission of charge at atmospheric pressure	Admission of charge at atmospheric pressure	Admission of charge at atmospheric pressure
	Charge is compressed into separate receiver	Charge is compressed in working cylinder
Ignition at constant volume	Ignition at constant pressure	Ignition at constant volume
Expansion during working stroke	Expansion during working stroke	Expansion during working stroke
Exhaust stroke. Products expelled	Exhaust stroke. Products expelled	Exhaust stroke Products expelled

The first type of engine is the simplest in principle; it was the first to be tried and occupied the minds of inventors up to the late 1860's. The method used in such engines was simply to admit the inflammable charge* at atmospheric pres-

* The method of admission of gas and air was often a complex procedure. Ideas on this are discussed in Chapter Four.

sure into the working cylinder, and then ignite it when the piston had travelled about one third to one half of its stroke. The resulting expansion, often preceded by a violent shock, forced the piston to its extreme end, performing the working part of the cycle as it did so. If the engine was of a double acting type, the process would be repeated in the opposite end of the cylinder. The exhaust products present in one end of the cylinder would be expelled by the piston as it performed its working stroke, brought about by combustion in the other end.

Two comparatively successful users of this particular cycle were the Lenoir and Hugon engines of 1860 and 1863 respectively. It had been tried a number of times previously, but including the Lenoir and Hugon, never became totally successful for reasons mentioned later. More successful applications of this cycle were the so-called 'Atmospheric Engines' of Otto and Langen from 1867 and the 'Bisschop' engines from 1872. In these engines, the piston is not directly connected to the connecting rod and crank via a cross-head as in the Lenoir and Hugon engines, but is allowed an unrestricted movement, being propelled by the force of the explosion beneath it. Much greater expansion was thus obtained. Atmospheric engines as the name implies, utilised atmospheric pressure to effect the working stroke, they became highly successful in use and caused the abandonment of direct acting non-compression engines during the 1860's.

The second type of engine involving a constant pressure cycle was first suggested in 1801 by Philippe Lebon, a French engineer. C.W. Siemens took the idea a little further in

1861, but it was an American, George Bailey Brayton, who produced a fully-working engine using this principle in 1873. Several Brayton engines were made during the following years and they proved a serious threat to the four-stroke engine of Otto soon after it was introduced in 1876. The chief virtue of these constant pressure engines was the absence of explosive shock, which had been experienced in constant volume engines working without compression. The mixture burned steadily as it entered the motor cylinder and not explosively as in the Lenoir engines; a smoother, quieter running engine being the result. Their disadvantages proved to be greater fuel consumption and lower thermal efficiency than the Otto engine, which used a constant volume cycle of operation but with compression. In these constant pressure cycle engines, two cylinders were normally used, a motor or working cylinder and a pumping or charging cylinder, which usually compressed the charge into an intermediate receiver before being admitted to the motor cylinder.

A similar arrangement to this was used on two-stroke cycle engines, which first appeared in 1878. These are discussed in Chapter Eight.

The final type of engine, that is the one that ultimately became successful, was that in which compression of the charge took place within the motor cylinder, and is the one now used on modern engines. The root cause of its success was compression, although this fact was not appreciated until several years after the first successful commercial application of this engine by Otto in 1876. Oddly enough, the concept of compression had occurred much earlier in the experimental period; a hint of it was given by L.W. Wright in 1833, which was followed by a more positive suggestion by W. Barnett five years later and M. Beau de Rochas most clearly described how it should be applied to an internal combustion engine in 1862. In the same year, so also did another Frenchman, M. Million. Prior to 1862 and Beau de Rochas, the attempts to use compression involved the use of two cylinders in the manner described above, but without a separate receiver. Similar designs were also used much later by inventors seeking an alternative mode of working to that of the Otto cycle; the object being mainly to avoid infringing Otto's patent.

1.5 The role of the gas engine

It has been pointed out earlier that the steam engine, for reasons of economy and convenience, did not wholly satisfy the demands of industry as a means of motive power. Neither was the hot air engine an acceptable alternative. Hopes, therefore, rested on the eventual success of the internal combustion engine. The working engines of Lenoir and Hugon up to 1867 went some way to easing the situation, but by no means did they have the significant impact that the four-stroke engine of 1876 or even that of the Otto-Langen atmospheric engine of 1867 had. Indeed, there is a suggestion that their high consumption of gas and the practical problems associated with their use did much to depress the initial expectations of internal combustion engines. By the year 1870, events with regard to the usage of gas engines began to change and by the end of that decade, due largely to the success of the Otto-Langen atmospheric engines, gas engines had become an essential component of industry. There is little need to expand here on this point, since it is covered extensively in Chapter Nine, but the list of applications shown in Figure 1.1 gives some indication of how widespread the use of the gas engine had become. (A fuller appreciation may be obtained from Volume Two of this thesis, Appendix 3). By the end of the development period, c.1890, so effectively had developments in engine technology progressed that practically every corner of industry had derived some benefit from their use. The gas engine had come to occupy an exceedingly strong position as a trustworthy and economical prime-mover, revolutionising the employment of small motors and was firmly established in a high position among prime-movers of the nineteenth century. As the decade progressed, so also did the quality and quantity of gas engines. The steam engine, its use having already been seriously threatened, began to be supplanted as very large gas engines of several hundred horse-power became possible. Accompanying this progress, were appreciable social benefits and these are also outlined in Chapter Nine.

- Agricultural machinery
- Bakeries
- Blacksmiths
- Biscuit making
- Boot and Shoe making
- Bottle washing
- Brewers
- Builders' yards
- Cabinet makers
- Cartridge makers
- Chaff and hay cutting
- Clock makers
- Clothing manufacturers
- Coach builders
- Coal and coke breaking
- Corn crushing
- Cycle works
- Dairies
- Electric lamp making
- Electric lighting (generation)
- Engineer workshops
- Foundries
- Gas works
- Glove makers
- Grocers
- Hoisting
- Joiners' workshops
- Laundries
- Leather works
- Malt works
- Meet cutting
- Mineral water works
- Newspaper offices
- Organ blowing
- Paint manufacturers
- Printing
- Refrigeration
- Rope manufacture
- Sail makers
- Saw mills
- Spinning
- Tanneries
- Tobacco merchants
- Water pumping
- Weaving
- Wood chopping

Extracted from manuals and prospectuses of various gas engine manufacturers to 1900.

Figure 1.1 A list of applications of Gas Engines

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3. English Patent 1833/1791
4. English Patent 1983/1794
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7. Mechanics Magazine Vol. 5 (1826) p.386. Apart from his various contributions on the subject of motive power, nothing is known of Cheverton. In 1826, he suggested a 'carbon dioxide engine'. See Chapter Two.
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12. Samuel Griffin. 'Modern Gas Engine Practice'. Soc. of Engineers (1889) p.169
13. Friederick Klemm. A History of Western Technology (London 1959). p.212
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15. Klemm. Op. cit (13) p.220

CHAPTER TWO

THE FORMATIVE YEARS

A successful product is, more often than not, preceded by a series of unsuccessful ones and, in this respect, the internal combustion engine is no exception. A period of serious experimentation began in 1791 and from that time many hundreds of ideas for motive power were put forward, which culminated eventually with an acceptable working gas engine - the Lenoir - in 1860. Only a small number of these varied ideas, however, proved to be worthy of consideration and the more notable, those which attempted to utilise the explosive power of inflammable fuels that is, are described in this chapter.

It will be seen that working engines were produced quite early in the period mentioned above and that throughout these formative years, many outstanding suggestions for engines were made that came surprisingly close to modern-day engine construction and operation.

2.1 1791 - 1830

2.1.1 John Barber's impulse - gas turbine

Interest in explosive engines was revived by an Englishman, John Barber in 1791, after a century of inactivity, with a proposal to 'obtain and apply Motive Power'. The experimental period may well be said to have begun with this idea of Barber's and then continued, gaining in strength until the appearance of the Lenoir engine in 1860, which in itself acted as an incentive to produce something better.

Barber is described as a 'Gentleman' of Attleborough, Nuneaton, and in his patent[1] claims that:

> 'After much trouble, care and expense, I have found out and invented, a method Rising Inflammable Air for the purpose of procuring motion and facilitating Metallurgical operations and which may be applied to the grinding of Corn, Flint, Manganese or other Matter, also to Rolling, Slitting, Forging and Battering Iron and other Metals, Turning of Mills for Spinning and Engines, for Turning up Coals, Minerals from Mines of all sorts, Stamping of Ores, Raising of Water and other motion that may be required'.

Figure 2.1 shows Barber's proposed engine, which contains all the elements of an impulse gas turbine, two metallic vessels, at A, which he called retorts, contained a combustible material such as coal, wood or oil and a fire was applied to them to produce an inflammable gas*. This gas would then enter a receiver, B, where it was cooled by a 'circumambient cistern of water', passing then into pumps D, one for air and one for the gas - which were worked by the overhead beam. The purpose of the pumps was to pass the cooled gas into one of the compressors (the second

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* The purpose of two vessels was that one could be emptied of 'coals and ashes' while the second was kept in operation

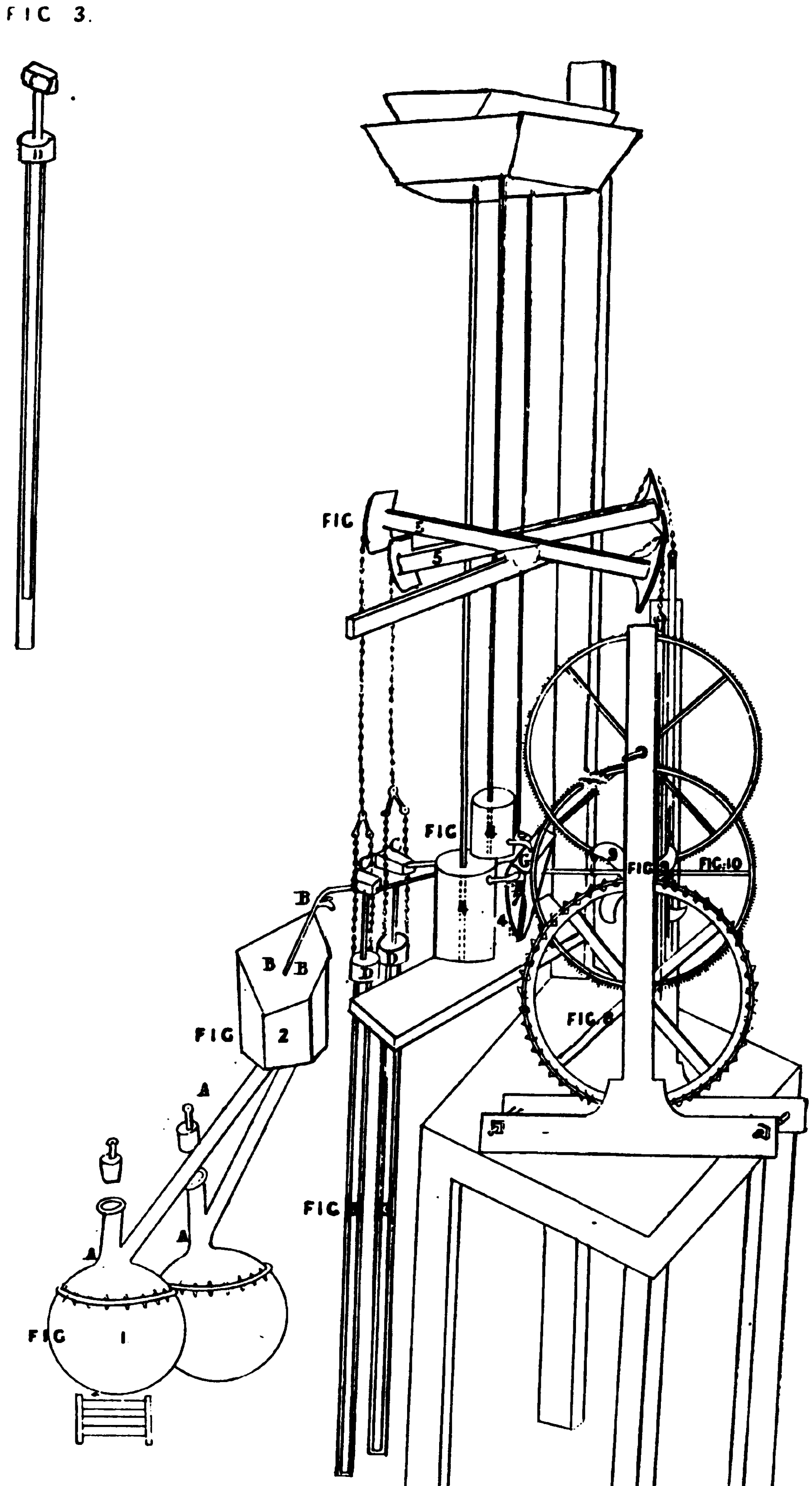

Fig. 2.1 John Barber's 'impulse gas turbine' of 1791, which signalled the beginning of the experimental period.

compressor was for air) which was compressed by the action of the head of water contained in the overhead cistern. The inflammable gas and air would then be forced separately into the exploder (just visible at G) being regulated by stop-cocks as it left the compressors.

The exploder, G, is shaped remarkably like a nozzle used in modern turbines and produced exactly the same effect, namely, an increase in the velocity of the fluid as it passed through. The inflammable gas was ignited as it emerged from the exploder, and, as Barber states:

> 'the combined streams of air and water do issue out with amazing force against the flywheel'

(The 'flywheel' is shown with vanes placed round its periphery).

Whether or not Barber produced a working form of his patent ideas is not known; he did, however, see or, if he made the device work, may possibly have experienced the need for cooling the exploder, since he arranged for an auxiliary pump to inject a small stream of water into the burning gases as they left the combustion chamber. This was, he said:

> 'to prevent the inward pipes and mouth of the exploder from melting by the intenseness of the issuing flame'

Despite this precaution, it is difficult to imagine a successful application of the whole idea. The material technology of his day would hardly be able to match up to engine requirements. Furthermore, no details whatever are given which describe how the admission valves are to work and there is a considerable vagueness as to how the compression is produced by the head of water.

Barber was far-sighted enough to see another intriguing application of his idea, by claiming that the fluid stream could be:

> 'passed out at the stern of any ship, boat, barge or any other vessel, so as by an opposing and impelling power directed against the water carrying such vessel, the vessel with its contents may be driven in any direction whatsoever'.

While Barber's knowledge of reaction kinetics is suspect, his intention is clear enough and his ideas were not taken up until something like a hundred and forty years later.

2.1.2 Robert Street. A vertical engine with iron piston

There is seemingly no apparent connection between Barber's ideas and those of another Englishman, Robert Street, which followed three years later. Street's patent[2] describes the first real gas or vapour engine of this period and earns him the distinction of being the first to suggest an iron piston in a cylinder. The patent drawings are very simple and totally lacking in detail, but the principle on which he supposed his engine to work (first suggested by Huygens a hundred years previously) formed the basis of ideas over the next thirty years. After a further thirty year period, during which Street's principle was ignored, it was revived again in the 1850's by two Italians, Barsanti and Matteucci, and again by Otto in 1866*.

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* The work of these two Italians is described later in this chapter and that of Otto in Chapter Five.

Street was a varnish-maker from Christchurch, Surrey and his patent claimed:

> 'An invention to produce an inflammable vapour force by means of liquid air, fire and flame, for communicating motion to Engine, Pumps and Machinery'

The vapour he suggested could be used, was obtained from turpentine, about 'ten drops to a cubic foot of space', which were dropped onto the base of the cylinder heated by a fire beneath it, see Figure 2.2. His description from the patent reads as follows:

> 'A, is an iron cylinder; B, a solid iron piston fit into the cylinder; D, a strong frame in which the cylinder is suspended; E, is a stove to keep the bottom of the cylinder hot; F, a counter-sunk touch hole near the bottom of the cylinder.
>
> 'To cause the engine to work, a fire is lit beneath the base of the cylinder and when sufficiently hot, the fuel is poured via a funnel to fall onto the heated base whereupon it instantly vapourises. At the same time, the piston is raised by the lever G, which sucks in air and also raises a light to the touch hole. The vapour takes fire, forces up the piston, raising with it the long shaft K which descends with the piston, thus working the pump or other machinery at the opposite end.'

Street seems quite unaware of the principle on which his proposal depends, namely, the creation of a partial vacuum beneath the piston, thus allowing atmospheric pressure to act on its upper face, at least, he makes no mention of this. The engine was not capable of continuous operation either, since it had to be hand-operated. Again, as with Barber, there is no evidence to show that Street ever developed this idea, but Witz[3] - without any supporting evidence - claims that Street was described as a genius for his ability to produce an inflammable vapour from a liquid fuel.

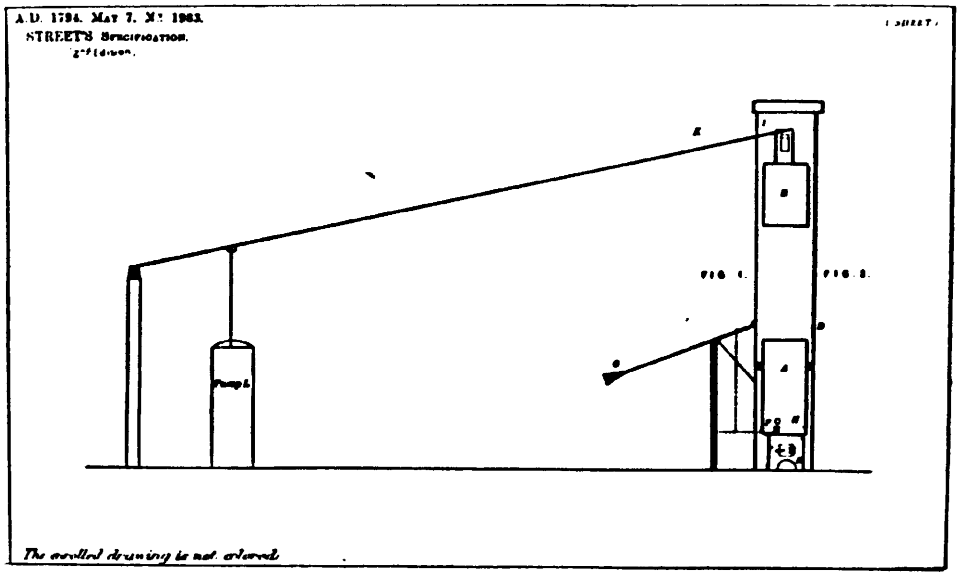
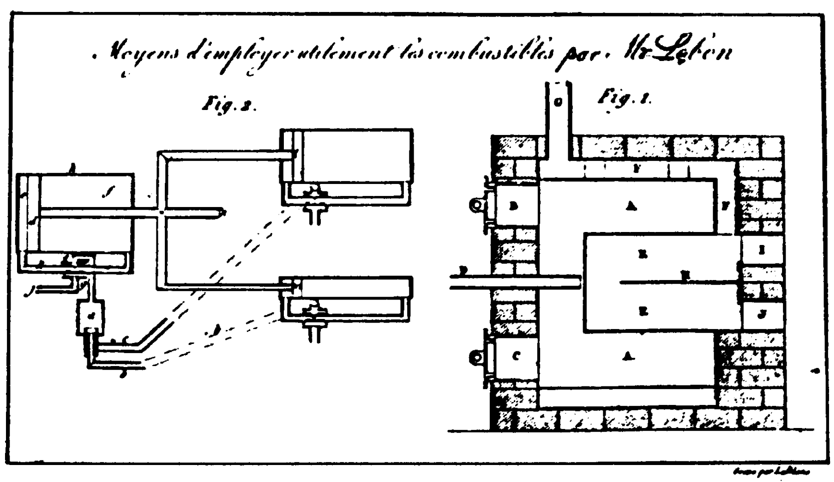


Fig. 2.2
Robert Street's explosion engine of 1791



Engine

a. Air-gas mixing & ignition chamber.
b. Gas supply pipe.
c. Air supply pipe.
d. Double-acting power piston.
e. f. Combustion & expansion chambers.
g. Box containing engine actuated supply & exhaust valves.
h. Power cylinder.
i. Pipe for incoming burning & then exhaust gases.
j. Exhaust pipe.
k. Same as i. but serving opposite cylinder chamber.
l. Air supply pump piston.
m. Gas supply pump piston.
n. Connecting rod.

Gas Generator

A. Sealed gas generator box.
B. C. Closable ports for adding coal and removing coke at end of distillation cycle.
D. Gas outlet to engine or lamps.
E. Furnace to heat the closed chamber A.
F. Circulating flue to pass hot furnace gases around A.
G. Furnace chimney.
H. Platform to hold second coal bed.
I. J. Combustion air supply and openings for charging and cleanout.

Fig. 2.3
Compression engine using separate pumps, by Phillipe Lebon in 1801.

2.1.3 Advanced ideas by Philippe Lebon

The turn of the eighteenth century saw a remarkably far-sighted suggestion for motive power by a Frenchman, Philippe Lebon d'Humbersin (1769-1804). Lebon, unlike those before him, had the advantage of a good education and had become a successful engineer and chemist. He recognised the lighting potential of gas at about the same time as William Murdoch did in Great Britain and in 1799, registered a patent to produce an inflammable gas from the distillation of wood[4]. After two years, during which he did much to develop the gas lighting industry in France, Lebon took out a patent of addition to his former one dated August 25 1801, in which details of his engine are given. This was a double-acting engine, and the ideas proposed by Lebon for its operation were far in advance of their time.

Figure 2.3 shows the arrangement of Lebon's engine, together with the gas generator. An excellent grasp of essential engine requirements is illustrated by Lebon's recognition of the need to control the quantity of gas and air, to utilise pressure in some way and a use of the expansive force brought about by combustion. He also suggested that electric ignition should be used. The air and gas cylinders are seen to be proportioned in size and this is how Lebon believed the correct volumes of each could be obtained. The pistons in these two cylinders being connected by rigid rods to the main, or working piston, ignition was to take place in a small ante-chamber as the inflammable charge entered; ignition then occurred and the burning gases would be admitted into the working cylinder. The form of working cycle proposed by Lebon, therefore, was one in which combustion took place at constant pressure, a cycle that was not adopted until seventy years later by Brayton of America.

Whether or not Lebon put his far-sighted proposals into a working form is not known. Had he attempted to do so, it is certain the difficulties would have arisen; the state of electrical technology at that time, for instance, being sufficient in itself to ensure ignition difficulties would have occurred*. But in no way does this detract from Lebon's excellent appreciation of what needed to be done to produce motive power by such means. Unfortunately, he never got the opportunity to develop his ideas further; in 1804 he died, following an attack upon him in the Champs d'Elysée, where he was robbed and stabbed.

* Lenoir used electric ignition in 1860, but it was not successful. Reliable electric ignition methods did not materialise until the 1880's despite numerous attempts during the intervening years to use it.

2.1.4 Propulsion by Isaac de Rivaz

While Lebon was tossing thoughts about in his mind, ideas of a similar nature were fermenting in that of a Swiss engineer, Isaac de Rivaz (1752-1828). Since 1784, Rivaz had considered the possibility of using explosive means to propel a wheeled carriage. Initially, he tried gunpowder but abandoned these attempts in favour of steam, but in 1802, turned once more to explosive means[5]. In 1805, he succeeded with an engine, which was a considerable improvement of Street's idea in 1794*. Figure 2.5 is a diagrammatic version of the Rivaz carriage and Figure 2.4 a model, exhibited in the Swiss Museum of Transport, Lucerne. The engine by Rivaz used atmospheric pressure to produce the working stroke and a free-wheel arrangement to allow the unrestricted ascent of a piston, which was flung up by an explosion beneath it. All of these were the essential features in the engines by Barsanti and Matteucci in 1857 and by Otto in 1866, although neither of the latter make any mention of Rivaz, who obtained a patent in 1807[6].

The arrangement shown in Figure 2.4 was used to propel carriages built in 1805 and 1813. A long vertical cylinder contained a piston fitted with a rod, to which was attached a chain. The chain was formed in a loop around a pulley, so that as the piston moved up and down, the pulley was caused to rotate. A ratchet and pawl arrangement allowed the free ascent of the piston and when a partial vacuum had been created beneath it, atmospheric pressure act-

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* There is no indication that de Rivaz was aware of Street's proposals.

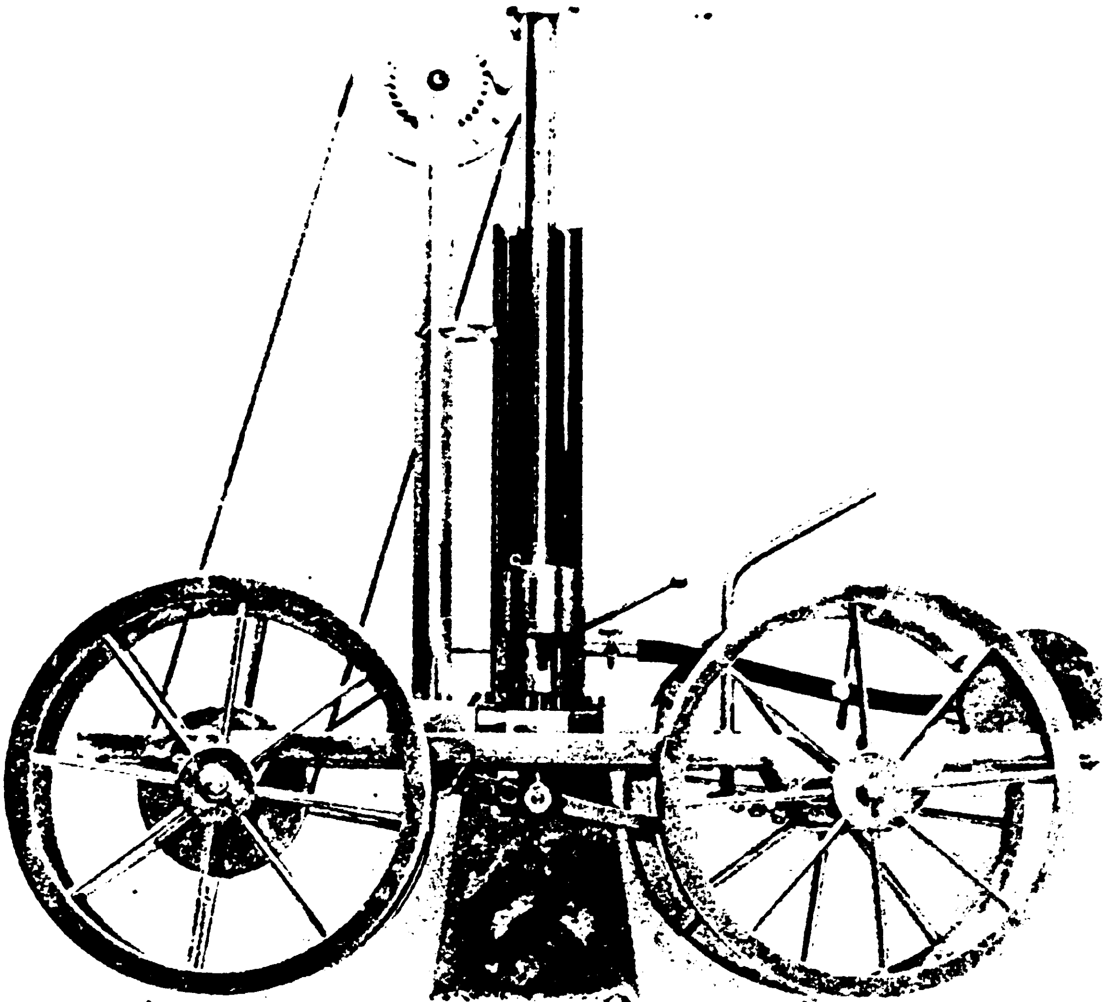

Fig. 2.4
Model of the Rivaz engine of 1807

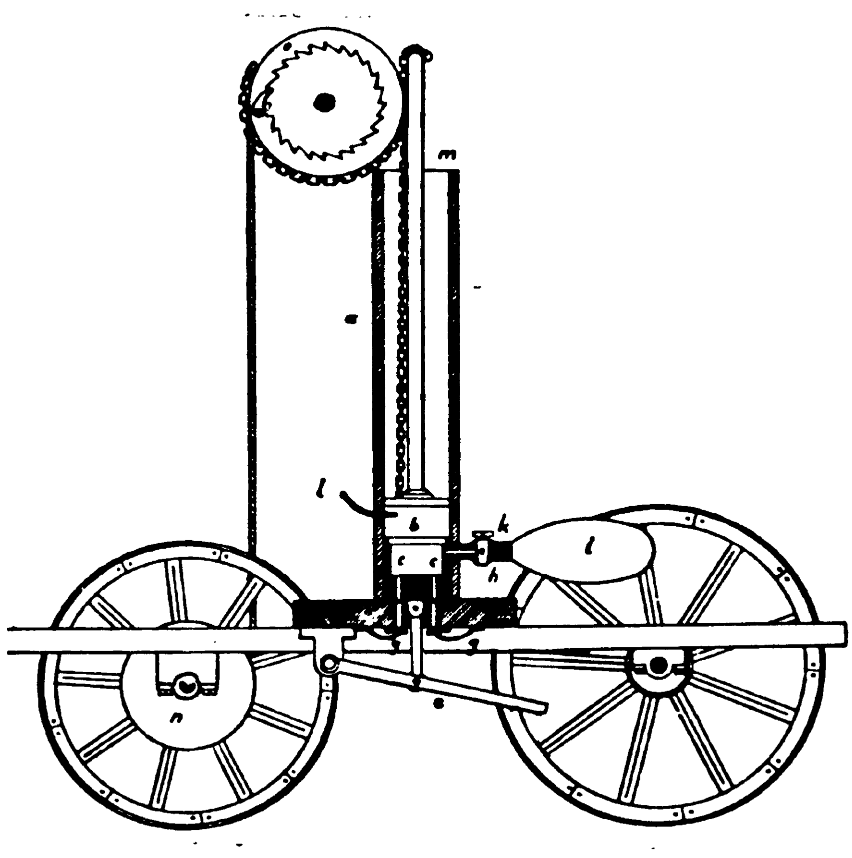

Fig. 2.5
Diagrammatic version showing the ratchet arrangement

ed on the upper face, forcing it downwards. The ratchet would then become fixed, driving a second pulley, to which one end of a rope was attached; the other end was fixed to a third pulley on the carriage axle.

This drive arrangement was crude and highly unlikely to work for sustained periods and this particular component (the free-wheel) later proved a formidable obstacle to both the Italians and the Germans in their ideas for a similar, but stationary engine, using an identical principle of working.

In 1807, a vehicle fitted with his engine was built for Rivaz by the brother, Jean and Co. of Croix-Rousse, in Lyon[7]. Between then and 1813, when a test run was recorded, several modifications to it were made. The 'Grand char mechanique' of 1813 was of impressive dimensions. It was 5.2 metres long and 2.1 metres wide and weighed nearly one ton. The cylinder bore was 36.5 cm (14.6 inches) and stroke of 150 cm (60 inches). The piston weight was 160 pounds and each working stroke, which occurred every five seconds, propelled the carriage about 18 feet. A speed of three miles per hour was possible. No fly-wheel was fitted and on an incline the vehicle would come to a stop. The test run took place near Vevey, Switzerland, on October 18, 1813[8].

The operation of the engine required assistance by hand or by foot. A lever, e. (Figure 2.5) connected to a piston in the base of the cylinder, was pressed downwards, creating a suction to draw in gas (Rivaz used hydrogen) and air. At the same time, electrical contact was made causing a spark from a Voltaic pile to jump between two wires placed in the combustion chamber.

The exhaust gas was almost completely cleared from the cylinder by the descending piston forcing it through pressure-operated valves, which closed when the pressure in the cylinder fell below atmospheric. This latter expedient was an essential requirement, which prevented the exhaust gases being drawn back into the cylinder on the suction stroke.

Despite the primitive means by which Rivaz sought to achieve his goal, there is no denying his ingenuity. His ideas, as will eventually be seen, anticipated in every respect the so-called atmospheric engine by Otto and Langen which, from 1867, was so successfully used in industry. Rivaz overcame many difficulties related to fuel, materials and design with his engine, and, in addition, managed to apply it to propulsion. For journeys of some distance, he proposed that gas generators should be positioned at frequent intervals along the road to re-charge the gas cylinder. The use of coal gas instead of hydrogen was also mentioned.

In 1813, Rivaz was sixty-one years of age and after a number of unsuccessful attempts to get someone to build his carriages, appears to have given up any further work. It would, perhaps, have been some consolation to him to know that his ideas were to be usefully applied more than sixty years later.

2.2 Self-operating engines - a further use of vacuum

2.2.1 Rev. W. Cecil, 1820

So far, the contribution of four pioneers has been discussed and a tenuous link between the ideas of Street and Rivaz is seen to exist in that both sought to achieve a vacuum. Over the next twenty years, attempts with vacuum became the order of the day and three other men, the Rev. William Cecil, Samuel Brown and an American, Samuel Morey each tried their hand using inflammable fuels.

Cecil (1792-1882) was a Fellow of Magdalen College, Cambridge and in 1820 read his paper 'On the application of hydrogen gas to produce a moving power in machinery' to the Cambridge Philosophical Society[9]. A model of this engine, which was totally self-acting, was demonstrated and its performance, together with the characteristics associated with the combustion of hydrogen, were analysed. Like Rivaz, Cecil recognised that the atmospheric pressure could be used, after first producing a vacuum. The main differences were in the method of admission of the gas and air, that flame ignition was used as opposed to the electrical means used by Rivaz, and that a crank and flywheel were used.

The lecture by Cecil began with some pertinent comments as to what may have caused him to embark upon such work.

> '..... a steam engine may be constructed at greater or lesser expense in almost any place, but the convenience of it is much diminished by the tedious and laborious preparation which is necessary to bring it in to action. A small steam engine not exceeding the power of one man, cannot be brought into action in less than half an hour; and a four-horse power steam engine cannot be used under two hours preparation'.

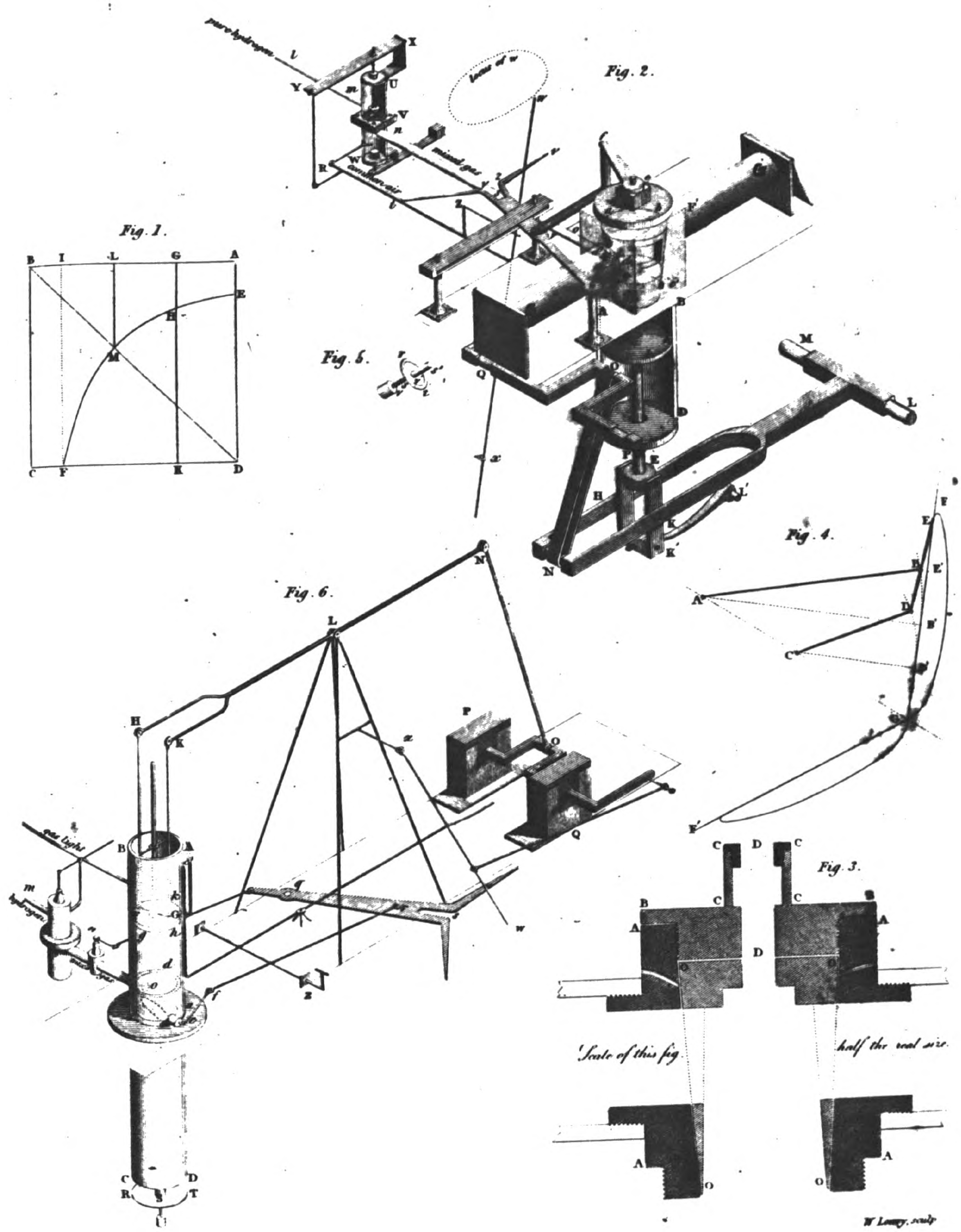

Fig. 2.6
Vacuum engine by William Cecil 1820

The working cylinder, D, of Cecil's engine (Figure 2 of 2.6) was vertical and fitted with a piston connected to a crank using a form of parallel link motion. The two cylinders, G (shown as B in Figure 2.7) acted as expansion chambers into which the burning gases after ignition entered and were cooled. To admit the gas and air into the working cylinder, a rotating conical plug, F, worked by the engine was used. With reference to Figure 2.7, the working cycle of the engine began with the piston, D, near the top. The momentum of the flywheel then moved the piston downwards, drawing in a mixture of hydrogen and air, the conical plug, F, being so positioned at this instant so that no communication to the horizontal cylinders was possible. When admission had ceased, the plug was rotated through 90^{o}, allowing the touch hole to line up with the external pilot flame, H. After ignition, the plug was rotated once more until large ports connected all three cylinders, allowing the mixture to burn and expand. Cooling of the gases took place - aided by water in a stuffing box used to seal the plug - creating a partial vacuum and allowing atmospheric pressure to push up the piston. The cycle was then repeated.

To estimate the pressure developed within the cylinder, Cecil conducted separate experiments using a thin cylinder, ten inches long and two inches diameter, seamed up one side and soft soldered. One end was sealed, but the other had a cork accurately fitted and confined by several strings arranged parallel to the cylinder axis with their tensions equal. After causing an explosion in the vessel, Cecil then observed how many strings could be broken by the force acting on the surface area of three square inches. The

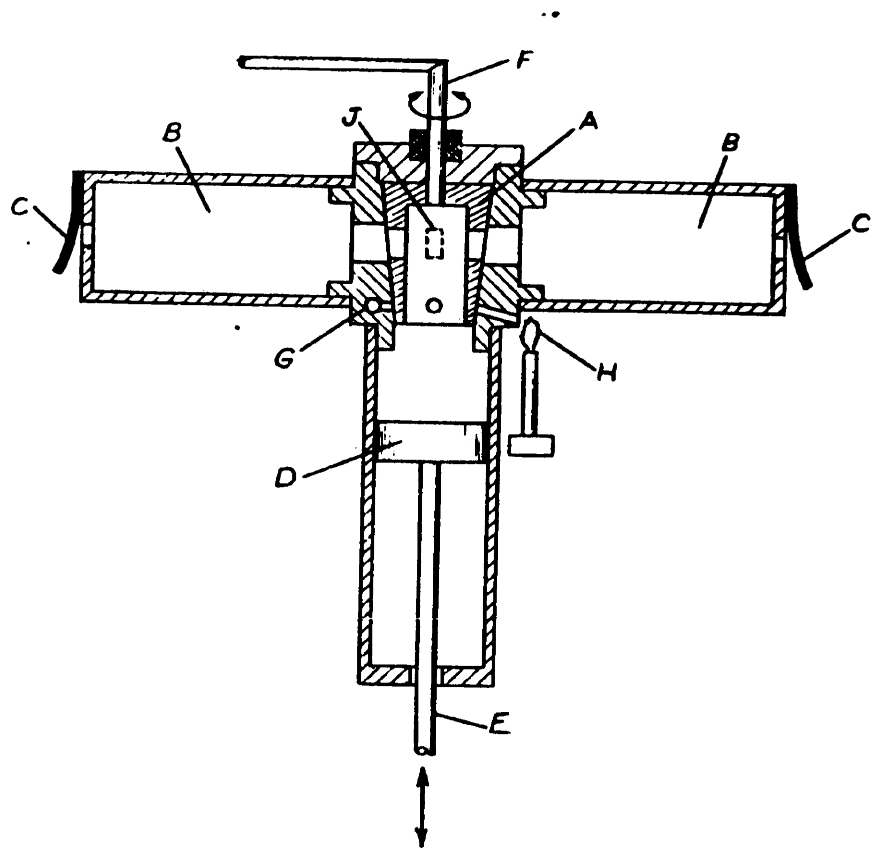

Fig. 2.7
Sectional view of the expansion chamber (B), vertical working cylinder and admission arrangements of Cecil's engine

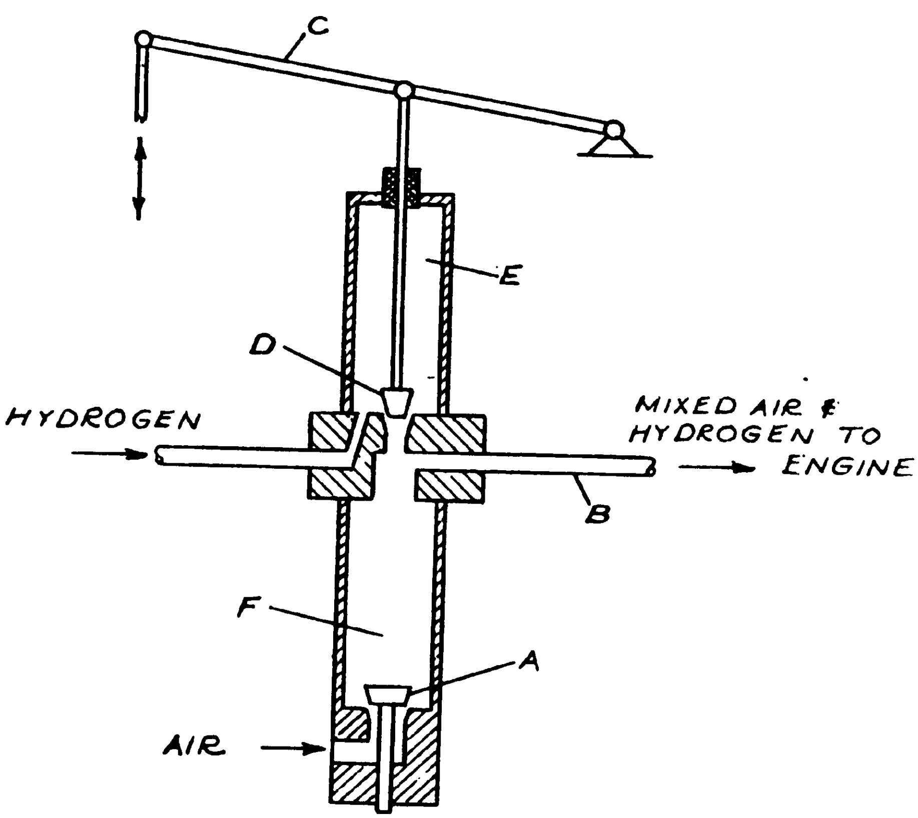

Fig. 2.8
Air and hydrogen metering valve.

same strings were then transferred to a common steelyard, from which it was observed how much weight they could sustain. From the results of several trials, Cecil concluded that a force of 500 pounds acted upon three square inches. Allowing 45 pounds for atmospheric pressure, a pressure of 180 pounds to the square inch was said to act. The result is about twice what it should be - Cecil was unaware of the 'shock loading effect' due to the explosion, which induces twice the stress in the strings that would otherwise have been present if the force had been gradually applied.

The capacity of the cylinder, Cecil states, was thirty cubic inches and when running at a speed of sixty revolutions per minute, consumed 15.6 cubic feet of hydrogen per hour with a further 2 cubic feet for the ignition flame. The engine was supported on two horizontal boards, 8 inches wide, 2 inches thick, 30 inches long and 15 inches apart. Figure 6 in Figure 2.6 is a construction by which Cecil thought his gas engine may be put to practical use. He makes reference to other fuels which he thought may be suitable such as carburetted hydrogen, coal gas, vapour of oil or turpentine and, although none of them had been tried, he was quite sure that they would be as effective as hydrogen. He also stated that 'an engine might be constructed to work by the exploding force, or by the exploding force and the pressure of the atmosphere jointly'.

2.2.2 An enterprising venture 1823 - Samuel Brown

In August 1824, The Mechanics Magazine announced that

> '....... a very curious engine has been constructed by Mr. Samuel Brown, to be employed as the actuating principle of machinery instead of the steam engine and is put into operation by the agency of fire, water and air' '...... it consists of many parts and it is not altogether free from complications, but at present we see nothing in its principle inimical to philosophy and have no doubt that it will act, though as to its power and operating costs as compared with the steam engine, we have no favourable opinion.' 10

At the time, Brown had a workshop in South Kensington* and the principle of his engine was in line with current thinking at that time, namely, that a vacuum was first obtained, so allowing atmospheric pressure to produce the working stroke. Just how much Brown had been influenced by Cecil (if at all) is unknown. In all correspondence and discussion related to Brown's engines, there are occasional reminders of the similarities between the working principle of these two men, but Brown himself never makes any acknowledgement that he was inspired by, or sought to improve upon, the efforts of Cecil, or even those of Rivaz. Samuel Brown, however, was the first man ever to apply an internal combustion engine to industrial use.

Figure 2.9 shows Brown's first engine[11] which he built and claimed was a one and a half horse-power version capable of raising 300 gallons of water about fifteen feet for each cubic foot of gas consumed. Shortly afterwards, he made another pumping engine which used pistons. The Mechanics

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* On the south side of Old Brompton Road opposite the intersection with Gloucester Road. The site is now occupied by a branch of the Kensington Public Library (see reference 18)

No. 53.] SATURDAY, AUGUST 28, 1824. [Price 3d.

BROWN'S PNEUMATIC ENGINE.

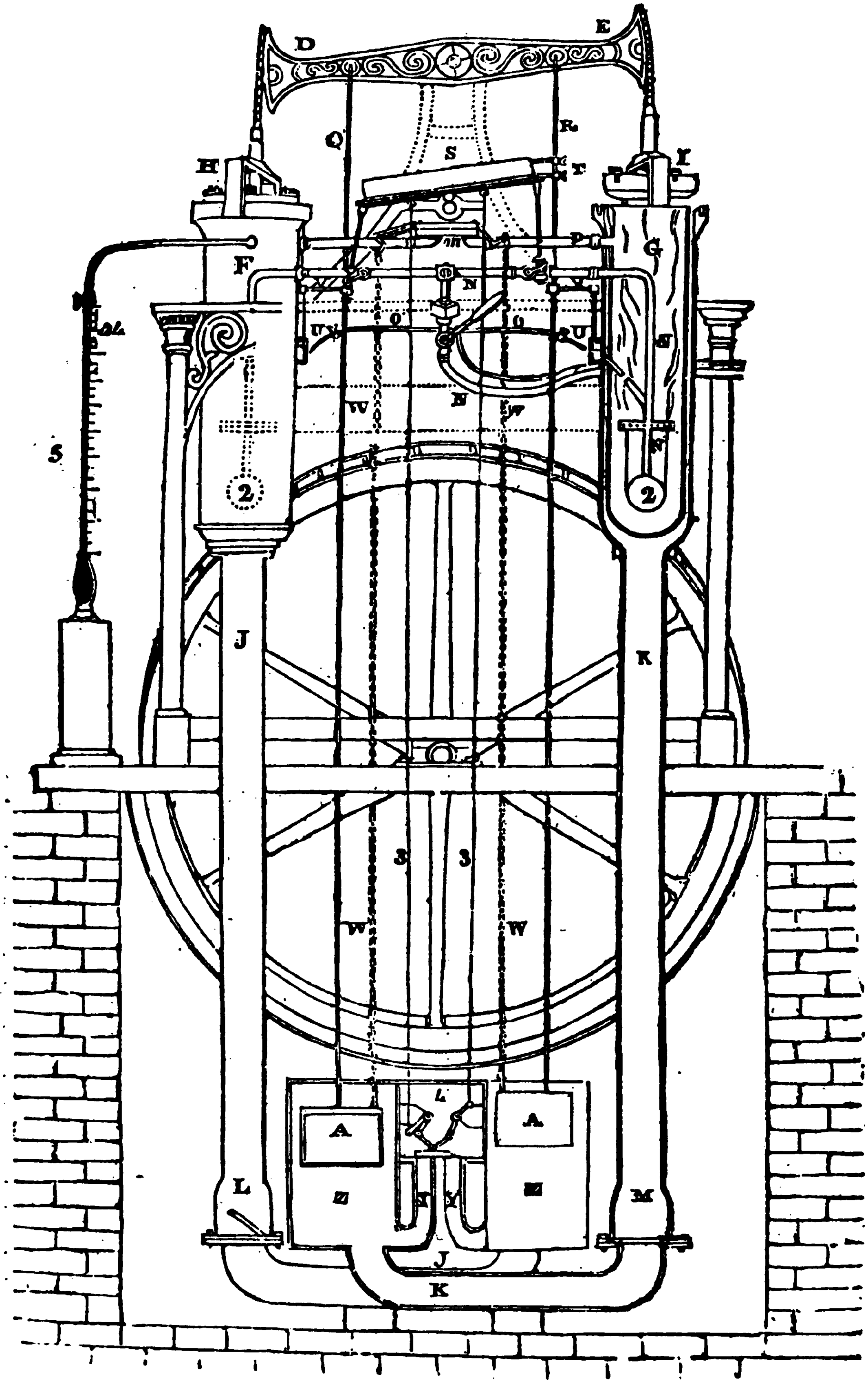


Fig. 2.9
Samuel Brown, vacuum pumping engine of 1824.

Magazine was obviously enthused about Brown's first engine:

> 'Mr. Brown has succeeded - has furnished this country and the world with a power which, judging from the first machine, (and what would have been the judgement from the first steam engine) will be convenient in its application, and cheap and safe in its use beyond all precedent.
>
> '....... We have examined the engine, very minutely in the company of the ingenious inventor, whose politeness is not less than his mechanical skill; and we hesitate not to say, that to us - to anyone who chooses to look at it, there is not the least doubt either of the soundness of the principle or the universality of the applications ....'

The vacuum was produced alternately in the cylinders, F and G (Figure 2.9) which were open at the top and closed at the bottom except for valves, which opened outwards to discharge water. This water was also used as a cooling agent. Placed around each 'working cylinder' was a second cylinder, leaving a space through which the cooling water would rise and flow over the top into the working cylinders F and G, quenching the flame that was set burning within them. This quenching action was the final stage in producing the necessary vacuum, which was initiated by the closing of the heavy lids or covers, H and I, over the two concentric cylinders once the flame had been set burning. After the vacuum had been obtained, water was drawn up from the base, Z, as a result of atmospheric pressure acting upon its surface, rising through pipe J and between the two cylinders. One of the floats would then fall and pull down the beam; a form of slide valve then being operated to admit gas and air into the opposite cylinder.

In the model shown, Brown shows an overshot water wheel onto which the drawn water falls. In practical use, this wheel would be removed and a pipe placed between the water to be

Fig. 2.10
Samuel Brown - Inventor of the first gas engine known to be applied for industrial use.

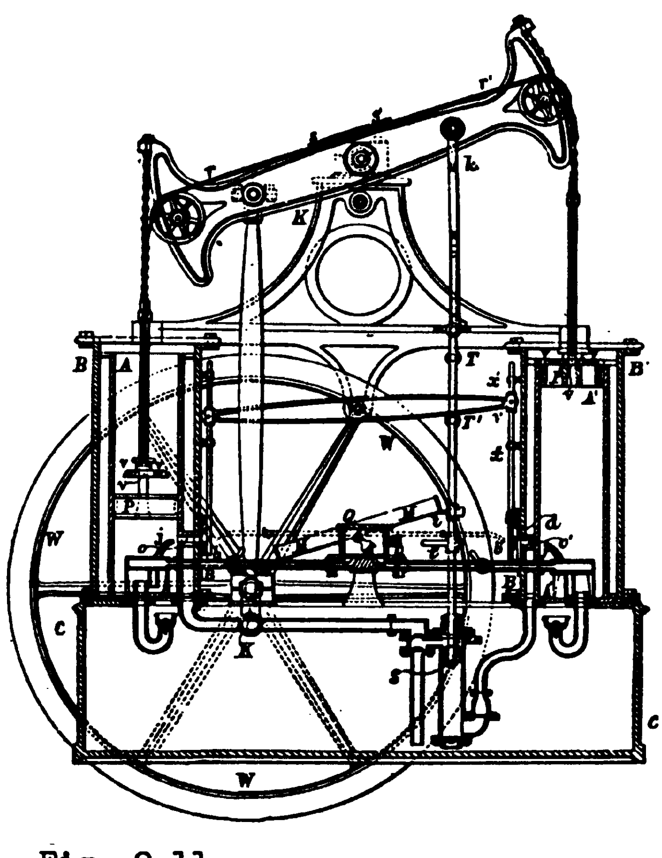


Fig. 2.11
A later version of Brown's engine using pistons

raised and the reservoir situated at the base of his engine. The piston version, Figure 2.11, used the same principle except that the beam transmitted motion directly to the crankshaft.

Ignition on both engines was by a small pilot light, shown at U, permanently burning outside each cylinder; the gas admission being controlled by the rise and fall of the rod, R, which is connected by a tube, S, containing mercury. The mercury flowed alternately from one end of the tube to the other, thus operating the gas cocks.

2.2.2.1 Uses of Brown's engine for propulsion - The formation of companies

The polite Mr. Brown was in no doubt as to the potential of his engine and claimed:

> 'a small consumption of gas, lightness and portability, (its weight being one fifth that of a steam engine and boiler) and a freedom from danger of explosion so often occasioned with steam boilers.'

In April 1825, having introduced his piston version, Brown, with enormous confidence, announced that

> 'A company upon a large scale has been formed in the city for the purpose of applying Brown's engine to the propelling of a wheel carriage. Capital is £200,000 to be shares of £10 each; 10% in advance and no more will be required until a carriage is driven from London to York and back again, at the rate of 10 m.p.h.'
>
> '....... Work on the first carriage was to begin in two months' time and a man would be able to carry a two horse-power engine upon his back ....' 12

Despite consistent demands to supply the performance details of his engine, (which Brown, with equal consistency, refused to reveal) the enterprising Mr. Brown announced shortly afterwards that a company had been formed for the purpose of boat and barge navigation[13]. A premium of 100 guineas was to be awarded for the best model ..... 'exemplifying the power when applied to the head, stern or sides of a vessel'. A prize of 30 guineas for the second best, and 20 guineas for the third best was also offered.

There is ample evidence in the correspondence contained in The Mechanics Magazine to show that these engines and subsequent modifications which Brown made, actually worked and were practically employed. But by August 1825, mainly because of his reluctance to supply the eager public with operating costs of his engine, Brown came in for some heavy criticism. Tredgold attempted to make some assessment of its operating costs and drew attention to a very extravagant use of gas[14], and because of this, he cast several doubts on the extensive practical use of Brown's engine. Seemingly, quite undaunted by such criticism, however, Brown pursued his enterprises and in December 1825, a Mr. J.R. Whitfield, of Bedlington Iron Works, gave a description of the cylinder to be applied to Brown's engine for the purpose of working the carriage. The descriptions and drawings are extremely vague, but they incorporated the use of pistons. Mr. Whitfield was also fired with enthusiasm, stating that:

> 'Mr. Brown's flying gas engine can be made, I should think, to go sixty miles an hour on a rail-road, however, I estimate that by the plan I have proposed, with a supply of gas every two hours, it will do twenty five at least. The weight will not exceed 20 cwt' .... 'it could be applied to turnpike roads, the cost would be one half-penny per mile for the gas ....' 15

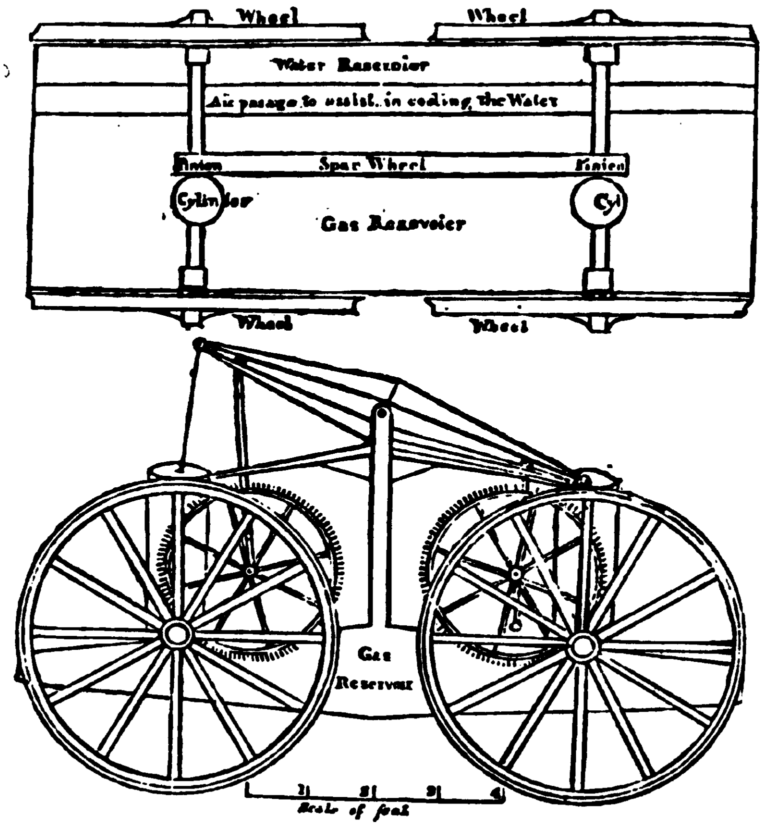


Fig. 2.12
Brown's 'iron carriage' that ascended Shooters Hill, Kent in 1826

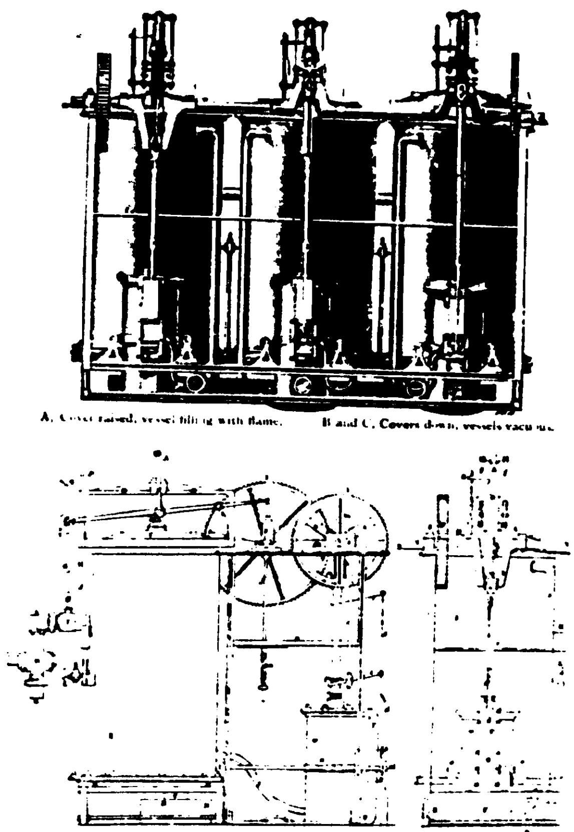


Fig. 2.13
Three cylinder arrangement used to propel boat on the Thames in 1827

In point of fact, a wheeled carriage was actually made, (Figure 2.12), and about the middle of 1826, successfully surmounted the steepest part of Shooter's Hill, Kent. The wheels were five feet in diameter, the wheel base six feet three inches and the track, four feet six inches. The engine cylinder was twelve inches diameter with a stroke of twenty-four inches [16]. The event was followed on January 31, 1827 by the successful propulsion of a boat on the Thames, starting from Blackfriars Bridge, at seven to eight miles per hour. The power unit for the boat was essentially that as described in a patent of 1826 [17], and consisted of three cylinders, (Figure 2.13) each having a combustion chamber, the working principle being the same as that of the previous engines.

The physical dimensions of the boat were: length thirty-six feet and total weight including engine, six hundred pounds. The test on the Thames was witnessed by the Lords of the Admiralty and was apparently a success; the boat it was said 'proceeded with all the regularity of a steamer, the paddle wheels worked quite smoothly and seemed capable of continuing to go, as long as the gas was supplied'.

During the short time he had actively been involved with engines, Samuel Brown, a one-time Cooper by trade [18] had succeeded in some notable achievements, having made two versions of a pumping engine, propelled a road vehicle and also a boat. Oddly enough, it was the success of the latter which brought about the abandonment of any further development. A decision had to be made in the light of the Thames test whether or not to make further developments.

This entailed a critical analysis of the engine's performance and at a meeting of the shareholders, called to receive a report of the Committee appointed to examine the progress made by the engine, Mr. Routh, the Chairman, stated:

> 'although the power was quite adequate, he considered that the expense in procuring gas would entirely prevent its application as a prime mover instead of steam. I am, therefore, of the opinion that the Company should be dissolved.' [19]

Following a good deal of discussion, during which Brown forcibly stressed his belief in the feasibility of his engine, the motion by Routh was carried and in February 1827, the Company was dissolved.

The reference to the expense of the fuel used is interesting. It appears that Brown was attempting to use hydrogen; at no point in the references up to that date (1827) is there any indication that he used coal gas - the descriptions refer quite simply to gas, without any specific information as to what kind. Support for the suggestion that Brown was using hydrogen is given later, when, after a few years' absence from the public eye, he emerged once again with a new engine and his own method of producing gas. In the meantime, Brown had packed his son off to Philadelphia to try his hand there. A letter in The Mechanics Magazine reveals the interest in gas engines in America at that time[20]:

> '....... the Brown engine is considered a failure in view of the large gas consumption and Mr. Brown's son is now working in Philadelphia, having gone there particularly to develop the principle of his father; the engine was not completed as yet.'

It is not possible to deny the mechanical success of Brown's engines, but it seems from the evidence, he was well aware that it consumed large amounts of a fuel that was expensive to produce; hence his reluctance in revealing operating costs.

2.2.3 The Croydon Canal Gas Engine

Samuel Brown remained absent from the public eye for about five years, during which time such comments as 'nine-day wonder' and 'prodigious expectations which it excited, but failed to realise' were made regarding his engines. About 1832, however, Brown emerged quite undaunted and as enthusiastic as ever, to announce that:

> 'he had overcome the only difficulty which stood in the way of the most triumphant success.'

and without exactly stating the nature of the difficulty, positively invited a barrage of criticism by claiming that he

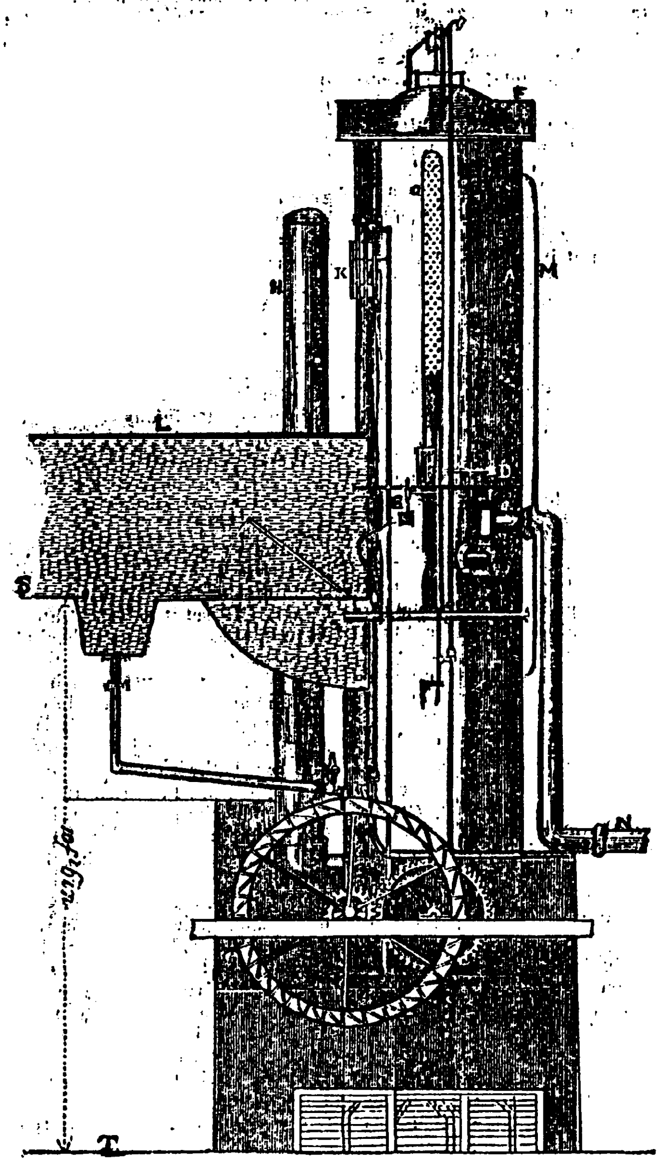
> 'had now produced an engine that will do everything and cost nothing.' 21

The essence of Brown's new claims were contained in three papers. The first was a circular dated May 1, 1832, which said that he was ready to contract for the construction of a gas vacuum engine of any power, and to guarantee their working for any number of years at half the annual expense of steam engines of the same power and in the same situations. The following engines had already been constructed; the first two of which were in constant operation.

1) On the Croydon Canal for raising water
2) At Eagle Lodge, Old Brompton (Brown's workshop)
3) At Soham in Cambridgeshire for draining part of the Middle Fens

Mechanics' Magazine,
MUSEUM, REGISTER, JOURNAL, AND GAZETTE.
No. 469.] SATURDAY, JULY 28, 1832. [Price 3d.

THE CROYDON CANAL GAS VACUUM ENGINE.



VOL. XVII. 1

Fig. 2.14
The Croydon Canal Gas Vacuum Engine
by Samuel Brown

4) As 2, but of a different construction

The second paper contained copies of certificates from the Committee of the Croydon Canal, all bearing testimony to the satisfactory and economical working of the engine. The third paper was a full and comprehensive account of the running costs of the Croydon Gas Engine, a summary of which is as follows:

<u>Croydon Gas Engine Account</u>

Dr	£	s	Cr	£	s
To 50 bushels small coal at 22s per chaldron, for 24 hours, or 417 chaldron for 300 days	458	14	By 35 bushels best coke from oven, or 202 chaldron in 300 days at 26	379	12
To one man to attend the engine, 5s per day, and coal 3s per week	85	16	By 36 bushels coke from retorts, or 300 chaldrons in 300 days at 22s	330	00
To repairs of machinery ovens, retorts, etc, 25 per cent on 3001	75	00	By 16 gallons tar in 24 hours, 4,800 gals in 300 days at 3d	60	00
To oil for machinery, leather for valves &c., 2s per week	5	4		769	12
To seven per cent on value of building	35	00	Deduct Dr. Account	666	14
To ground rent of premises	7	00	To Profit & Loss per annum	£102	18
	£666	14			

(1 chaldron of coal = 53 cwt or 85 bushels;
1 ton of coal = 8/4d)

The working principle of the Croydon engine, Figure 2.14 was the same as that of the former engines, namely, the extinction of a peaceable flame to create a vacuum. The Croydon engine made four strokes per minute, the length of the stroke was twenty-two inches and the cylinder was three feet, eight inches diameter. It was started by opening the cock B and allowing water to flow onto the wheel C. The rotation of this wheel controlled the number of strokes per minute and also operated various mechanisms, such as the valve used to admit gas into the cylinder. The purpose of the engine is not clearly stated; presumably it raised water from a lower to a higher level.

The basis of Brown's claim that his engine would do everything and cost nothing was that he had discovered a new means of producing gas. Instead of the retorts being heated by a coal furnace, as was the common practice, they were heated by coke ovens - the coke having previously been produced in the retorts. He required only a small amount of coke and proposed to sell the remainder, thus realising a profit.

Samuel Brown received few accolades for his efforts, but in retrospect, his tireless inventiveness and enthusiasm must surely be acknowledged. Although only a little practical use was made of his engines, it cannot be said that the failure to do so was entirely his. One must bear in mind the numerous difficulties such as those concerned with ignition, materials, design and cooling which Brown faced and which had not previously been encountered on such a scale. When viewed in this light, his was a story of remarkable achievement. A further positive contribution was the fact that his efforts had become known throughout the length and breadth of the country; arousing immense interest and creating critical discussion.

Samuel Brown died in 1849, three years after registering a patent for the propulsion of a wheeled carriage. No specification for this idea, however, was enrolled.

2.2.4 The first American contribution - Samuel Morey

Ideas have a peculiar habit of occurring simultaneously in different places. Samuel Morey (1762-1843) was America's equivalent of Samuel Brown and at the same time as Brown, was likewise experimenting with vacuum engines. An important difference was that Morey used a liquid fuel and for this purpose a form of carburettor was needed, which he duly designed. Morey was a prolific inventor and, although little is known of his contribution to early American technology, he was granted eighteen U.S. patents before that of April 1, 1826, which was his engine[22] and included steam engines, pumps, lamps and gas producing apparatus. Morey's gas engine was patented[23] in England under the name of Erskine Hazard, an American engineer and friend of Morey's, who, at the time, was living in London.

After three or four years which he spent carrying out experimental work, Morey attempted to create interest in his engine by applying it to carriages on railroads. By 1830 he still had not found anyone interested enough to do business with him and the steam locomotive was rapidly becoming established in America at that time. Consequently, Morey's engine failed to achieve commercial acceptance. His efforts with liquid fuels, however, were not wasted. Many later workers were to pick up where Morey had left off.

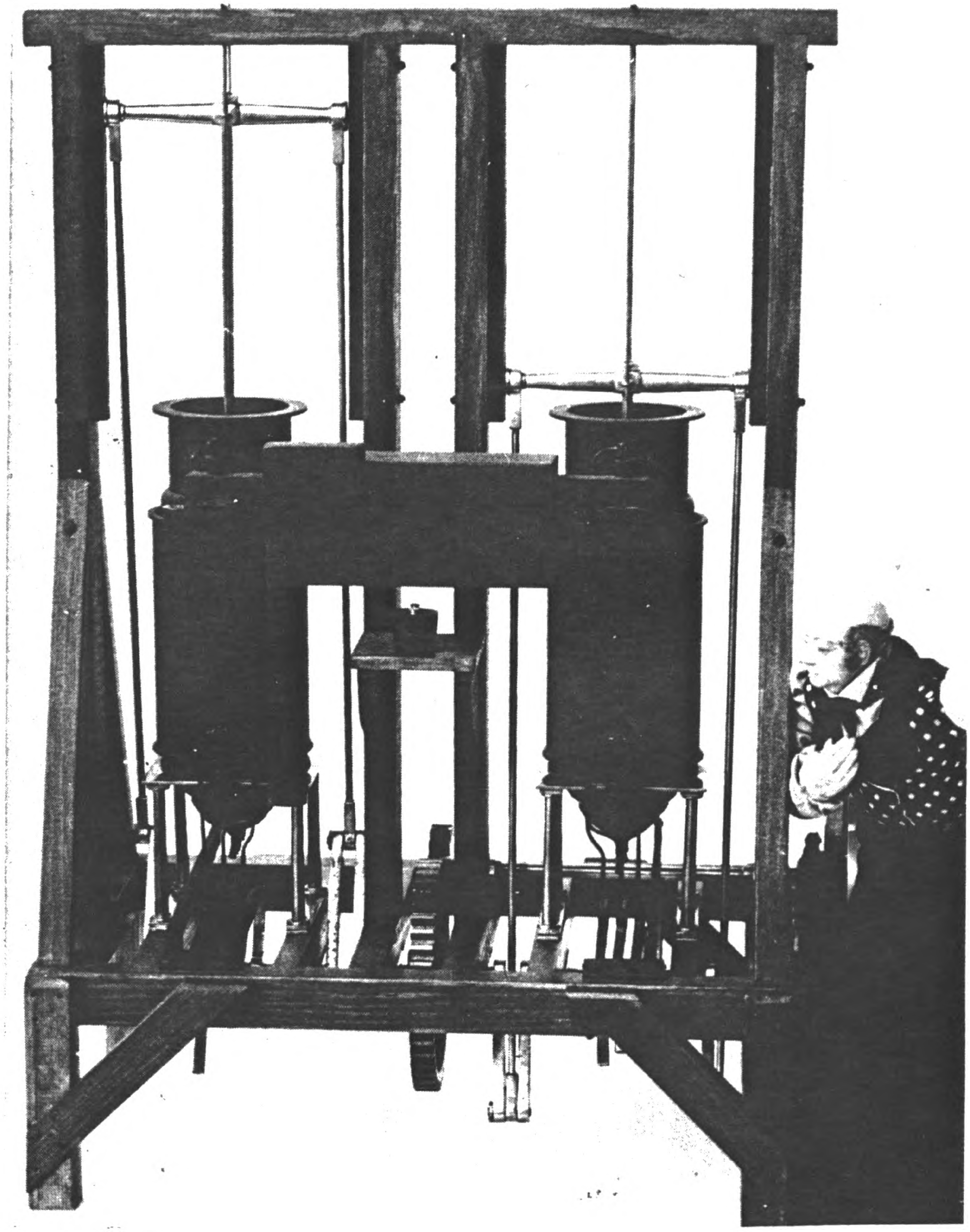


Fig. 2.15
Liquid fuel engine by Samuel Morey, 1826
(A model displayed in the Smithsonian Institute, Washington)

2.3 Carbonic acid gas engines - Brunel, Cheverton and Oxley

Attempts, during the first quarter of the nineteenth century to harness the explosive power of inflammable gases or vapours, brought about a realisation of two basic problems associated with combustion engines. Firstly, there was the difficulty of obtaining a suitable fuel and, secondly, when these attempts sometimes succeeded, it was found that when ignited, a violent explosive force was produced which was seemingly impossible to contain. It is not surprising, therefore, that consideration should be given to other substances that would prove useful, but less violent. Interest in carbon dioxide, or carbonic oxide as it was then called, was a direct result of these troublesome explosion experiences and came about as a consequence of the work by Faraday and Davy on the liquefaction of gases in 1823.

One of the earliest suggestions that such fluids could be used is contained in a patent of 1801, No. 2504, by an Englishman, John Glazebrook, who mentions the possibility that 'other airs such as hydrogen, nitrous air, carbonic acid, ammoniac and azotic air' could be used to produce power. Nothing worthwhile resulted from Glazebrook's proposals, however, but the idea was revived by Marc Isambard Brunel in 1826. An article, entitled 'A new motive power' in The Mechanics Magazine of that year states:

> '....... many and various have been the modes resorted to by those engaged in experiments, in this arduous affair, to construct a vessel so impervious as to confine these highly attenuated gases, Mr. Brunel has at last succeeded in casting a cylinder in which to confine carbonic acid, this being the substance he has chosen for his operations ....' 24

DESCRIPTION OF MR. BRUNEL'S CARBONIC ACID GAS ENGINE.

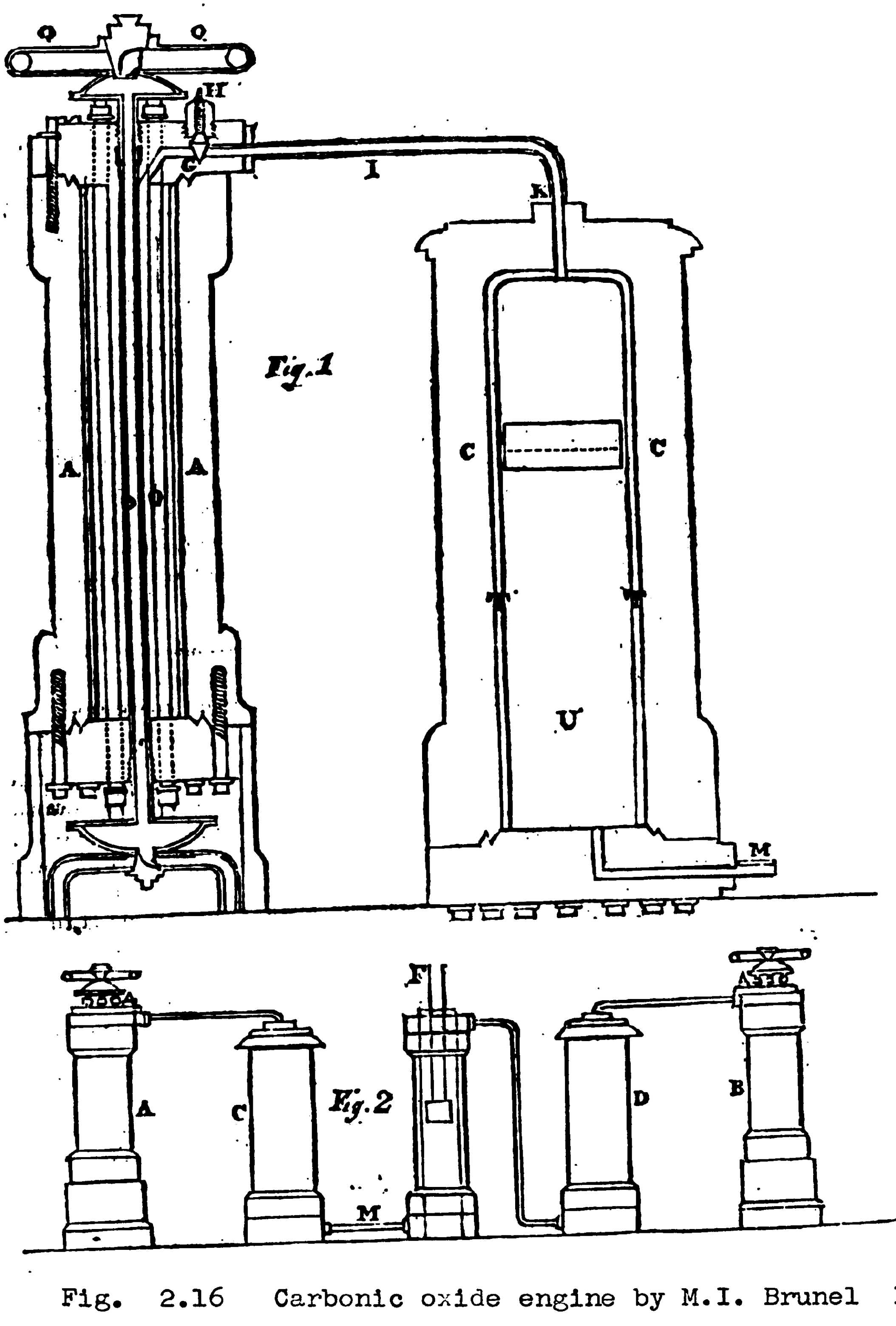


Fig. 2.16 Carbonic oxide engine by M.I. Brunel 1825

The article refersto a meeting which took place at the Royal Institution the previous evening (February 10, 1826) during which Faraday related the principles on which an engine, using carbonic acid, could be made to work. M.I. Brunel's patent for an engine was registered in 1825[25] of which Figure 2.16 is the general arrangement. Five cylindrical vessels are used; A and B contain the liquid CO_2, these two vessels were called receivers. Two adjoining vessels, C and D, were called expansion vessels, both of which communicated with the working cylinders, E, containing a piston acted upon by the alternate expansion and condensation of the vapour. The detailed construction of the cylinders, A and C, which are identical to cylinders B and D, is also shown.

To bring about the change of state in the CO_2, hot water at 120°F would be allowed to flow through the tubes of receiver A and simultaneously, cold water through receiver B. The liquid in A, it was claimed, would be at a pressure of 90 atmospheres, while that in B would be about 50 atmospheres. The difference between the two was the effective pressure acting upon the working piston. To reverse the cycle, hot water would be passed through B and cold water through A.

Work on this engine was subsequently taken over by Brunel's son, Isambard Kingdon, who carried out many experiments and was heavily subsidised by the Admiralty[26]. Young Brunel saw himself taking charge of a large works which would manufacture the engine and, for many years, work on the engine was his favourite activity.

Many technical problems were overcome, not least was the design of a vessel capable of withstanding the enormous pressure (at the time, steam pressure of 50 pounds per square inch were considered extremely high). But in January 1833 even I.K. Brunel had to admit defeat and wrote in his notes:

> '....... I fear we must come to the conclusion that with carbonic acid no sufficient advantage on the score of economy of fuel can be obtained'
>
> 'All this time and expense, both enormous, devoted to this thing for nearly ten years, therefore, wasted. It must therefore die ....' 27

Interest in the use of CO_2 around 1826 was very great and it was in April of that year, almost nine months after Brunel, that a Benjamin Cheverton made known his views[28]. Cheverton is something of an unknown quantity; apart from his quite eloquently expressed feelings on the need for a motive power unit and opinions as to how such could be achieved, little to nothing is known about him. His ideas for obtaining motive power, although lacking a consideration of overall cost are intelligently expressed and he was obviously aware of scientific developments of his day, since he states it was from reading accounts of Davy's and Faraday's work on gases, that stirred his thoughts with regard to high pressure engines. In putting forward his proposals, he does, of course, stress that he had no prior knowledge of Brunel's experiments .....? Cheverton never patented his engine, shown in Figure 2.17. The description and proposed method of working being as follows:

- AA are two refrigerators containing cold water
- BB are calorators containing hot oil
- CC alternators lined with wood and filled alternately with the hot and cold medium
- DD generators, consisting of a cylindrical assemblage of capillary copper tubes, about half filled at

the minimum pressure with liquid CO_2, these communicate with the upper end of strong copper gasometers, EE, which are lined with wood, nearly full of oil at the minimum pressure of the gas, but at the maximum expels nearly the whole of it into the cylinder H in which the piston I is placed

LL are solid wooden plungers

NN pipes for a constant supply of cold water

OO pipes through which gas is, in the first instance, introduced and oil occasionally injected

PP are boards floating in the oil

SS are circular cisterns in which a circular row of lamps are placed.

The dashed lines indicate the water and oil levels and the dotted lines the level of the separation between the water and oil. Its principles of working were similar to Brunel's engine in that a cylinder, E containing liquid CO_2 was alternately heated and cooled. A change of state of the CO_2 would take place and at once exert a pressure on the wooden piston P and hence upon the oil, forcing it downwards and filling the cylinder H with oil. The piston, I, would then move, either to the right or to the left. To reverse the cycle, the generator is now flooded with cold water causing condensation of the CO_2 reducing the pressure in the generator and gasometer; the piston I then reversing in direction.

Cheverton then goes on in considerable detail, anticipating possible difficulties, suggesting remedies in each case. He is obviously aware of the enormous pressure that is obtainable and stresses the need for strong vessels. From his writing it is clear that up to that point Cheverton had not constructed an engine and no evidence can be found that he ever did. An engine of eighty horse-power he thought would occupy a space less than seven cubic feet and he envisaged its use for locomotives.

NEW GAS POWER-ENGINE,
INVENTED BY MR. B. CHEVERTON.

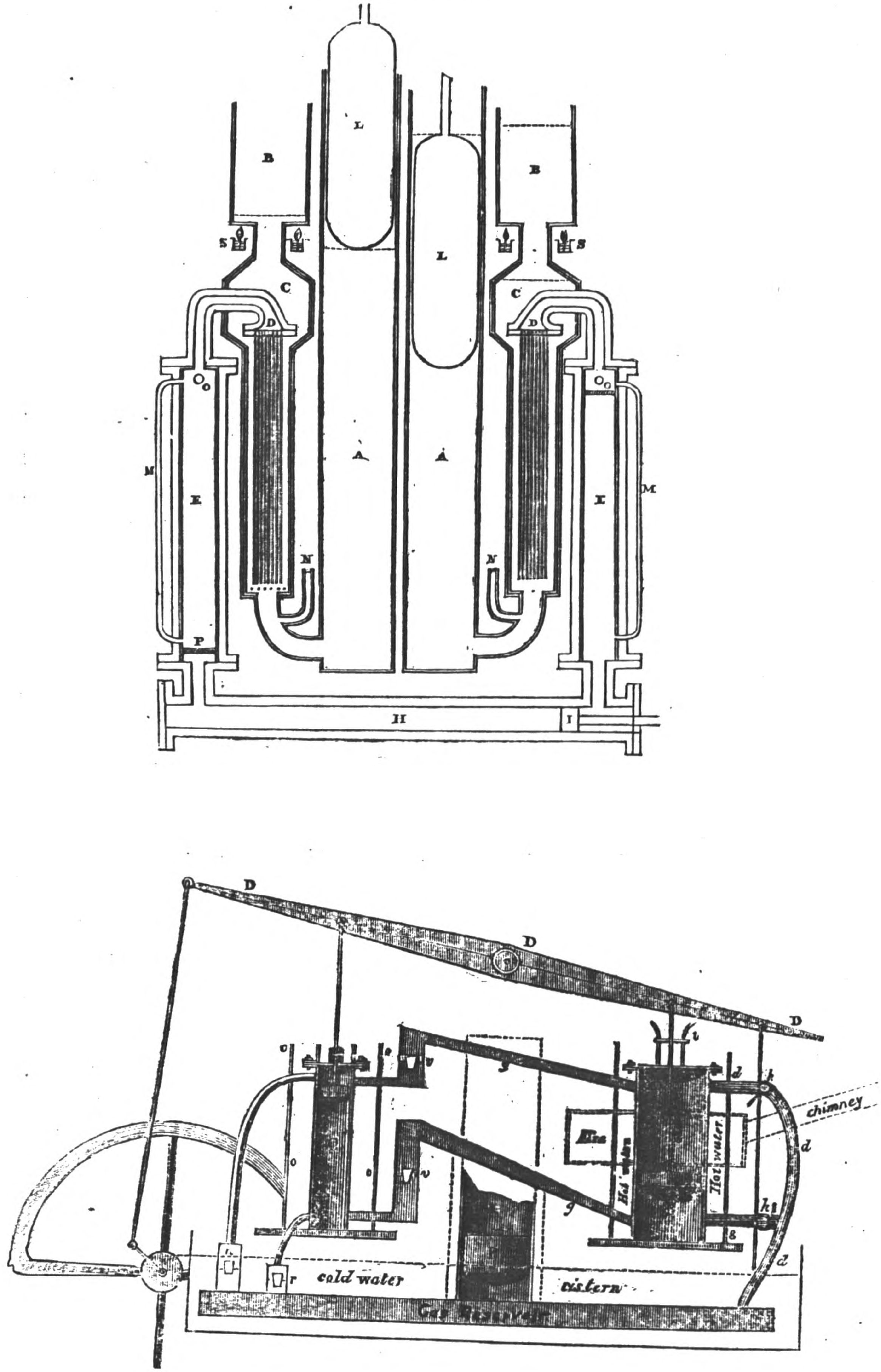


Fig. 2.17
Carbonic acid gas engines by B. Cheverton and T. Oxley
1826

Again in 1826, the following extract of a letter from Thomas Oxley, a 'Mathematical Tutor' of Liverpool, was received by The Mechanics Magazine[29].

> '....... I now send you a sketch of a gas engine, invented by me, a considerable time prior to my hearing either of Mr. Faraday's or Sir H. Davy's propositions for applying carbonic acid gas as a motive power. My attention was drawn to this subject by mere accident. As I was taking my usual morning walk down Main Street in Virginia, I heard a tremendous explosion* from a druggist's cellar ....'
>
> '....... a few days after this (the summer of 1822) I invented the Gas Engine of which I send you a sketch.'

The cylinder A, Figure 2.17 of Oxley's engine contained a piston P, over which a quantity of oil was placed to keep a seal and aid lubrication. This cylinder is surrounded by a second, filled with cold water. BB is the working cylinder containing a piston and is kept at 212°F by an external cylinder filled with boiling water provided by a furnace or fire. C is the condensing or cold cylinder surrounded by another cylinder, OO, also filled with cold water.

The only difference in the proposed working of Oxley's engine with those of Cheverton and Brunel is that the CO_2 vapour was expanded before entering the working cylinder. This, it was suggested, could be achieved by forcing it through supply pipes, v and g, which were spiralled for three or four coils around the working cylinder, BB.

---

* caused by the bursting of a vessel being charged with CO_2 for the purpose of making 'Dr. Cullen's patent magnesia'

2.3.1 The feasibility of carbonic acid gas engines

The physical properties of CO_2 at first sight make it appealing as a working fluid for engines. It has a critical temperature of about 31°C; at -32°C it has a vapour pressure of 27.8 atmospheres and at 0°C, 36 atmospheres. For comparatively small increases in temperature, therefore, CO_2 can produce quite substantial increases in pressure. The objection to its use lies in the economics, not only of providing the CO_2 in the first place - which at that time was by the action of acid on carbonates, but also in the energy required to supply a heated medium necessary to produce the change of state in the CO_2; none of which is recoverable. The Brunels obviously discovered this and for nearly ten years, having overcome numerous technical problems, concerned with the high pressures experienced, failed to overcome those which gave rise to high operating costs..

The engines of Cheverton and Oxley, therefore, mechanically commendable as they might have been, were quite imbalanced in their conception and gave no consideration at all to the thermodynamics involved. Despite these failures, however, the idea crops up repeatedly, and in 1848, there appeared the following article in the Architect and Civil Engineers' Journal[30]. No diagrams are given to assist the descriptions and it serves only to indicate the constant interest and difficulties that were still present.

> 'Another attempt to apply CO_2 as a motive power has been brought before the notice of the Paris Academy of Science by M. Jagu, a Civil Engineer who proves very satisfactorily the great power that may be obtained by imparting a comparatively low temperature to carbonic acid gas; but the difficult problem of condensing the gas to render it again available, seems not to have been solved ......'

The article then goes on to describe how M. Jagu envisaged the placing of suitable apparatus at various stations, in which CO_2 could be compressed to six atmospheres and capable of filling the receivers, (presumably a locomotive prime mover was being considered).

It is also worth noting that in the latter part of the 1820's there was much interest in hot air engines. Stirling took out his first patent in 1827 and the principle of the two types of engine, air and CO_2, have a number of similarities in that both utilise a regenerative cycle requiring alternate heating and cooling.

2.4 A return to flammable fluids

2.4.1 The foundation of modern internal combustion engines Wright and Barnett, 1833 and 1838

The pattern of events between 1791 and the early part of the 1830's indicate generally that two outstanding difficulties were present in the attempts during those years to produce a new prime mover. One is shown by the various experiments that were made to obtain a suitable working fluid. The second, possibly a consequence of the first, was a fear of explosions, which it seemed at the time could not be effectively controlled. The problem of a suitable fuel is quite significant and is discussed fully in the next chapter, but it would seem that after the failure of the CO_2 engines and the difficulties associated with hot air engines*, inventors were once more forced to consider the use of inflammable fuels.

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*Large engine bulk for a given power; low thermal efficiency and a frequent tendency to burn away the base of the cylinder.

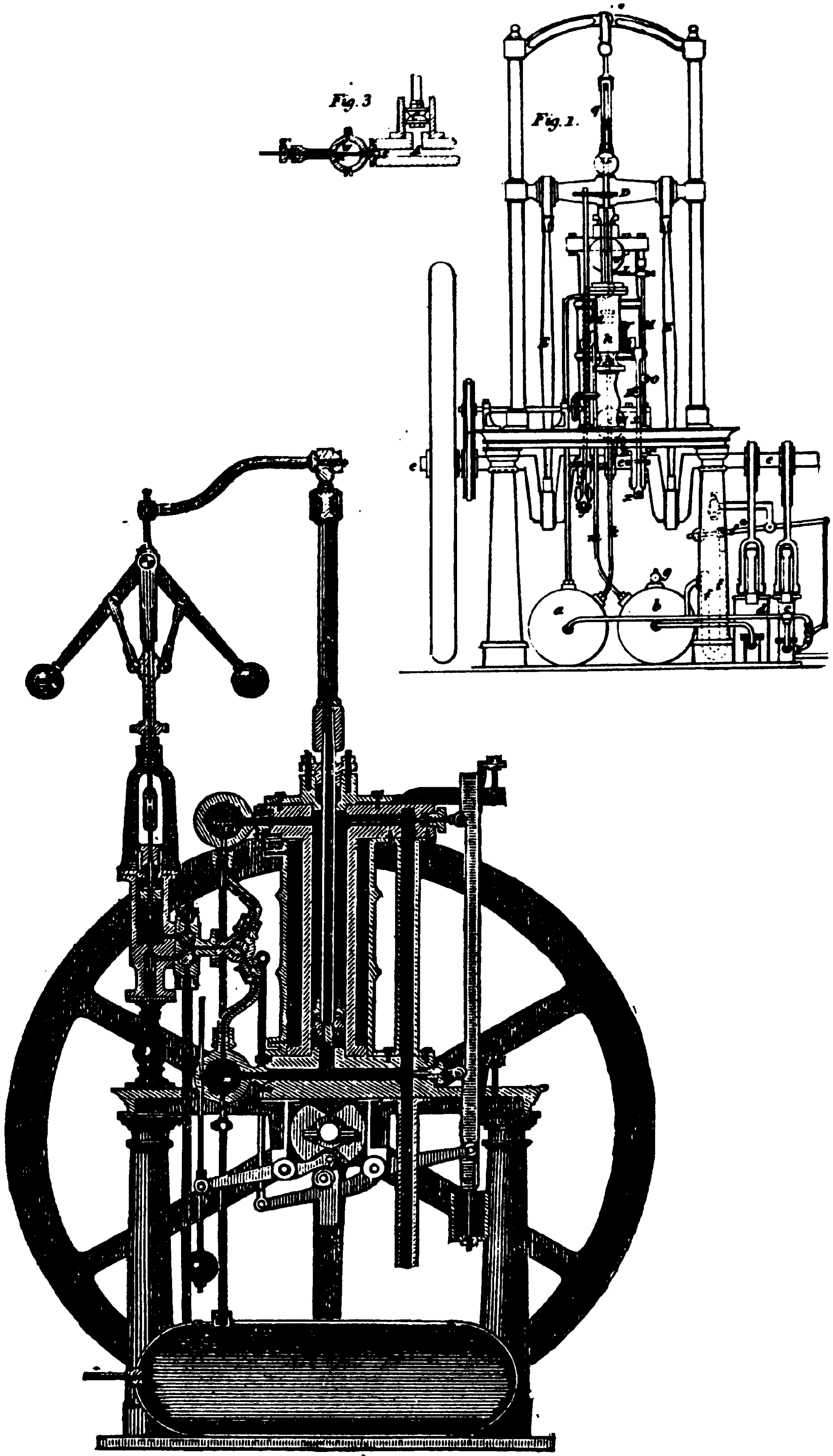


Fig. 2.18
Explosion engine by L.W. Wright 1833

In this respect, the ideas of two Englishmen, Lemuel Wellman Wright (1833) and William Barnett (1838) are particularly notable. Many features of their proposed engines were later used by other inventors.

Wright's engine of 1833[31] shows evidence of being influenced by a design of steam engine known as the 'table model' very popular at the time. The drawings are extremely well presented and it is obvious that Wright had given careful consideration to the design and operation. He recognised the need, for instance, for cylinder cooling and designed a water jacket to surround the cylinder (Figure 2.18). A centrifugal governor to regulate speed is shown and a two-throw crank shaft is used with guide rods and a cross-head, D*.

Plunger pumps, driven by the crankshaft, were used to supply gas and air to the double-acting cylinder. Ignition was brought about by a pilot flame burning outside two spherical chambers, W, in which combustion took place. To meter the gas and air into the chambers, a rotary valve, e, was used. The gas chamber had a fixed volume, but the air chamber situated beneath the governor would vary in volume under the action of the governor. None of these features had previously been used by anyone else in this way and, although the design is over-complex, it warrants serious consideration as to whether or not Wright ever made a working form of his idea. He was not without experience of steam engine design and his patent describes him as an engineer of Sloane Terrace, Chelsea (a popular area at that time for millwrights).

---

* The Otto-Langen atmospheric engine of 1867 used almost an identical method of 'guide' for the piston as it ascended.

Several patents can be found in Wright's name, a number of which were quite successful.

An intriguing aspect of Wright's contribution arises in the last but one paragraph of his patent specification. In referring to a small inset drawing of an alternative design of the spherical combustion chamber, he mentions the use of compression and also the addition of steam:

> '....... by means of which I propose to introduce, in addition to the admission of gases, a volume of condensed (compressed) atmospheric air, which is to occupy the spaces A and F and the end of the working cylinder. The air may be supplied by a forcing pump and a small quantity of steam may also be advantageously introduced ... and when the explosion of the gaseous mixture in the spherical vessel takes place, the valve will be forced open and the vapour allowed to pass into the passages A and F, when, by mixing with the condensed air and steam, the expansive force will become greatly increased.'

Wright's engine embodies much of what is required for successful engine operation and is an outstanding contribution when one considers its radical departure from the general ideas of that time. Many subsequent inventors are seen to use various features of Wright's proposals, but no acknowledgement of his particular contribution is ever given.

2.4.2 <u>The first mention of compression by the working piston</u>

William Barnett was an Iron Founder from Brighton who suggested three types of engine in 1838[32], the quality of which shows an increasing understanding of engine requirements. Barnett's engines are an improvement upon that of Wright and in some ways an adaptation of them. Several new features are included, notable of which is the device for ensuring ignition under compression. Quite obviously, Barnett recognized that this was an obstacle to be overcome. The first of his three engines is single-acting, the second and third are double-acting; all compress the mixture before ignition, either by separate charging pumps or, in the case of the third engine, by the piston itself, (the first ever mention to be made of compression in this way). In all three, ignition takes place at the dead centre of the piston.

Figure 2.19 is a sectional elevation of the first engine; A is the motor or working piston; B is the air pump piston, which serves a dual purpose; the lower face pressurised the air into the passage, D, whilst the upper face was used to push out burnt gases. The gas pump piston is not shown on this view, but is worked by the same cross-head as the air piston. All three pistons move up and down simultaneously. The working cycle of this engine begins with all three pistons moving up (ignition having occurred in the working cylinder). Gas and air are drawn in after which all three descend. The main piston pushes out the burnt gases and the gas and air pistons compress a mixture into the passage, D called the receiver. To admit this inflammable charge into the cylinder, the valve, E, was lifted. The particular valve was a plunger type, all others worked either by suction or pressure.

The igniting cock is shown at F, Figure 2.21, being the exploded view. It consists of a hollow plug, A, accurately fitted into a shell, B, and kept in position by a gland, C. The plug, A, rotated and a cut-out section would communicate alternately with a constantly burning pilot light situated externally and the passage, G, as the valve rotated, the

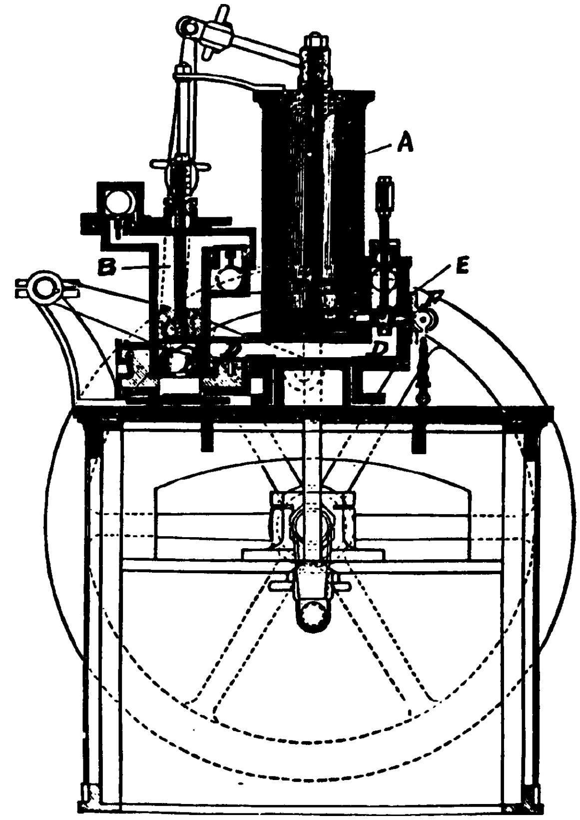


Fig. 2.19
Single acting engine by Barnett, 1838
(the igniting valve is shown at F)

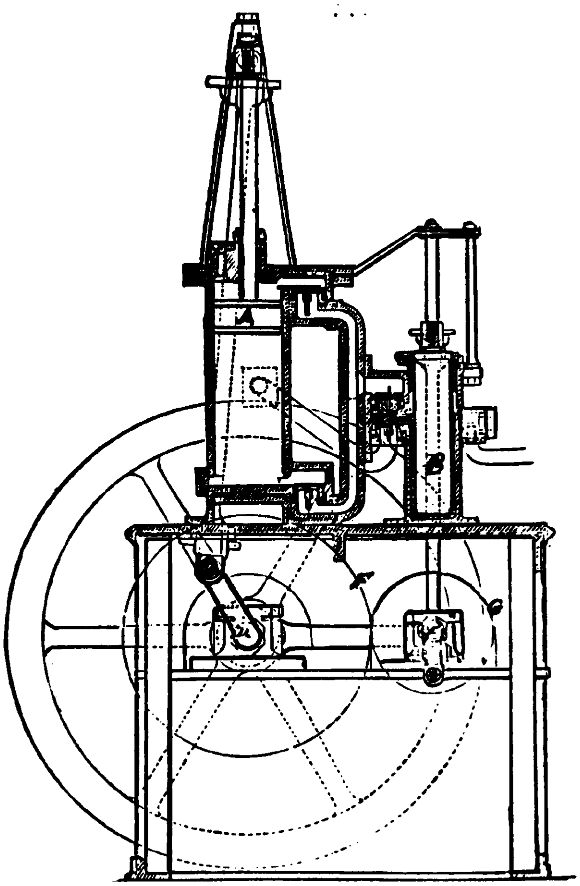


Fig. 2.20
Double acting engine by Barnett, 1838, in which compression of the charge within the working cylinder took place

igniting flame, e, would be lit and the valve sealed to atmosphere. Further rotation would allow this flame to ignite the new charge.

Barnett's second engine was similar in action to his first, except that it was double-acting. Two ignition valves were provided and an intermediate reservoir contained pressurised gas and air. As in the former engine, expansion was supposed to take place throughout the whole of the stroke.

The third engine by Barnett, Figure 2.20, is notable for its mention of compression by the working piston and not solely by an auxiliary piston as in his previous engines. It also describes a new form of ignition - the use of 'spongy platina', a mass of fine platinum wire which, when an inflammable gas is passed through, causes it to be ignited. The working cylinder, A, was double-acting and contained an exhaust port in the centre. B is the air pump cylinder containing a piston, C is a gas cylinder and piston (lying directly behind B). The pump shaft was driven via a toothed gear, G, half the size of another F, attached to the main crankshaft. Ignition occurred when the piston was at the extreme ends of the working cylinder. (Barnett did not state that he preferred his 'igniting valve' to the spongy platina).

The essential ingredients of engines that became successful thirty years later are thus seen in Barnett's third engine, namely, compression by the piston, a camshaft running at a speed which is at a measured difference than that of the engine, a flame ignition system and the metering of gas and air. No evidence has been found to show that a working engine was actually produced and the engine, as described

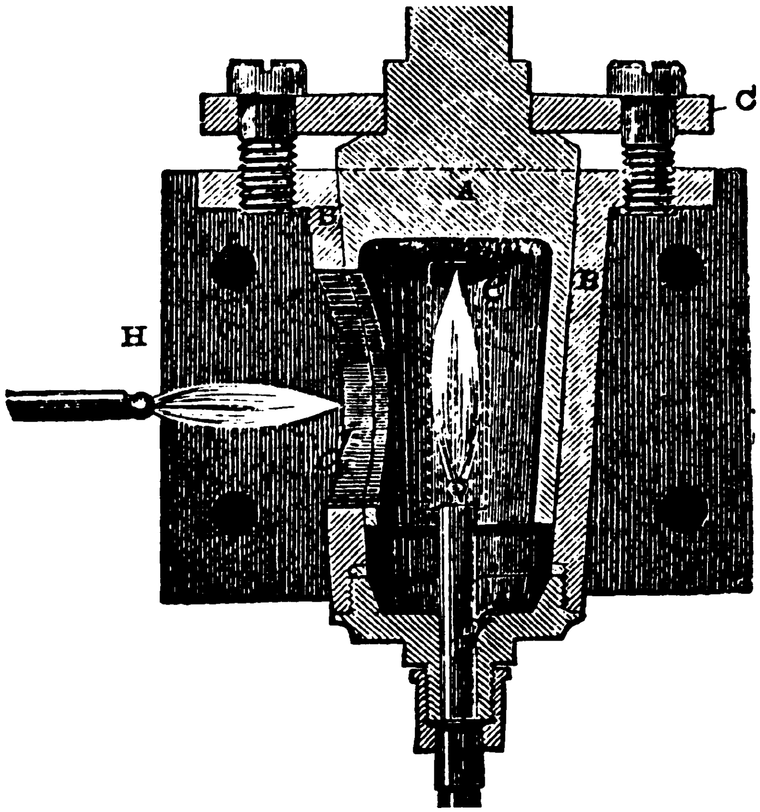


Fig. 2.21
Flame igniting device suggested by William Barnett in 1838. The inner section A, contained a small gas jet and rotated continuously. It communicated, first with the atmosphere to purge the chamber and receive a new charge, then with the stationary pilot light H and lastly with the new charge waiting in the working cylinder.

The idea was used nearly thirty years later by Hugon of France and Otto of Germany.

by Barnett, possessed deficiencies which would have made its running difficult. There is, for example, an insufficient expansion taking place only to half-stroke and the valve arrangement admitting the charge to each end of the cylinder was such that the charge would always flow into the chamber with the lowest pressure. At speed, the pressure in the end of the cylinder requiring a fresh charge could well be greater than that in the opposite end and the charge, therefore, would probably be directed to the wrong end of the cylinder. Lastly, no mention of a cooling jacket is made. All these defects could well have been overcome by experiments on a working model, had one existed, and care must be taken not to place too much reliance on the patent specifications as giving a true representation of the inventor's ideas.

2.5 Further American contributions

2.5.1 The first working reciprocating engines of Perry and Drake

The subject of motive power using inflammable vapours or gases was now beginning to attract a good deal more attention. Between 1840 and 1850 nearly one hundred English patents concerned with motive power were issued and during the next decade, this number had more than doubled. A great many reached only the provisional stage; a number were registered in the name of a resident in Great Britain, the actual patentee residing abroad. The next notable contribution to engine technology, followed this pattern with two separate ideas from America, followed in turn, by others from

Italy, France, and finally Germany. Meanwhile, a number of ideas came forth from Great Britain, such as that of James Johnson of Greenock[33] who suggested that one part oxygen mixed with two parts hydrogen be admitted below a piston and exploded, driving up the piston to cause a vacuum beneath, thus echoing the ideas of de Rivaz, but in the main, the lead that had been gained by Brown, Wright and Barnett was lost about this time and the countries just mentioned grasped the initiative.

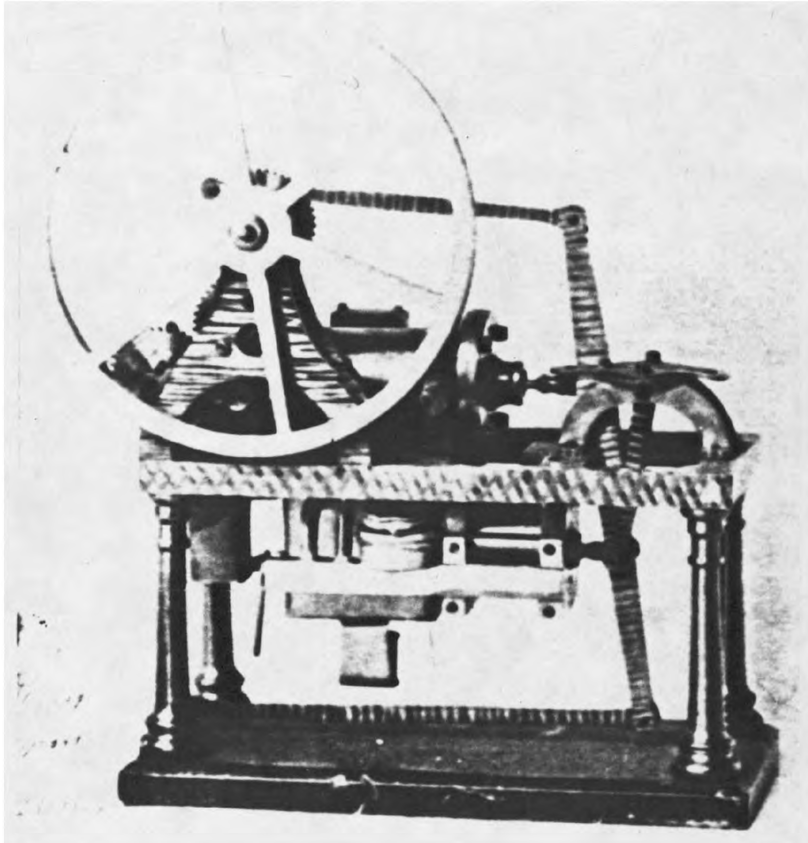
Stuart Perry of New York and Dr. Alfred Drake of Philadelphia began their work on engines about the same time, but quite independently from each other. Perry's work is well recorded since he took out patents. Drake didn't patent his early work, but the evidence is that he had a working model some months before Perry. Both the American versions were horizontal and double-acting and were obviously attempts to copy the steam engine.

The following extract from the Philadelphia Courier and Enquirer of about September or October 1843 appears in the Mechanics Magazine[34] and is about the only indication of Drake's early work:

> 'A new motive power engine invented by Dr. Alfred Drake has been exhibited in the City for the past few weeks and appears to be of the greatest value ....'

After relating the disadvantages of steam engines, the report continues:

> 'Dr. Drake has constructed an engine of three horse-power, the consumption of fuel being one and a half pounds of resin per hour ..... and when using its natural fuel of spirits of turpentine or lard, combined with whisky will require no furnace or pipes and could be placed



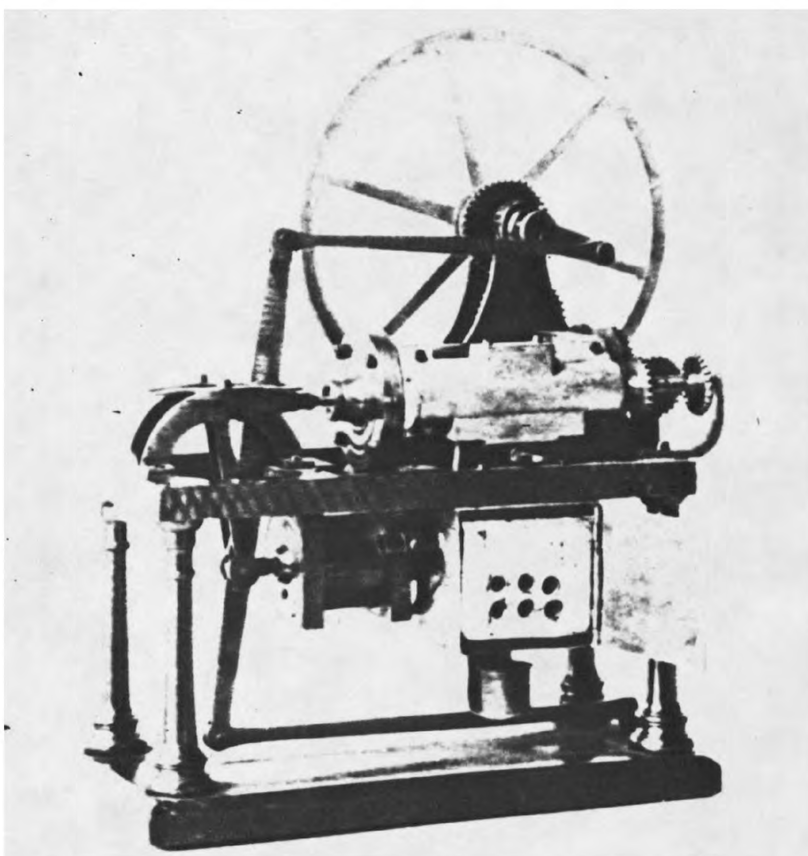


Fig. 2.22
An engine to run on resin by Stuart Perry of New York 1844.
(Model constructed by the Smithsonian Institute, Washington)

> below decks so that it could not be reached by shot. The engine can be set in motion in one minute and can be stopped when required.'

Drake did not patent an improved version of his engine in England until 1855[35]. This later engine, the construction and operation of which will be described later, contained some novel features. The ignition, for instance, was effected by an incandescent cast iron thimble - the forerunner of the incandescent tube method that did not become general practice until 1888. It is not clear, however, that he used this idea in 1843 and, in any event, despite their obvious ability to run, none of these engines by Drake, or for that matter, those of Perry, achieved any notable degree of acceptance.

The patent of Stuart Perry of 1843 gives a much greater insight into the technical appreciation of engine requirements existing at that time[36]. Figure 2.22 shows this engine which is a model*. It shows a double-acting single-cylinder placed over retorts, in which the fuel - spirits of turpentine or resin - was stored and heated by the exhaust gases to produce a vapour. Alongside the retorts was a double-acting air pump which forced air through them, picking up the inflammable vapour before passing into the working cylinder. A throttle valve was placed between the air pump and retort to give control over the mixture ratio. Ignition was by flame, admitted through a valve operated by a pin attached to the piston. The main claim for Perry's 1843 patent was as follows:

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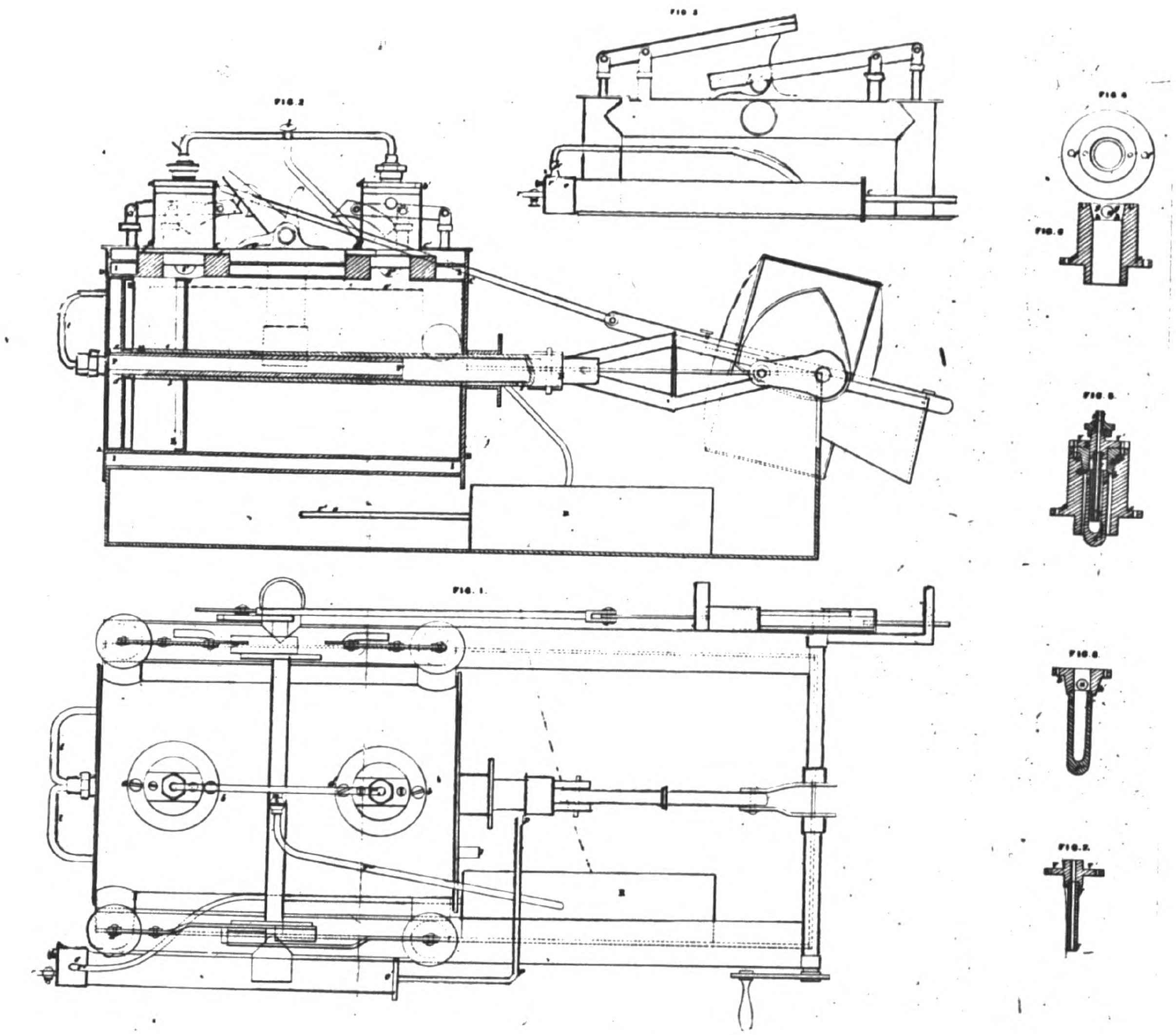
* Prior to 1870 a model was a requisite part of an American Patent application.

> 'the manner in which I have combined and arranged the air pump, the reservoir, the retort, the air regulator and cocks, which govern the admission of the charge at atmospheric air into the valve box. I claim also the manner of heating the retort by employing the heated air which escapes through the eduction tubes.'

Perry continued to work on his engine and in 1846 took out an American patent for an 'Improved Engine Operated by the Explosion of Gases'[37]. No English patent for this engine was taken out and the only notice of it in Great Britain appears in The Mechanics Magazine[38]. Evidence of Perry's continued work and experience is seen by the number of improvements that are listed which included: a water jacket for the cylinder, a cooling arrangement for the connecting rod and stuffing box, and also one for the piston. This was done by injecting water onto it as it passes a supply port in the cylinder wall. A new method of ignition was suggested by which platinum wire was heated by a flame, the platinum being so situated 'as to communicate by a valve directly with either end of the cylinder or with passages through which the mixed gases would pass'. Lastly, a receiver containing compressed atmospheric air for starting was suggested. The engine also used poppet valves and push rods, whereas the earlier engine used a rotating cylindrical valve with slots machined at the appropriate points on its circumference.

The description and design of Perry's 1846 engine with its poppet valves and incandescent ignition brings it remarkably close to the engines which eventually appeared forty years later. He demonstrated it to his brother, Samuel, in 1846 and it is described in Scientific American[39] as capable of working ten horse-power and, when using resin instead of



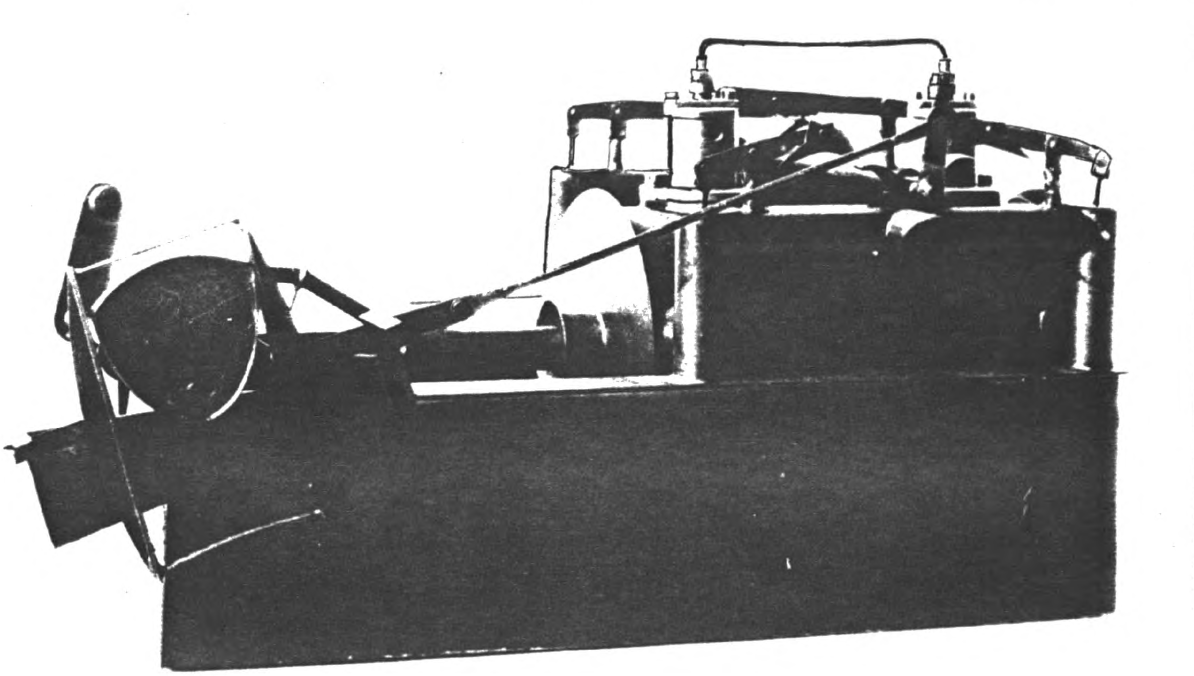


Fig 2.23 Alfred Drakes engine of 1855 taken from the patent specification. The incandescent ignition is shown at the inset figures

Lower figure shows a patent model submitted in 1855 turpentine, could be run for fifty cents per day. Unfortunately, it never enjoyed acceptance; it seems clear that Perry had great difficulty with cooling, but it is highly likely that the greater problem was that of procuring an acceptable, but cheap fuel. This possibility is discussed in Chapter Three. The lack of success of his engine affected Perry very little and occupied only a short space of time in his career with inventions. He eventually succeeded in obtaining forty patents, many of which proved very remunerative.

After the demonstration by Drake of his 1843 engine, nothing was heard of him until 1855 when, at the New York City Machinery Exhibition of that year, he demonstrated an improved version of his earlier engine. Figure 2.23 shows the design of this later engine, taken from his patent specifications. A test of the engine which lasted two hours, is reported in the Civil Engineer and Architects' Journal[40] by T.D. Stetson and reveals much about the difficulties that were still being experienced at that time in attempting to get such engines running successfully. Gas from the city mains was used in the ratio of one to nine of air and the engine cylinder was sixteen inches diameter and of eighteen inches stroke. Although designed as a double-acting, it was run as a single-acting for the purpose of the test; no brake was applied, no estimate of gas consumption was made and no attempt was made to determine cylinder pressure. Engine speed was reported as 60 rev/min. Elaborate cooling methods were used, which consisted of water circulating around a jacket; water was also passed into the piston via a hollow connecting rod and a flexible tube.

Apparently, the engine did not work too well during the test and Stetson reports that:

> '....... as the engine now stands, it cannot be recommended; the power is violent, vacillating, noisy and of unascertained economy.'

Drake also had problems with either the gas-air ratio (or gas composition); in addition, the igniters frequently cracked. It was a pity that Drake did not pursue his work further, since the working cycle of the engine - drawing in a charge at atmospheric pressure, followed by ignition - was used by Lenoir and made reasonably successful only five years later. The means of ignition used by Drake, a cast-iron thimble projecting into the cylinder and heated to red-heat by an external flame, was modified and became universal usage thirty years after Drake's engine. It would seem, therefore, that both Drake and Perry displayed a level of understanding of the requirements for a successful engine that had not previously been appreciated. Both, however, appeared to lose interest in their projects. Some ten years later, an English journal[41] made reference to the Drake engine and observed that for some time after the New York Exhibition it lay there, unused for several months. The now dormant interest, it was said, was due to the death of Dr. Drake and to the high cost of gas in New York which, at 12/6d per 1000 cubic feet*, must have proved a high disincentive to persevere with the problems that had emerged.

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* Cost per 1000 cubic feet in Great Britain varied widely, but in 1855 the average cost was less than one-third that of the American gas.

2.6 The Italian contribution

2.6.1 A return to atmospheric engines

The attempts by Wright and Barnett in the 1830's to harness the explosive power of inflammable fluids may well have sparked off a number of similar notions in the minds of inventors over the next twenty years. In trying them out, however, problems arose which had not previously been encountered in the vacuum engines that had already been used. The main problems at that time were those concerned with overheating and explosive shock* and it is highly likely that an awareness of these difficulties influenced the work of two Italians, Eugenio Barsanti (1821-64) and Felice (or Felix) Matteucci (1808-87).

Both Barsanti and Matteucci had distinguished academic backgrounds, Barsanti was a lecturer in mechanics and hydraulics at the Institute of Ximeniano, Florence; and Matteucci was a practising hydraulics engineer[42]. Their acquaintance with each other began with a professional assignment involving a lake near Florence. Prior to their meeting, Barsanti had been experimenting with explosions in closed vessels and whether or not he had his mind on a motive power unit is not quite clear, but such work would certainly have made him aware of the problems associated with explosions and explosive forces. This fact appears to explain why their first thoughts on internal combustion engines evolved round the 'free piston' arrangement first used by Rivaz. The first patent by the Italians for an engine, which utilised atmos-

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*A fuller discussion of the early problems encountered is given in Chapter Three

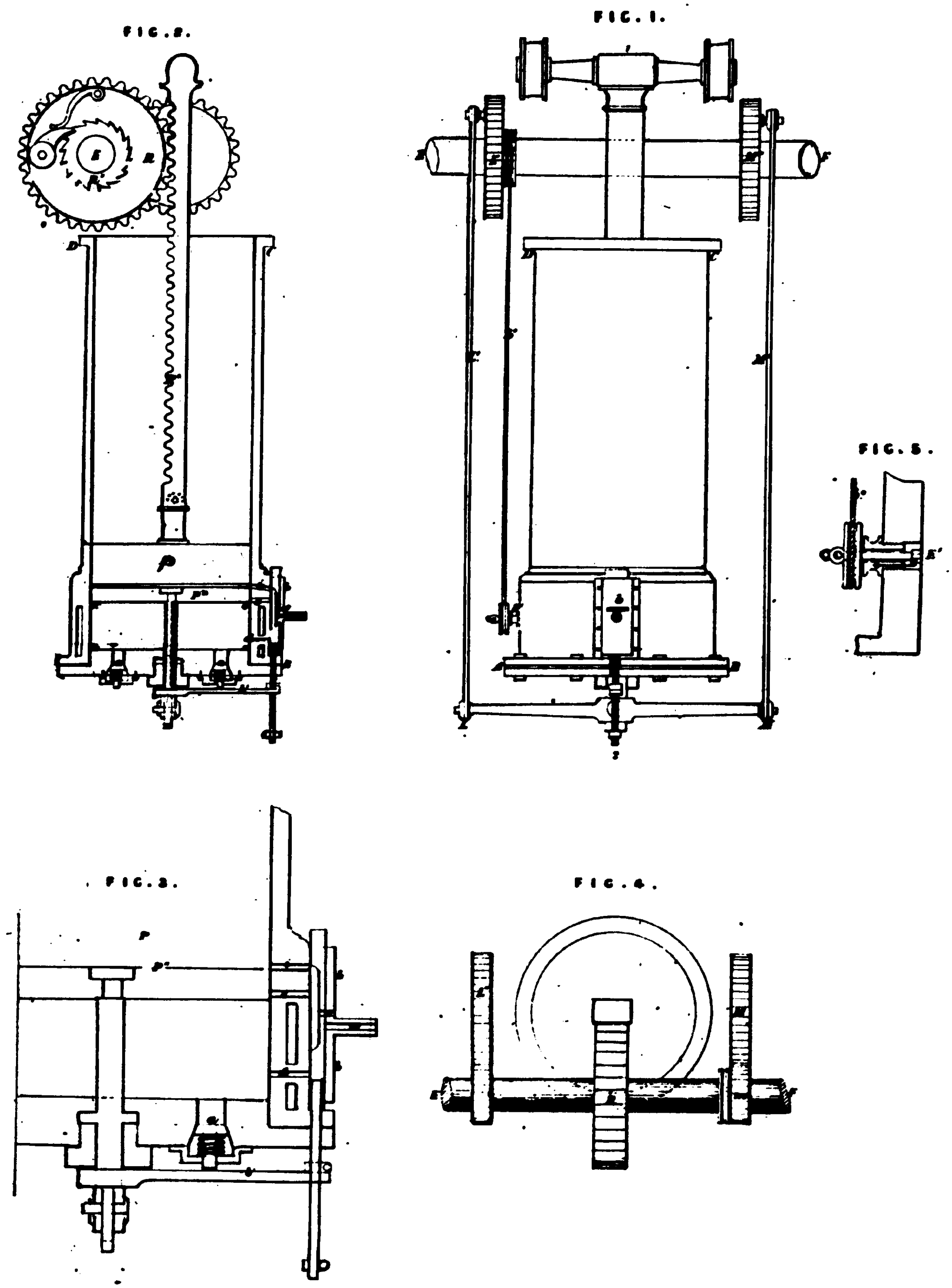

Fig 2.24 The two piston Atmospheric Engine of Barsanti and Matteucci.
From the patent drawings of 1857

pheric pressure appears in 1854[43]. During 1856 an engine was actually built by Benini of Florence and installed in a Railways Works near Florence to drive machine tools in the workshops.

The first English patent of 1854 by the Italians was quite lacking in many important details, but a second patent of 1857 is much more explicit[44]. Many improvements are shown, the construction and operation is described and numerous suggestions for its application are contained. The 'Engineer'[45] however, obviously quite unaware of the fact that a working engine had been produced, makes the comment that 'it is no doubt more curious than useful'. Figure 2.24 shows the design and general arrangement of the engine, which very nearly went into mass production. The working principle is best seen from Figure 2 of these drawings, from which it can be seen that a long-geared rack had a piston, P, attached to its base. The gear and ratchet arrangement for allowing the free ascent of the piston is shown at the upper end, R and R" respectively. A second piston, P", at the base by moving downwards a short distance, would draw in a new charge and when returned, would expel the burnt gases. The principle on which it worked was extremely simple. A charge of gas and air - hydrogen was first mentioned - is drawn into the base of the cylinder and ignited; the resulting explosive force flings up the piston and rack until a partial vacuum is created beneath, allowing atmospheric pressure to act on the upper side and produce the working stroke. Ignition was by a De la Rive multiplier*, worked by the engine

* An early form of induction coil

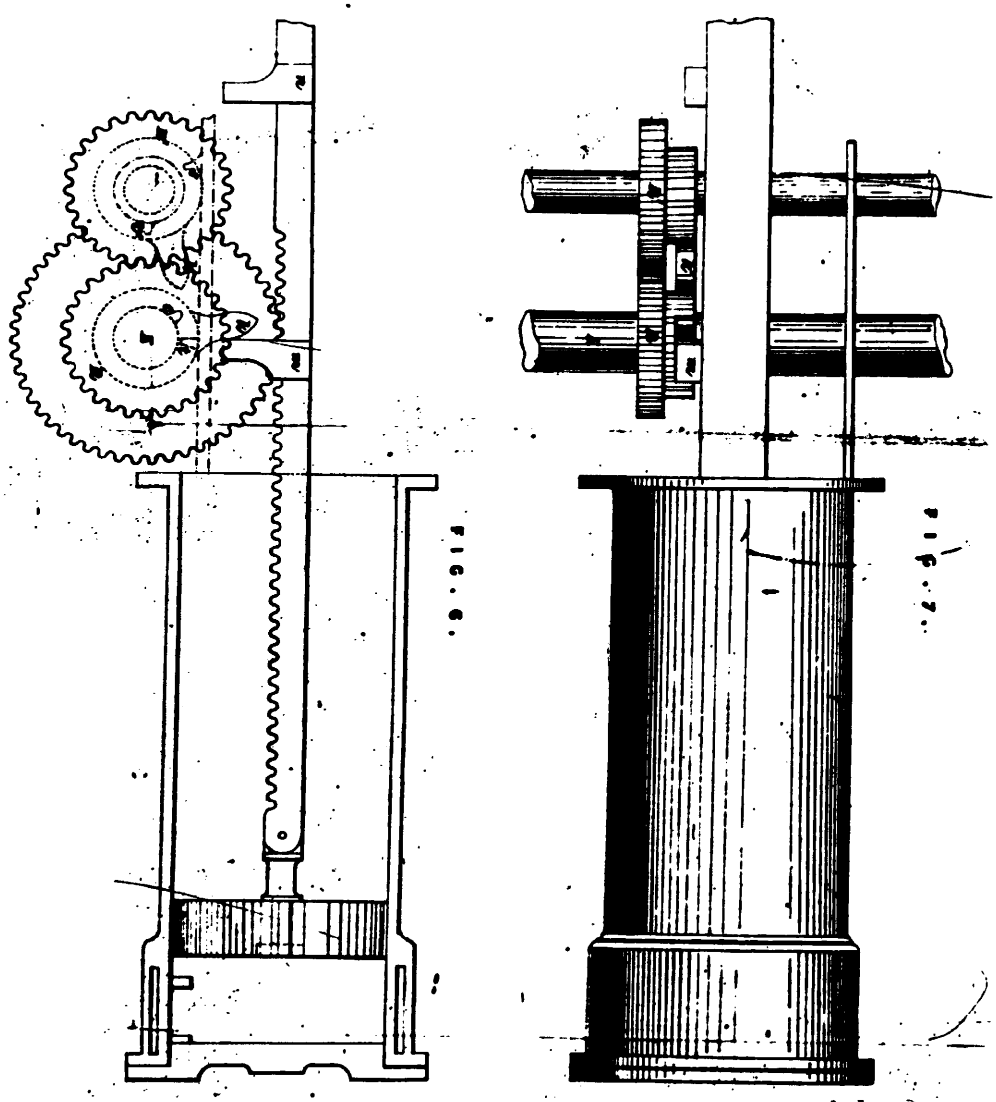

Fig. 2.25
Gearing arrangement of the 'free piston' atmospheric engine by Barsanti and Matteucci.
From the patent drawings of 1857

and the current supplied by Bunsen cells. A series of sparks were made to jump a gap in the combustion chamber created by a flat-bladed spring making and breaking contact as it rotated with a second earthed electrode. The gearing and ratchet arrangement which Barsanti and Matteucci adopted is shown in Figure 2.25.

During the next four years, although they were not to appreciate it, the two Italians embarked upon a course which was to deny them the distinction of being the first to produce a commercially successful engine. In 1857, instead of considering this particular engine as a production model, they continued with development work in conjunction with an engineer Giovanni Battista Babacci, eventually producing a single-cylinder atmospheric engine with opposed pistons. This second engine proved highly successful in trials and a company 'Societa Promotrice del Nuovo Motors Barsanti e Matteucci' was formed in October of 1860 and a twenty horse-power (claimed) version was shown at the Italian Exposition in Florence in 1861. A twelve horse-power version was built by Escher, Wyss and Co. of Zurich. Following these successful trials, a policy of production was worked out, but alsmost immediately a series of personal misfortunes befell Barsanti and Matteucci which, in turn, were then followed by some odd decisions by the company in Florence. The ultimate end was the abandonment of the whole project.

The first set-back occurred when Matteucci was forced to retire from the company because of ill-health soon after a decision to go into production with the earlier 1857 engine had been taken. This was followed by several unsuccessful attempts to find a reputable engine builder, but eventually,

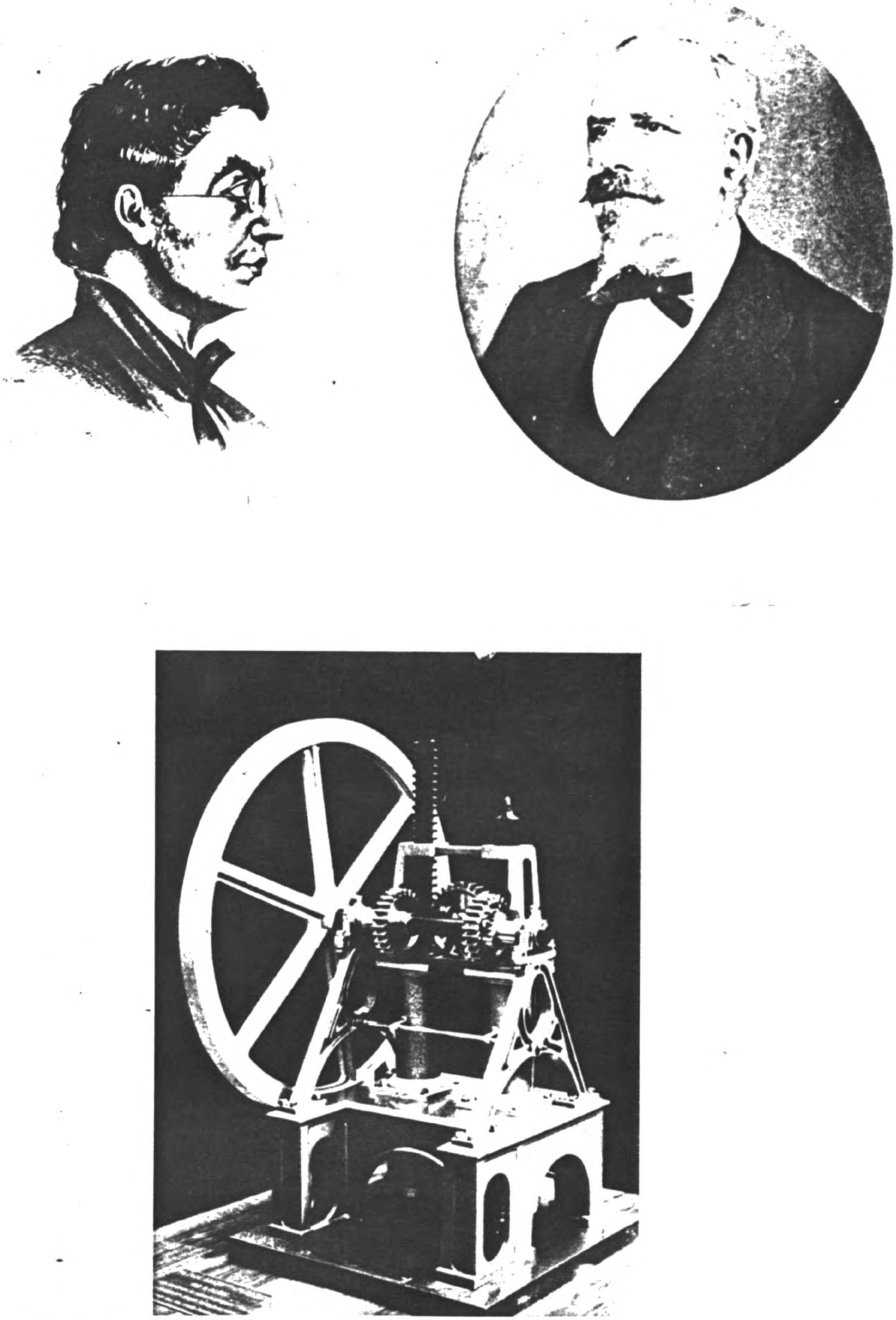

Fig. 2.26
Eugenio Barsanti (left) and Felice Matteucci

Below is a model of the two cylinder atmospheric engine of 1856 (now exhibited in the Fiat Centro Storico, Turin) in 1863, an order to build a number of engines was given to the Bauer Helvetia Co. of Milan. An engine was built and the first trials were promising; it was reported to consume slightly over twenty-eight cubic feet of gas per horsepower with a brake thermal efficiency of fourteen per cent. It was then that a second misfortune befell Barsanti who, by this time, was entirely on his own. The Bauer Helvetia Co. were unable to supply the number of engines required, and to add to his problems, the Lenoir engine was now establishing itself in the rest of Europe. Barsanti then sought the help of the Soc. John Cockerill of Seraing, Belgium to build his engine. They became interested and an engine was shipped over from Italy. Barsanti followed in March 1864 to demonstrate it and discuss arrangements for its production. The third, and quite catastrophic act of fate then occurred. In the midst of negotiations, Barsanti contracted Typhoid and died on 19th April, aged forty-two.

This was, indeed, a major set-back for the company in Florence, but there then followed an extraordinary decision by the directors. Matteucci, who then offered his help, was prevented from taking any major role to continue with the work and, quite surprisingly, the company decided to concentrate on making hot-air engines. Babacci attempted to continue with such work, but without his two colleagues was unable to make any notable progress. The valuable and quite worthy achievements of Barsanti and Matteucci, therefore, came to nothing.

With the benefit of hindsight, one must resist the temptation to postulate what might have been had Barsanti and Co. embarked upon a different business course than they did. Although they acknowledged the mechanical difficulties associated with the ratchet and pawl of their engine (as also did Otto and Langen in their version three years later), there can be no doubt that they made a valuable contribution to engine technology. The one regrettable fact, as far as Barsanti was concerned, was that his encounter with Cockerill was four years too late.

2.7 James Robson and his engine - 1857-60

The name of James Robson (1833-1913) as an early pioneer of gas engines, is hardly likely to be found in any of the few contemporary writings now available, which were written about the turn of the nineteenth century. It does not even feature in the patent lists until the year 1877, when his ideas and achievements entitled him to be classed as a pioneer of the two-stroke engine (see Chapter Eight). Yet, more than twenty years before this date, he built gas engines that worked to drive machinery. For an account of Robson's work, we are indebted to a private and thus, littleknown, publication by his son who, for a time, was employed at the Cornwall Works of Tangyes Ltd., Birmingham[46].

Robson, who lived in North Shields, was the son of a building contractor and apprenticed to his Uncle's ironmongery and hardware business. He became the proprietor on the death of his Uncle, during the early part of the 1860's. The gas engines that he built, first appeared during 1857. His interest in them began in 1851 when he was apparently inspired, by a visit to the Great Exhibition, to experiment using gas to heat an incubator instead of oil lamps. He succeeded in causing an explosion which almost cost him his life, but it was this experience which provided him with first-hand realisation of the explosive force of gas. To obtain a quantitive assessment of the force, he subsequently devised experiments using a small cylinder, fourteen inches long and three inches diameter, causing explosions to occur within it. Robson finally concluded that it should be possible to obtain a pressure of between sixty and seventy pounds per square inch from such explosions.

Robson's first gas engine of 1857 is shown in Figure 2.27 (upper); it became known as the 'Cogwheel Gas Engine' because the flywheel was one that had been appropriated from a disused quarry crane. The engine worked simply by raising the piston two or three inches to draw in a charge of gas and air and then igniting it using a pilot flame burning outside. Cooling consisted of surrounding the cylinder with a container made of wood and partly filling it with water. A board floated on the surface to prevent water splashing into the cylinder. The main use of this engine was experimental. From this work, Robson gained experience which enabled him to make a much improved engine. This first engine by Robson suffered a most ungainly end; during excavation work that was being done for the building of the Theatre Royal at South Shields in 1865, Robson's premises, which were next door, fell down and demolished the engine which was stored in the basement.

The next engine by Robson, is shown in Figure 2.17 (lower) and as can be seen, was a considerable step forward in de-

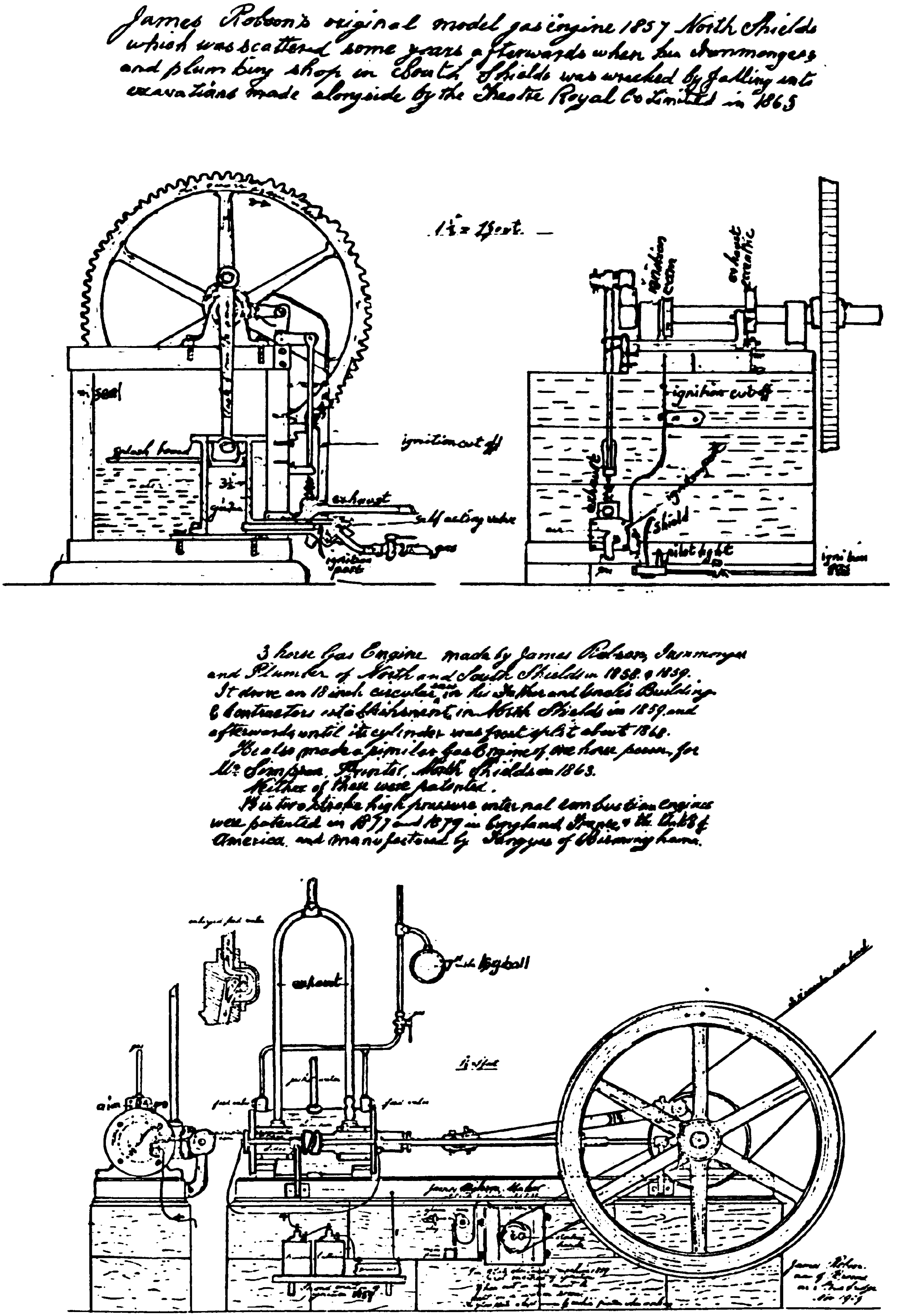

Fig. 2.27
Original drawings by James Robson of his Direct-Explosive gas engine (top) made in 1857 and his double acting engine of 1858-9. The 1858 engine is fitted with electric ignition.

sign. It was made in 1858-59 and was remarkably like the Lenoir engine - yet to be born - in both appearances and operation. It was double-acting, drawing in a charge at atmospheric pressure for about half the stroke at which point ignition occurred. This second engine of three horse-power, was used to drive an eighteen inch circular saw in his father's works for about nine years until frost cracked the cylinder jacket. Two similar engines to this were made by Robson, one was installed to drive the printing machinery at the offices of the 'Shields Daily News' and the other, a one horse-power engine, was also used to drive printing machinery at the works of Messrs Simpson and Mustard's, North Shields.

Robson's anticipation of engine design and operation that had yet to come, was remarkable, but a second important feature of his total contribution was that concerned with electric ignition methods, which he proved to be workable. Electric ignition was used on at least one of his horizontal engines*. The first attempts utilised electrostatic means to produce a spark and these subsequently led to his using a Ruhmkorff coil and Bunsen cells, with a make and break arrangement, which he called 'a primary current disrupter'. Lenoir, in his engine of 1860, used an identical system of electric ignition.

Robson's contribution during these formative years is significant, His fame was localised, since none of the engines just described were ever patented, but his design and ideas made quite substantial strides in engine technology. They

Probably the first, Robson later devised a gas ignition system appear to have been imitated, almost immediately first by Lenoir, then working in Paris and later by Hugon. Pressure of his business brought about by the death of his Uncle, the destruction of his premises at South Shields and the need to care for his aged father, meant that this far-sighted inventor could devote little time to his experiments and, although he proffered his opinions on the merits of gas engines, from time to time[47], it was to be some years before he again was to become actively involved.

* No direct evidence exists to show that either of them were aware of Robson's engines.

Refences - Chapter Two

1. English Patent 1833/1791

2. English Patent 1983/1794

3. Aimie Witz. Traite Théorique et Pratique des Moeurs à Gaz et à Petrole (Paris 1892) Vol 1 p.13

4. French Patent 356/1799

5. The work of de Rivaz was largely unknown until Henry Michelet's l'Inventeur Isaac de Rivaz (1965) pub. by Martigny. Rivaz made detailed recordings of his experiments which involved engineering and chemistry.

6. Michelet op cit p.208 The French patent is given as 30 Jan. 1807 but no number. A previous application in 1805 for a patent was rejected as 'too vague'

7. Ibid p.211

8. Ibid pp.222-227

9. W. Cecil. 'On the Application of Hydrogen Gas to produce a Moving Power in Machinery; with a Description of an Engine which is Moved by the Pressure of the Atmosphere upon a Vacuum Caused by Explosions of Hydrogen Gas and Atmospheric Air'. Trans. Camb. Phil. Soc. Vol. 1 (1820) Part 2 pp.217-39

10. Mechanics Magazine Vol. 2 (1824) p.360 Brown's engine is incorrectly described as an 'explosion engine'. A full description with drawings is given on p. 385 of the same volume

11. English Patent 4874/1823 dated Dec. 4. An American Patent is dated Mar. 2 1824

12. Mechanics Magazine Vol. 3 (1825) p.6

13. Mechanics Magazine Vol. 4 (1825) p.19

14. Mechanics Magazine Vol. 4 (1825) p.309

15. Mechanics Magazine Vol. 5 (1826) p.145

16. Mechanics Magazine Vol. 6 (1826) p.79

17. English Patent 5350/1826

18. A.K. Bruce 'Samuel Brown and the Gas Engine'

The Engineer Vol. 182 p.214

19. Mechanics Magazine Vol. 7 (1827) pp.82-84

20. Mechanics Magazine Vol. 9 (1828) p.278. The letter was from the Editor of the Franklin Journal. Reference is made to the work of Samuel Morey of Philadelphia.

21. Mechanics Magazine Vol. 17 (1832) p.273

22. List of American Patents 1790 to 1839. The classification is by subject and not by the patentee's name

23. English Patent 5402/1826 issued to Erskine Hazard

24. Mechanics Magazine Vol. 5 (1826) p.298

25. English Patent 5211/1825

26. L.T.C. Rolt. Isambard Kingdom Brunel a Biography 5th impression (London 1964) p.41

27. Ibid See also Proc. Inst. Civil Engineers Vol. IX (1850) pp.199-202

28. Mechanics Magazine Vol. 5 (1826) p.385 Cheverton later read a lengthy paper 'On the Use of Heated Air as a Motive Power' Proc. Inst. Civil Engineers Vol. XII (1853) pp.312-351

29. Mechanics Magazine Vol. 6 (1826) p.89

30. Civil Engineer and Architects' Journal Vol. 11 (1848) p.178

31. English Patent 6525/1833 A good description and drawings are given in The London Journal of Arts and Sciences and Repertory of Patent Inventions. Vol. 5 No. XXXI (Conjoined Series) p.137

32. English Patent 7615/1838

33. English Patent 8841/1841

34. Mechanics Magazine Vol. 39 (1843) p.304

35. English Patent 562/1855 issued to A.V. Newton, a Patent agent. An American Patent 12715/1855 is also recorded

36. English Patent 9972/1843 issued to Joseph Robinson, a Patent agent. An American Patent 3597/1844 is the

same specification.

37. American Patent 480/1846

38. Mechanics Magazine Vol. 48 (1846) p.523 which gives selected patents from the Journal of the Franklin Institute

39. 'A New Gas Engine' Scientific American Vol. 1 (1846) of July 23

40. Civil Engineer and Architects' Journal Vol. 19 (1856) p.340 Stetson was an engineer appointed by the New York Tribune

41. The English Mechanic Vol. 2 (1866) p.351

42. Vincenzo Vannacci. L'invenzione del motore, a scoppio realizzate dai toscani Barsanti e Matteucci, 1854-1954 (Florence 1955)

43. English Patent 1072/1854 (Provisional only) No drawings are given

44. English Patent 1655/1857 A French Patent 1858 and an Italian Patent of 1858 are similar to the English Patent

45. The Engineer Vol. 5 (1858) pp.73-74

46. J. Robson. A Brief Memoir of James Robson, the Inventor of the Two-Cycle Internal Combustion Engine and of the Gas Hammer (Birmingham 1915)

47. 'Coal Gas Motive Power' The Engineer Vol. 18 (1864) p.74 Robson describes his experiments with the pressure vessel and makes comparisons of running costs with various means of motive power.

CHAPTER THREE

AN ASSESSMENT OF THE IDEAS TO 1860

THE RISE OF THE GAS INDUSTRY AND ITS POSSIBLE INFLUENCE ON GAS ENGINE PROGRESS

3.1 The Problems encountered

The previous chapter has described the more notable of many hundreds of ideas for motive power that were suggested by hopeful inventors, several of which are seen to exhibit a degree of perceptiveness and foresight, which does credit to their originators. It has been seen that few were actually brought to a working form; others had what may be considered to be the basic requirements to become operative and with perseverance, they might well have become so. But in reality, none of the engines proposed during this period succeeded in becoming commercially acceptable despite the urgent need that existed for one. The pertinent question now, therefore, is what possible reasons can be advanced which would explain this state of affairs?

In this chapter, the answer to this question is sought by examining the various problems that were encountered, such as those of a mechanical and thermal nature; ignition difficulties were present - and, indeed , existed almost until the end of this century - and these also are described and discussed. There are strong indications too, that problems arose with fuels and, to clarify this, an examination of relevant events that took place in gas making and gas technology are given.

3.1.1 Mechanical and thermal problems

Patent drawings and descriptions are useful in providing a valuable guide as to the inventors' general idea, but in studying them, a great deal of care must be exercised, if conclusions are sought as to the feasibility of a particular idea. They make no allowance, for instance, for the capabilities of those who would be called upon to put such ideas into a practical form, and further, there is the fact that patents taken out during the period under consideration, are notorious for their poor quality of presentation and omission of detail - held by many to be deliberate. In attempting to establish reasons why the creditable schemes referred to earlier did not become successful, a cautious study of patent drawings has been made, but with due allowance for the skill of the craftsmen likely to be involved in their manufacture.

A fact which emerges from such an examination of patent drawings (and also written accounts of the performance of these early engines) is that inventors seemed unable to divest their minds of the construction and working principle of the steam engine. In itself, the double-acting method of working, so commonly used with steam, is quite worthy, but its application to internal combustion engines produces problems of quite a different nature to those associated with a steam engine. Examples of inventors who so modelled their ideas were, Wright, Barnett, Perry and Drake.
The adaptation of the steam principle to an explosion engine would seem quite a natural thing to do, but explosions in confined spaces produce extremely high rates of pressure rise which, with the non-compression cycle that was used, gave

rise to severe mechanical shock loads which were troublesome in the extreme. The materials generally available at that time were wrought iron and cast iron, with steel in very limited quantities. After correct heat treatment*, wrought iron is capable of withstanding tensile shock loads, but it is notably poor at coping with compressive loads of the kind experienced by connecting rods and crankshafts.

There is also the fact that it work hardens in practice, becoming brittle**. The effect, therefore, on the two highly stressed components just mentioned, needs no further explanation; sustained or continuous running of an engine using such materials would have been difficult to achieve.

Further mechanical problems arose with lubrication, mainly as a direct result of the heat that was generated, but not effectively used. The root cause of this difficulty lay in the failure to provide a sufficient expansion for the burning gases, consequently, the exhausting gases, still at a high temperature, would cause excessive heating of the exhaust slide valves. Another design fault occurred with the pistons that were used; they tended to have but a small contact area with the cylinder and were thus unable to conduct away the heat that was so quickly generated by a firing stroke occurring on each side of the piston. Provision for cylinder cooling appears also to have been inadequate, as it seems not to have been fully appreciated that the cylinders of a steam engine should not be allowed to lose their

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* No evidence that this was carried out can be found

** Present-day safety statutes require that chains, rings and hooks, etc. of wrought iron should be annealed every six months heat, but those of internal combustion engines must be sufficiently cooled. Efforts to achieve satisfactory cooling produced some quite ingenious methods, such as the hollowing out of connecting rods and pistons, so that they could be filled with water; the injection of water into the working cylinder was also tried. Despite these measures, accounts of buckled connecting rods and of glowing pistons and seizures, can frequently be found. Examples in which such problems were experienced were the Perry engines of 1843 and 1846, the Drake engines of 1843 and 1855, and even the early Lenoir engines of 1860-2.

3.1.2 Combustion and ignition problems

Thermodynamic problems were encountered with engines at a time when there was a total lack of knowledge of gaseous explosions and of combustion. It was not until 1857 that Bunsen published his only book 'Gasometrische Methoden' in which he makes a brief reference to the nature of flame propagation and to his experiments that he had carried out on the ignition of various dilutions of inflammable gases with air*. Such work was followed by Schmidt 1861 who, in attempting to evaluate the theory underlying the operation of the Lenoir engine, suggested that a compressed mixture would be more beneficial to its working[1], (this worthy proposal was nullified by another which advocated the retention of exhaust gases and excessive air, the purpose of which was to 'render a more gradual explosion', (see Chapter Four,

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*The possible effect of Bunsen's work on Lenoir and his theories related to his engine is discussed in Chapter Four 4.3

section 4.3). Gustav Adolfe Hirn, in his 'Exposition analytique et expérimentale de la théorie mécanique de la chaleur' of 1862, made reference to the effect of the cylinder walls upon the available heat energy, but up to this date none of these works can be considered as likely to be of any great help to those who were grappling with the real life problems and, in any case, would possibly not have understood their scientific content sufficiently to make effective use of it.

In 1867, Bunsen produced some results of experiments he had carried out, which showed the extremely high temperatures attained by burning gases[2]. This was quite useful, but at that time was responsible for confused thinking; the temperatures actually attained by the burning gas, for instance, was observed to be appreciably less than that arrived at by calculations - the phenomena of dissociation and the cooling effect of the enclosing vessel, being little understood. A satisfactory explanation of this situation proved elusive for several years and it was not until the 1880's* that information related to the behaviour of gaseous explosions became available for useful application to engines. The workers in this field who were the main contributors were Dixon[3], who compared the explosion rates of different gases using different mixtures of gas and air; Mallard and le Chatelier[4], who covered similar ground and determined the time to reach peak pressure; Berthelot and Vielle[5] whose contributions over a wide field were substan-

*This means that at the time Otto produced his four-stroke engine in 1876, there was a very frail understanding of the basic theory allied to the working. A fuller discussion of this, which proves to be important, is given in Chapter six tial between the years 1882 to 1885; and Dugald Clerk[6] and Professor Aimie Witz[7] whose experiments, both on actual engines and simulated cylinder arrangements with increasing pressures, proved extremely valuable. The work of Clerk is particularly notable; as well as making engines of his own (see Chapter Eight) he had received a scientific training and thus possessed the opportunity to link theory to practice.

In seeking to establish the beneficial effects that scientific experiments on combustion might have had upon ideas for engines, it should be borne in mind that during the 1880's the use of compression had become firmly established. This was not the case during the formative period, when the cycle that was used consisted simply of the piston drawing in a charge at atmospheric pressure, then igniting, but leaving only about a half, or at best, two-thirds stroke in which to make use of the available energy. Each of these quite different modes of working - compression and non-compressions - require to be studied from a totally different standpoint. The non-compression cycle, of which the Lenoir engine of 1860 is perhaps the best example (described in the next chapter) is one that proved almost impossible to operate economically, even at a much later period and this particular cycle was extremely common prior to 1860.

The principal defects of such a cycle, which unfortunately were not at all appreciated, are that with low piston speed engines such as were used, explosion shock, which gave the piston a severe blow, were bound to occur. The actual impact, when no compression is used was greater than that if a compressed mixture was present in the cylinder. Another limitation of this particular cycle was its poor thermal efficiency and, consequently, poor economy. The cause of this - a very large surface area exposed to the burning gases - was also not appreciated until very much later, indeed, until some years after the four-stroke compression engine appeared in 1876.

Ignition difficulties were very troublesome and most likely, were amongst the first problems encountered. They remained so until the late 1890's by which time electromagnetic machines became reliable. As far as internal combustion engines are concerned, four means of ignition are possible - electrical, flame, incandescence and catalytic, or chemical - and by 1860, all of these had been tried. Electric ignition, using electrostatic means, appears to have been the first to receive consideration[8] and from about 1850, 'galvanic electricity' or electric current ignition was tried, but little success attended either of these methods. Electrostatic means were very much dependent upon atmospheric conditions and with current electricity, the development of primary cells up to and including the 1860's left much to be desired*. With electrostatic and electrical methods thus proving unreliable, flame methods along the lines suggested by Barnett in 1838, became standard usage and continued to be used until 1888. The problem with the flame method of ignition was that when the mixture is ignited, the igniting flame is extinguished and some means of re-

* This is discussed in more detail in Chapter Four

igniting it must be provided, usually a second flame situated at a distance from the igniting port.

It is here that the greatest difficulty with flame systems lies; not only must the igniting flame be transported from the auxiliary flame to the igniting port but effective sealing must be provided, so that at the moment of ignition, leakage from the cylinder does not occur. Barnett quite obviously appreciated this, so also did Perry.

Alfred Drake in 1855* used an incandescent form of ignition, the operating requirements for which are less exacting than those for flame ignition. In essence, all that is required is for the inflammable charge to be brought into contact with a material, metallic or porcelain, which is at a temperature high enough to ignite it. The principle difficulty with this method is that of ensuring ignitions occur at the precise moment. When a heated tube is used for ignition, the timing depends upon such factors as: dimensions of the tube, its temperature, the ratio of air to fuel, position of the tube within the cylinder and of the flame which is heating the tube. From reports of his engine tests, it would appear that Drake, in 1855, experienced ignition difficulties. The cast iron tube (or thimble as it was called) which projected into the cylinder frequently cracked and irregular ignitions were also a problem. Had Drake persevered, he might well have come to appreciate that placing the tube so as to project out of the cylinder (a method successfully used thirty years later) would have

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*He may well have used it in his 1843 engine, but no evidence of this can be found provided greater flexibility and control over ignition timing and, apart from the non-compression cycle that he used, might well have achieved a greater success.

Catalytic, or chemical methods of ignition, never became established in practice. Barnett proposed their use in 1838 as an alternative to his igniting valve and the idea crops up continually throughout the whole period of technological development with internal combustion engines[9]. In this type, the intention was to utilise the property of spongy platinum to cause the spontaneous ignition of a stream of inflammable gas when directed into it. It is unsuitable for engines because the method suffers from two disadvantages; the platinum does not retain this property for very long, and secondly, the action is far too slow to be of any use in an engine.

3.2 Other considerations

3.2.1 The craftsmen and their training

The description given so far of the problems with which the early pioneers had to contend in trying to make engines work leads to several relevant questions. Were the difficulties insurmountable, for instance, and beyond the abilities of engineers and mechanics of the day to overcome them? What degree of incentive was there to replace the steam engine? and what obstacles, if any, were present which prevented a cheap and satisfactory fuel becoming available?

The first point relates to the skill of the inventors and craftsmen that were involved. In order to assess the quality of this, we need only to survey the ingenuity that is displayed in the design and manufacture of machinery such as machine tools and steam engines that were being made at that time. The skilful way in which design problems were overcome implies that talent of a sufficient calibre was, in fact, available but yet it seems not to have been used on the problems connected with internal combustion engines. It is very likely that the best brains would be preoccupied with improvements to the steam engine, but it must be remembered that there was a good deal of incentive present to replace the latter. Additional evidence of this to that of Cheverton* is provided by T.C. Hansard, a Parliamentary printer when he describes the labour force required to operate a machine in his works[10].

> 'I have three men to the crank in order that one may be alternately at rest or sitting to receive and lay even the printed sheets as shot from the cylinder; thus every man of these three has 20 minutes relief in each hour. Another man of more intelligence acts as foreman or overlooker' .... 'a little boy performs the business of layer on'.

A description given later[11], relates how, in the operation of a bullet-making machine in the 1830's, twelve men and five boys were needed. With tiring operations of this nature, the desire for mechanisation by those called upon to carry out these arduous tasks is understandable.

Thirty years later, it would seem that little progress has been made in the quest for a convenient prime mover. Charles Babbage[12], in echoing the words of Cheverton in 1826, suggested that a network of underground high pressure

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* Benjamin Cheverton's letter of 1826 is quoted in Chapter One

water mains should be constructed.

> 'Machines of small and fractional horsepower, such as those used by light industries could then be used'.

Babbage was led to express such views after visiting the Great Exhibition. He was impressed by the array of machine tools, which included lathes, planing machines, slotters, shaping and milling machines but, at the same time, was concerned that their use was prohibited to anyone unable to afford a steam engine.

It would seem, therefore, that in the conception, production and operation of any contrivance, three categories of person are involved; the inventor, the builder and the operator. Within the limits of the available materials, it has been shown in this section that there was an ample level of manufacturing skill available; it was by no means the 'precision engineering' standard of today, but would have been sufficient had it been supported by sound thinking on the part of the inventor. The quality of the operatives left much to be desired. Examples, of their neglect to provide such basic requirements as lubricating oil and water, can be found with Lenoir engines during the 1860's and even with the Otto-Langen engines during the 1870's. In point of fact, however, events during the formative period only occasionally got to the point where operatives were required, and even in such few cases, the operator was also usually the inventor. The intermediary would be a manufacturer who would work to the inventor's instructions.

In the three-cornered figure of production just described, the onus to ensure that his engine worked would appear to be on the inventor and point now to be considered, as far as their qualities were concerned, is their ability to appreciate the scientific principles that are inherent in the running of internal combustion engines. Upon examination, no evidence whatever has appeared to show that they possessed the necessary appreciation of detail and an inquiry as to the cause of this neglect must examine the facilities for an appropriate education that were available in these matters. Regrettably, opportunities for technical education in Great Britain during the period being considered, were sadly lacking; a situation which was in stark contrast to that on the Continent, particularly in Germany. There, under the forceful teachings of Ferdinand Redtenbacher, whose declared objective was 'to link science with practice', men like Eugen Langen, Franz Reuleaux, Gottlieb Daimler, Wilhelm Maybach and Karl Benz emerged, all destined to have a pronounced effect upon developments in engineering throughout Germany*. All of them, in addition to a rigourous practical training, received a course of scientific study in the elements of mechanics, mathematics, engineering drawing and design. The provision of such training began in Germany as early as 1817, when Wilhelm Beuth formed his Trade schools. The Polytechnic at Karlsruhe followed in 1825, Munich in 1827, Dresden in 1828, Stuttgart in 1829 and Hanover in 1831[13]. By the 1850's the output of these establishments meant that a number of engineers of the calibre of Reuleaux and Langen were already about in industry. Their equal, or anything even remotely like it, was non-

* Their contribution to the internal combustion engine is discussed in subsequent chapters.

existent in Britain at that time.

William Fairbairn, FRS, the Highland Scot who founded a great engineering enterprise in Manchester, was conscious of the contrasting attitudes to training that existed in these two countries and in lamenting the failure of the State to provide the initiative was moved in 1852 to declare[14]

> '....... how very few of our best practitioners in Architecture, Civil and Mechanical Engineering are acquainted with the rudiments, or even the simplest theoretical rules of their professions; and how often they have to depend upon chance instead of sound elementary knowledge for the various constructions on which they elaborate defective, if not abortive, results.
>
> '....... for many years past, we have suffered severe inflictions on our national pride in being called upon to witness failures and abortions in the art of construction, which a cultivated taste, superior skill and extended knowledge would have prevented.'

On the necessities which exist for a knowledge of science in union with practice, Fairbairn goes on to say[15]

> '....... it is extraordinary, that in this country - which above all others - is famed for the extent of its manufactures, mechanical skill and extensive practice in the useful arts - there should be no institute nor any establishment whatever to teach and instruct the rising generation in the elementary rules of their respective profession ......'

In a most eloquent but forthright manner, Fairbairn then goes on to describe the absurdity of considering theoretical knowledge as a 'dangerous and a useless attainment'.

The evidence showing the deficiencies of a technical education system in Britain is strong and there is an equally strong argument for suggesting that the negative attitude to theoretical training exhibited by the majority of practising engineers in Britain, was instrumental in its failure to complete what it had started. Unlike the steam engine, the internal combustion engine has not the same forgiveness factor for any manufacturing and other shortcomings that are detrimental to its running and a failure to appreciate this, together with the basic scientific theory, would seem to have hindered the efforts to overcome the problems experienced with the engines of the 1830's and afterwards.

3.2.2 Problems with Fuels

A glance through the pages of the Patent Abridgements is sufficient in itself to show that many difficulties were experienced throughout the formative period in obtaining a suitable fuel. The number of substances that are suggested for use in engines is quite astounding. The use of hydrogen is frequently mentioned, which was obtained either by the elctrolysis of water or the reaction of acids with various metals; but, apart from the inherent danger associated with the use of hyrdrogen, such a method of production would be neither practical nor economical for the purpose intended.

The second most popular choice is the use of turpentine and resin, which was heated to produce (hopefully) an inflammable vapour. Vapours produced from such fuels, however, are difficult to ignite and almost certainly would vary in composition depending on the source from which the raw materials originated. A further factor militating against the use of resin was that some form of heating device, external to the engine was required. The use of alcohol is also frequently mentioned, but what must surely rate as a desperate attempt to obtain a fuel is a recipe by a patentee, Berthiez[16],,which consisted of '70lb of sulphuric aether, 9lb of empyreumatic oil, 1lb of animal fat, 4 gallons of water, 60 drachms of soda and 50 drachms of potash'. By way of dessert, a ¼ ounce of bi-carbonate of soda plus a similar amount of tartaric acid, it was suggested could be added. One notable fact during this period is that coal gas hardly received a mention until the late 1850's.

An appreciation of the problems of trying to acquire a suitable fuel could well explain why such great interest centred around the use of other substances such as ammonia, ether and carbon dioxide, in the 1820's. Eventually, by a natural process of elimination and selection, coal gas or carburetted hydrogen gas[17] as it was sometimes called, became accepted, but not until a considerable time had elapsed after its introduction. The reasons for this are very relevant to the development of gas engines, since, from a study of the growth of the gas industry, it can be shown that events in the technology of gas making coincided with those of a significant nature in the field of engine technology. Such a study provides perhaps the most important insight as to why internal combustion engines only became successful in the latter half of the nineteenth century.

3.3 Developments in the gas industry and their influence on engine technology

3.3.1 Early growth and prejudice

It was William Murdoch who, while employed by Boulton and Watt to assemble and commission steam engines in Redruth, Cornwall, lit his premises in 1792 with gas he distilled from coal; he lit the factory at Soho, Birmingham in 1802 and the works of Phillips and Lee, Chapel Street, Salford in 1805 to 1807. The first gas company, The Westminster Gas Light and Coke Company, was founded by Royal Charter in 1812, being the brainchild of Frederick Albert Winzer, a German who possessed more enthusiasm than common sense and technical expertise. The company almost foundered under him to be saved by a Manchester-born engineer, Samuel Clegg (Senior) who was reputedly educated by Dalton and later apprenticed to Boulton and Watt. During the early years of its life, the gas industry owed much to Clegg's knowledge of chemistry and his engineering ability, which he combined admirably to steer it through its teething problems, a mixture of achievement and prejudice, chaos and comedy.

By the year 1816, gas was fairly common in London and by 1819 a number of gas works were in operation throughout the rest of the country. In London at that time, 5100 gas lights were in use with 300 miles of mains. Ten years later, 200 companies were in existence, many of them with little capital and even less expertise in the technology of gas manufacture [18]. There was bitter rivalry amongst them, competition was intense, the gas was of inconsistent quality, expensive, often of poor quality and the by-products were a costly embarrassment. Consequently, as late as 1853, it was not uncommon to find the four different companies would have gas mains in the same street - often on both sides - giving eight mains in all; the street would be continually dug up as consumers played off one company against another. Cartoons and caricatures showing the populace fighting for their breath when in the vicinity of lighted lamps and covering their noses to be rid of the obnoxious smell were common. The fear of explosion was ever present and the enemies of gas would make great play whenever one occurred.

Further illustrations of the prejudice and excessive caution in the use of gas were given by eminent men in Parliament. When the passages in the House of Commons were lighted with gas, the architect insisted that the pipes be placed some distance from the wall for fear of fire. It was believed that they would get hot while conveying the gas and the curious would cautiously apply their gloved hand to the pipes. Insurance companies were wary and gas companies were compelled to restrict their gasholders to 6000 cubic feet capacity, enclosing them in strong brick buildings (on advice from the Royal Society). Parish authorities would often obstruct the gas companies by preventing them placing lamp-posts in the street and political feelings were vigorously stirred when it was thought that the whale fishing industry, which supplied most of the oil for the lamps, was in jeopardy. Even as late as 1851, the Royal Commission responsible for the Great Exhibition of that year, stated that

> 'no apparatus should be exhibited which was in practical operation through the agency of gas.'

3.3.2 The availability of gas. The provision of 'Day Mains' and metering

With the introduction of the Metropolis Gas Act of 1860, the situation outlined above improved somewhat, but prior to this, there was little or no control over the purity and pressure of gas and no illuminating standard. Methods of metering up to the middle of the 1840's were unreliable and gas was priced purely and simply on the basis of time for which it was available to a particular establishment and the number of lights it contained. The supply would be limited to certain hours each evening (usually between sunset and sunrise), being cut off or its use prohibited during the day. This particular system was widely abused and inspectors were appointed whose task it was to patrol the districts and enforce the regulations. For obvious reasons, customers were reluctant to have their gas consumption metered and, in order to persuade them, companies laid 'day-mains', these being pipes which provided a metered supply all day. The first of these was in 1837, a customer availing himself of the privilege of using gas during the day would be allowed a 10% discount on the price of gas used. Inducements of this nature, however, seemed ineffective and the response by customers was to change their patronage to another company not using meters. The street would then be dug up once more to make a connection, often to the wrong mains.

3.3.3 Methods of gas production, quality and cost

This state of affairs, which strongly militated against any encouragement to use gas for anything other than lighting and, at the same time caused inconsiderable inconvenience to the public rather than provide a service, existed until 1853. It was then that four principle gas companies in London merged. The price of gas was raised from 4/- to 4/6d per thousand cubic feet and the quality improved. By 1871, the Act of 1860 which approved these privately agreed distributing arrangements, had covered the whole country. It took, therefore, something like fifty years for the gas industry to establish itself; the significant fact during this time being that gas was considered to have but one purpose, that of lighting and the main consideration given to it was its illuminating power. It was used to light streets, public houses, shops, warehouses, theatres and public buildings (private houses came later - c.1850) and apart from brief reference in Wright's engine patent of 1833, the potential of gas as a source of power seems to be completely disregarded. This is a puzzling situation and suggests either the quality of the gas was unsuitable or its cost was prohibitive. Both would have a significant effect upon the incentive to use gas and it is worth examining the methods of gas production that were used during this period. A consideration of this aspect of the gas industry has proved to be most informative and explains to a considerable extent why, until beyond the mid-century, it was not used for motive power purpose.

The relative proportions of gases, liquids and solids that are produced by the carburisation of coal depends greatly upon the temperature of distillation; a low temperature yields smaller quantities of gaseous products and large amounts of liquids such as ammonia and light oils. It also produces a much greater yield of illuminants - the heavier hydrocarbons such as ethylene, butylene, benzene and napthaline - which, when burned, give off an illuminant yellow flame. A good Scottish Cannel coal would yield about 5% by volume of illuminants, with the more common coals about 3% or less. The remaining gases that are produced, such as hydrogen, methane and carbon monoxide, would burn with a feebly luminous flame. When very cheap coal had to be used (or very poor luminosity) the expedient of 'enriching' the gas with napthaline was resorted to; this had the desired effect of improving its illumination, but did nothing to increase its heating value. The latter property, however, was quite unappreciated and consequently, was regarded as of no importance.

Great trouble and inconvenience was caused by the impurities contained in the gas and in no small way, was a contributory factor to the prejudice and objections that were often forcibly expressed against its use. These impurities consisted mainly of sulphuretted hydrogen, which has an offensive smell and burns to sulphuric acid and carbonate of ammonia, a highly volatile substance, damaging to brass fittings. Although it was possible to remove the sulphuretted hydrogen almost totally, the carbonate of ammonia presented a problem. It does not mix with water, and prior to 1860 no economical means for its removal existed. Efforts concentrated, therefore, on preventing its formation, mainly by keeping the temperature of distillation down, which was not difficult, but was a further factor which prevented the production of a gas suitable for engines.

Manufacturers of gas faced a constant dilemma on the question of what temperature to operate the retort. Too high a temperature reduced the percentage of illuminants, yet when too low, offensive smelling waste products would result. To some extent, the problem was virtually solved for them, the temperature of distillation being determined by the material that was used for the retorts. In England, cast iron was first used and in order to ensure a reasonable working life consistant with a worthwhile yield of illuminating gas, would be heated to bright red visible in daylight[19] giving a temperature of about 700-750°C.

3.3.4 The possibility of its use in engines. Probable running costs

As to whether or not an engine, supplied with gas of the composition just described would run, is difficult to say with certainty. At its best, it would be unsatisfactory, since the gas would have a slow flame speed and after burning would leave substantial carbon deposits. Corrosion of engine parts and fittings would occur and with ignition systems suggested at that time, it would have been difficult to ensure a precise timing and regularity of ignition. In addition, there was the problem of its cost. In the 1820's the cost of gas per thousand cubic feet was 15/-; in 1832 it was 12/- per thousand and in 1849 6/- per thousand[20]. Wide variations in gas prices can be seen throughout the country, but by the later 1860's, the price per thousand cubic feet was 2/- and 2/3d in Birmingham and Manchester respectively. The cost of common coal - a type used mainly for steam raising rather than gas making - lay somewhere between 8/3d per ton in the late 1820's[21], and about 10/- per ton in 1840. Cannel coals used mainly for gas making, were the most expensive at 22/- per ton[22]. Estimates of the gas yield from one ton of coal vary between 6000 and 9000 cubic feet[23]. The coal consumption of a Boulton and Watt high pressure condensing engine about 1863 is given by Goodeve[24] as 2.7lb per horse-power per hour. The average consumption for marine engines was about 4.2lb.

If now an assessment is made of the gas consumption likely to occur in the combustion engines of the 1830's and 40's, it would be possible to estimate probable running costs of both steam and gas engines. To obtain some idea of the possible gas consumption of these early engines, we can take a look at the figure achieved by later engines. Initial tests of the Lenoir engine in 1860 (Chapter Four), which is of the non-compression type similar to those proposed by Wright and Barnett, showed that it had a consumption of 100 cubic feet per horse-power per hour, subsequently being reduced to 80 cubic feet as improvements in design were effected. The Hugon engine of 1865 was slightly better at 70 cubic feet. A figure of 80 cubic feet, therefore, would serve as a guideline from which a one horse-power gas engine in the 1820's with a gas at 15/- per 1000 cubic feet would cost approximately 1/2d per hour's running. A similarly powered steam engine, assuming a coal consumption of 4lb per hour at, say 10/- per ton, would cost only 1/5th of a penny for one hour's running.

A complete analysis of running costs for each type of engine should, of course, take account of many other factors such as the cost of lubricant, cooling water, feed water and labour charges for attendants. The fact that the boiler of a steam engine is required to work continuously whilst the engine is used infrequently, is a point on which the gas engine scores, but the comparison just quoted shows how grossly non-competitive the early gas engines of the 1830's, 40's and even the 1850's would have been with these gas prices, and what an overwhelming disadvantage they possessed, compared with their steam counterparts, strongly militating against their use and acceptance. Evidence of this nature goes some way to explain why, in the latter part of the 1870's, when the consumption of gas engines was reduced (by the use of compression) to 30 cubic feet and the cost of gas reduced to something like 3/- per thousand cubic feet, their operation at last became economical, becoming an ever increasing threat to the steam engine.

3.4 Turning points in gas production techniques A more suitable fuel for engines

The situation with regard to the cost and quality of gas began to improve from about 1853, at which time two significant events in gas production took place. The first was the use of exhausters to extract the gas from the retorts as it was being produced. Although suggested as early as 1830, exhausters did not become widely used until twenty years or so later. The most probable reason for this was that the cast iron retorts that were then so fashionable, were well able to withstand the pressure created within them by the gas having to pass through the hydraulic main and wet-lime purifier. At the time, this pressure appears to have been considered as nothing more than an inconvenience, because it had the effect of breaking down to simpler compounds those hydrocarbons which yielded the illuminants. The later use of dry lime purifiers[25] helped to alleviate the pressure problem.

The second event was the use of clay retorts and, in the main, was a consequence of the use of exhausters. They were used in Scotland from about 1826 but, for some unknown reason, were not generally accepted in England until the end of the 1850's[26], when difficulties of leakage were resolved. The use of clay had numerous advantages over cast-iron; much higher working temperatures were possible (up to 1100°C), which resulted in a greater yield of gas; they had a larger working life and were cheaper to install. A company, once having invested in clay retorts, would be able to operate on a much more profitable basis and the cost of gas would accordingly be reduced.

Accompanying this reduction in cost of the gas was a marked difference in its quality in favour of its use in engines. The higher distillation temperature meant that a greater volume of those lighter gases, methane, hydrogen and carbon monoxide on which internal combustion engines prefer to run, was produced. There was, of course, a corresponding reduction of illuminants, but the Metropolis Gas Act of 1860 helped matters by establishing that illuminating gas should have a minimum luminosity of 12 candle power - a figure just about attainable using a well designed burner and without the need for excessive enrichment of the common coals with the more expensive cannel from Wigan and Scotland. Prior to this Act, the illuminant power of a gas was a truly haphazard affair. Cannel coal was capable of producing an illuminating power of 25-30 candles, but so much uncontrolled dilution of the cannel by inferior coals occurred, that the resulting candle power of the gas would be anything between 10 and 20.

These new and favourable circumstances relating to gas production in the late 1850's not surprisingly coincided with an increasing desire to use it for motive power, as seen by the patent lists of that time. In retrospect, one may quite naturally assume that ideas for engines would be influenced by the kind of fuels that were available and during the formative period of engine development, there is ample evidence that this is the case. The introduction of illuminating gas was sufficient to stir the imagination of Samuel Brown in the 1820's, but it has been shown that the gas produced then, and for thirty or so years later, was expensive[27] as well as unsuitable for use in engines - doubtless this was the reason why Brown attempted to make his own[28]. There was also a lack of efficient metering methods and restrictions upon its use during daylight hours. There is little need to wonder, therefore, why the initial flush of enthusiasm for the use of gas soon waned; the magnitude of the difficulties just mentioned would do little to generate enthusiasm for its widespread use and to a large extent, explain why it received little or no consideration for anything other than illumination.

The decisive period as far as gas engines were concerned was the latter part of the 1850's when, at that time, gas became acceptable in cost and in quality and also when metering and distribution methods by the gas companies became reliable. Problems with engines of a mechanical and thermal nature still remained, but the important thing now was that incentive to overcome them was present. It might be said, therefore, that the gas engine became possible when gas became usable in it.

References - Chapter Three

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7. A. Witz. Traite Théorique et Practique des Moteurs à Gaz (Paris 1892) Vol. 1 p.79

8. This probably arose from Voltas' achievements with his 'electric pistol' c.1776. Bern Dibner Allesandro Volta and the Electric Battery (New York 1964) p.31

9. Automotor Journal (London 1896)

10. C. Wilson and W. Reader. Men and Machines A History of D. Napier and Son 1808-1958 (London 1958) p.21

11. Ibid p.30

12. Charles Babbage. The Exposition of 1851 (London 1851)

13. Friederick Klemm. A History of Western Technology (London 1959) p.317

14. C.A. Russell and D.C. Goodman. Science and the Rise of Technology since 1800 (Open University 1972) p.262

15. Ibid p.264

16. English Patent 1740/1856. The ingredients suggest that some form of etheric substance would result.

17. T.S. Peckston. Practical Treaties on Gas Lighting (London 1841) p.100. refers to 'carburetted hydrogen gas'. Chemists would use the term when referring to 'marsh gas'.

18. A Lecture by D.E.F. Armstrong. Institute of Gas Engineers (1939) p.17. describes the growth of the gas companies and the disorganization that resulted.

19. Peckston op cit (17) p.411

20. W. Richards. A Practical Treaties on the Manufacture and Distribution of Coal Gas (1877) p.121. Also Peckston op cit (17) p.37

21. Mechanics Magazine Vol. 17 (1832) p.273. A description is given of how Samuel Brown attempted to make his own gas to offset the cost of working his gas machine.

22. Peckston op cit (17) p.100

23. Ibid pp.163-195

24. T.M. Goodeve. A Textbook on the Steam Engine (1884) 6th Ed. p.124

25. Dry lime purification was suggested by Reuben Phillips in 1817 but was ignored until 1840. By its use, large quantities of sludge effluent were avoided

26. An attempt to use clay retorts at Brick Lane Gas Works, Middlesex was sabotaged. Richards op cit (12) p.121

27. W.B. King. Treatise on the Science and Practice of the Manufacture and Distribution of Coal Gas Vol. 3 p.63 An account is given of how gas companies, not possessing Parliamentary authority to dig up the streets, would sell gas to local authorities at a ridiculously low cost in an attempt to secure immunity from complaints by the public. The cost of course was borne by the private consumer

28. It is not certain what purification methods Brown used (if any). Attempts to burn 'raw gas' results in sparks and produces a suffocating odour and sulphuric acid.

CHAPTER FOUR

THE END OF THE BEGINNING

4.1 High Expectations

The experimental period of the internal combustion engine was brought to a close in 1861 by the appearance of a working engine designed by Jean Joseph Etienne Lenoir, A Belgian by birth, but living in Paris at the time. It embodies much of what up to then had been found to be the best and as such, therefore, contained nothing that was new or novel. A prospectus by Lefebvre, the French builder in 1864 stated that[1]:

> 'The Lenoir engine uses Streets patented piston with direct and double action by Lebon, the ignition of Rivaz and the cylinder is cooled by water as in Samuel Brown's engine, it can be made to run in liquid fuel as suggested by Hazard and on it can be found the clever idea of Talbot's distributor...'*

The Lenoir engine was the first ever to be built in numbers and one reason for its acceptance and success was the excellent quality of workmanship displayed in its manufacture by Mr. Marinoni, an established and experienced steam-engine builder. It was enthusiastically received, but its introduction was accompanied by exaggerated claims as to its abilities and potential. There was some embarrassment, therefore, when it failed to live up to them. To its credit, the success - and shortcomings - of the Lenoir engine did much to inspire others during the decade beginning 1860 which, in regard to ideas for engines, proved to be a very active period. These other ideas and engines will subse-

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* This idea by Henry Fox Talbot is discussed later in the Chapter

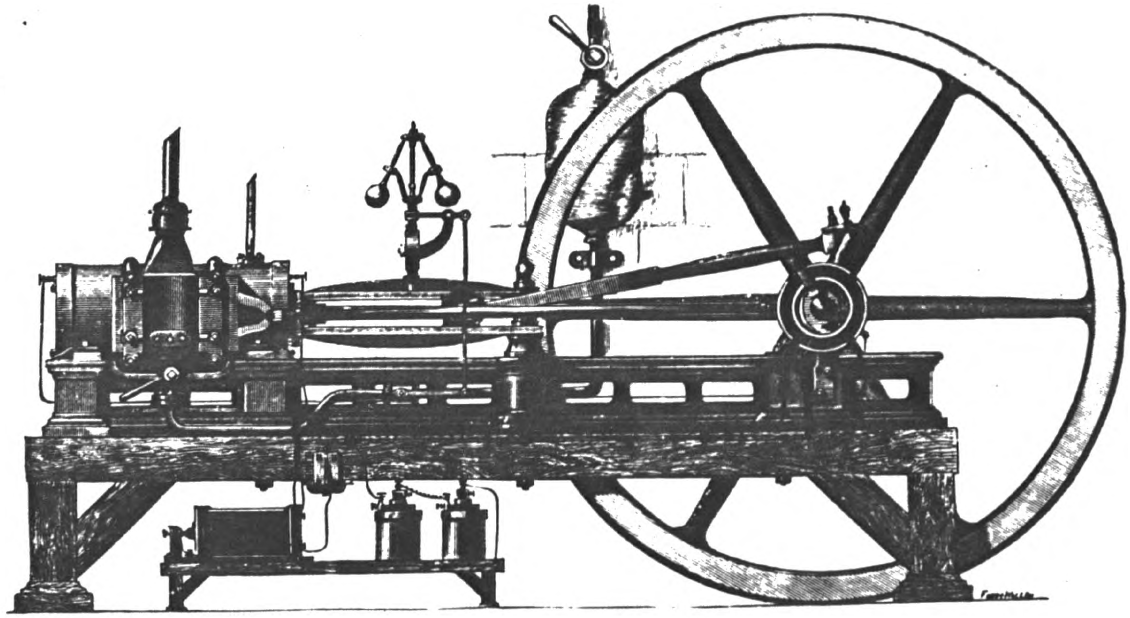


Fig 4.1 Production model of the Lenoir Engine by the Reading Ironworks, England C1865

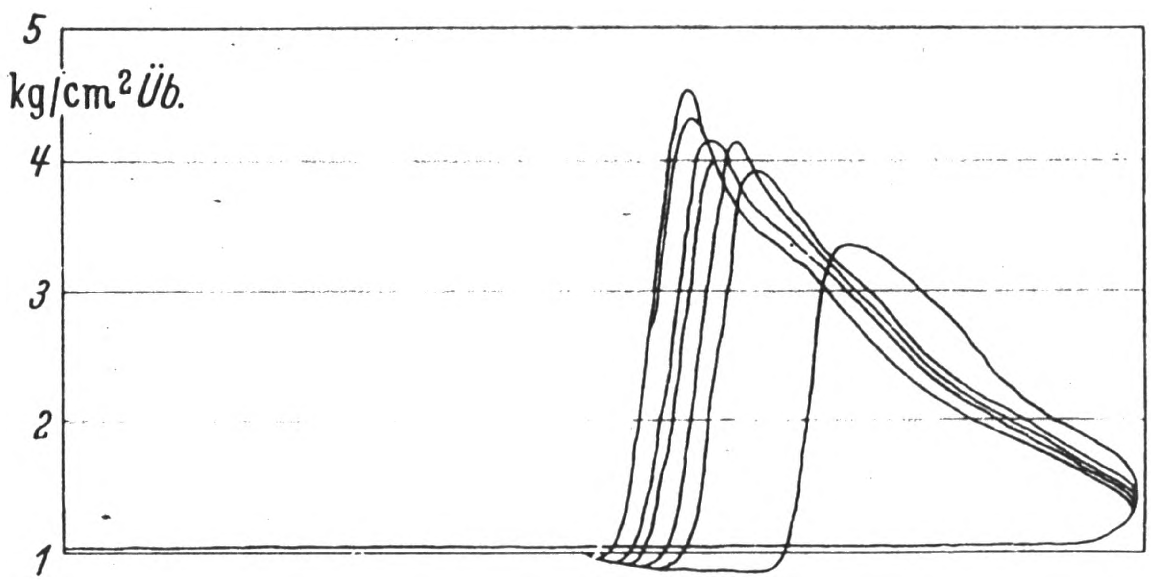


Fig 4.2 Pressure-Volume indicator diagrams of the Lenoir Engine. Note the scatter due to irregular ignition

quently be discussed in this chapter, but first a detailed account of Lenoir's work will be given.

4.2 Lenoir and his engine

It was during the year 1838 that Lenoir left the village of Mussey-La-Ville in Belgium, where he was born in 1822 to go to Paris. He had no money and little more than a basic education with which he had provided himself. His first employment in Paris was as a café waiter, but later he became an enameller and obtained the first of his many patents, which described the white tincture used on watch dials. In 1854, describing himself as a 'galvaniser' he took out patents for 'The application of one metal upon another' and for 'The galvanized reproduction of three-dimensional models'. His main interest at that time appears to have been the electric telegraph with its application to railways and he took out numerous other patents for electric brakes, an electric motor and a signalling system (1856). After studying the work of L'Abbé Caselli, who had produced a form of automatic telegraph system, Lenoir later made an improved form of it in 1865[2]. Some other inventions in which Lenoir was involved included a mechanical kneading machine, a method of silvering glass and a method of tanning leather using ozone[3]. Lenoir it would seem, possessed an inherent gift for inventions and it is not surprising that such an inventive mind would be attracted to the idea of motive power.

Little to nothing is known of any experimental work he may have carried out in relation to gas engines. The first indication of such interest was a year before the appearance

Fig 4.3 Jean Joseph Etienne Lenoir (1822-1900)

of his engine, in 1859 when a 'Societé des Moteurs Lenoir' was formed with a capital of two million francs. He took out a French patent in January 1860 entitled 'Moteur à gaz dilaté par la Combustion du gaz' followed by an English patent two weeks later[4]. Figure 4.1 shows a view of the production engine. Figure 4.4 is taken from the patent of 1860 and shows the general arrangement and Figure 4.5 is from the patent of improvement issued in 1861[5].

As may be seen from Figure 4.1, it resembled the high pressure steam engine in use at that time and used many features of principle and design that had already proved successful with steam engines such as slide valves, cylinder and piston construction and eccentrics. The slide valves were adapted to admit gas and air and to expel exhaust gases, a slide being positioned vertically on each side of the cylinder. Their operation and timing was by eccentrics fixed to the crankshaft and the working cycle was the same as that suggested by Wright and Barnett and later used by Perry and Drake, namely, drawing in an inflammable charge at atmospheric pressure for about one-third of the stroke followed by ignition; expansion then taking place for the remainder of the stroke. A repeat process would then take place on the other side of the piston. The Lenoir engine, therefore, was a non-compression, single cylinder and double acting engine, whose explosion acted directly onto the piston, which was connected to a crank. Ignition was by an electric spark produced from a Ruhmkorff coil. Engine speed was regulated by a centrifugal governor controlling a valve in the gas supply pipe.

The manner in which Lenoir sought to admit the gas and air into the working cylinder is interesting and gives an excellent indication of the state of knowledge of the combustion of gases existing at that time. He proposed to admit air only for the first part of the inlet stroke * the purpose of which, said Lenoir, was 'to neutralise the effect of the carbonic acid gas formed by the combustion stroke' and then, at a particular position of the inlet port, both gas and air would enter the cylinder without becoming entirely mixed together, to exist in the space behind the piston in distinct strata.

The purpose of Lenoir's attempts to obtain a stratified charge is discussed more fully in section 4.3, but it may be mentioned at this point that they had a profound effect upon a highly controversial discussion on combustion, that took place during the patent litigation hearing of Otto and Linford in 1883 and discussed in Chapter Six.

As stated previously, the Lenoir engine soon experienced operating problems, mainly concerned with the electric ignition. Lenoir had had considerable experience with electrical devices and he naturally chose to use them on his engine. The primary current supply came from two Bunsen cells connected in series, which consisted of an outer jar containing a solution of sulphuric acid and water (1:10) and the negative zinc electrode. Into this solution was placed a porous pot containing concentrated nitric acid and his positive carbon electrode; the total emf to the primary windings being about 3 to 3.4 volts. A circuit breaker could pro-

* Otto had similar ideas with his four-stroke engine of 1876. When he attempted to obtain a 'stratified' charge in the cylinder (see Chapter Six)

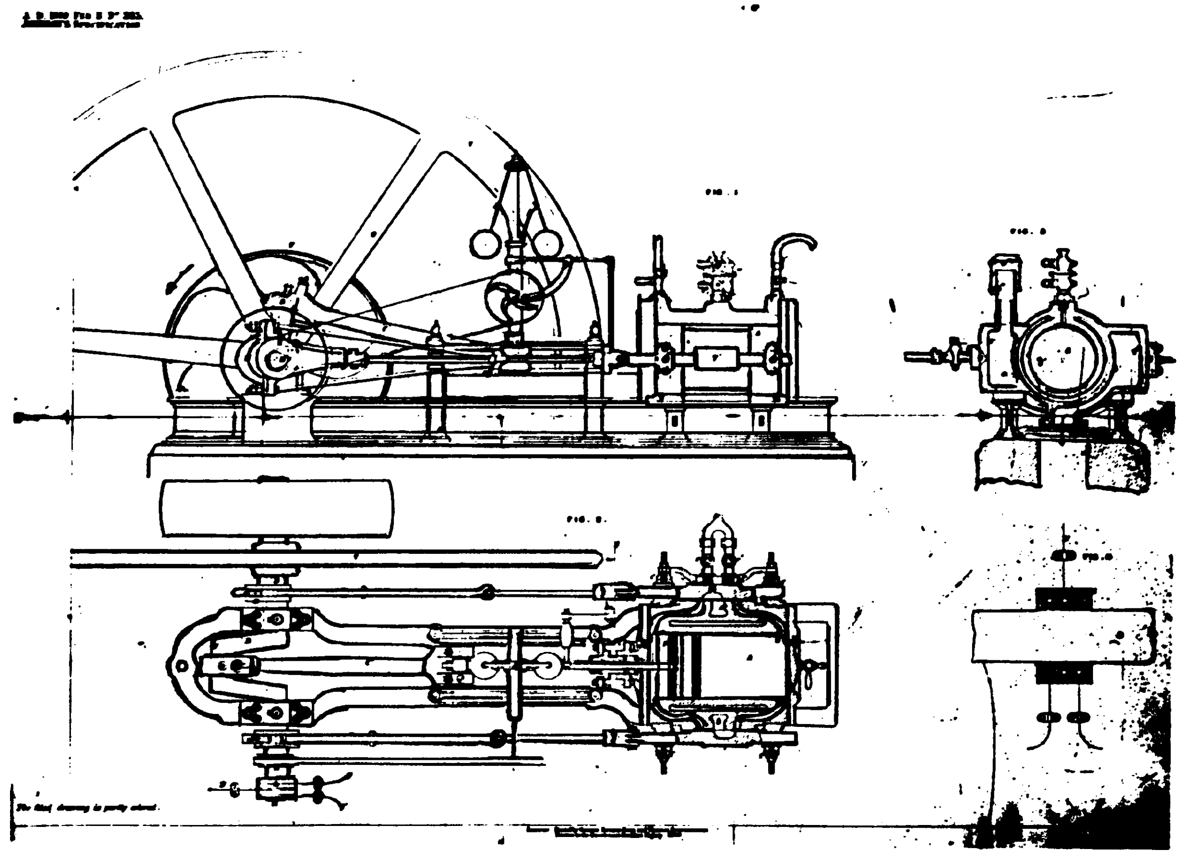


Fig. 4.4 The first patent by Lenoir (1860) with commutator distributor system

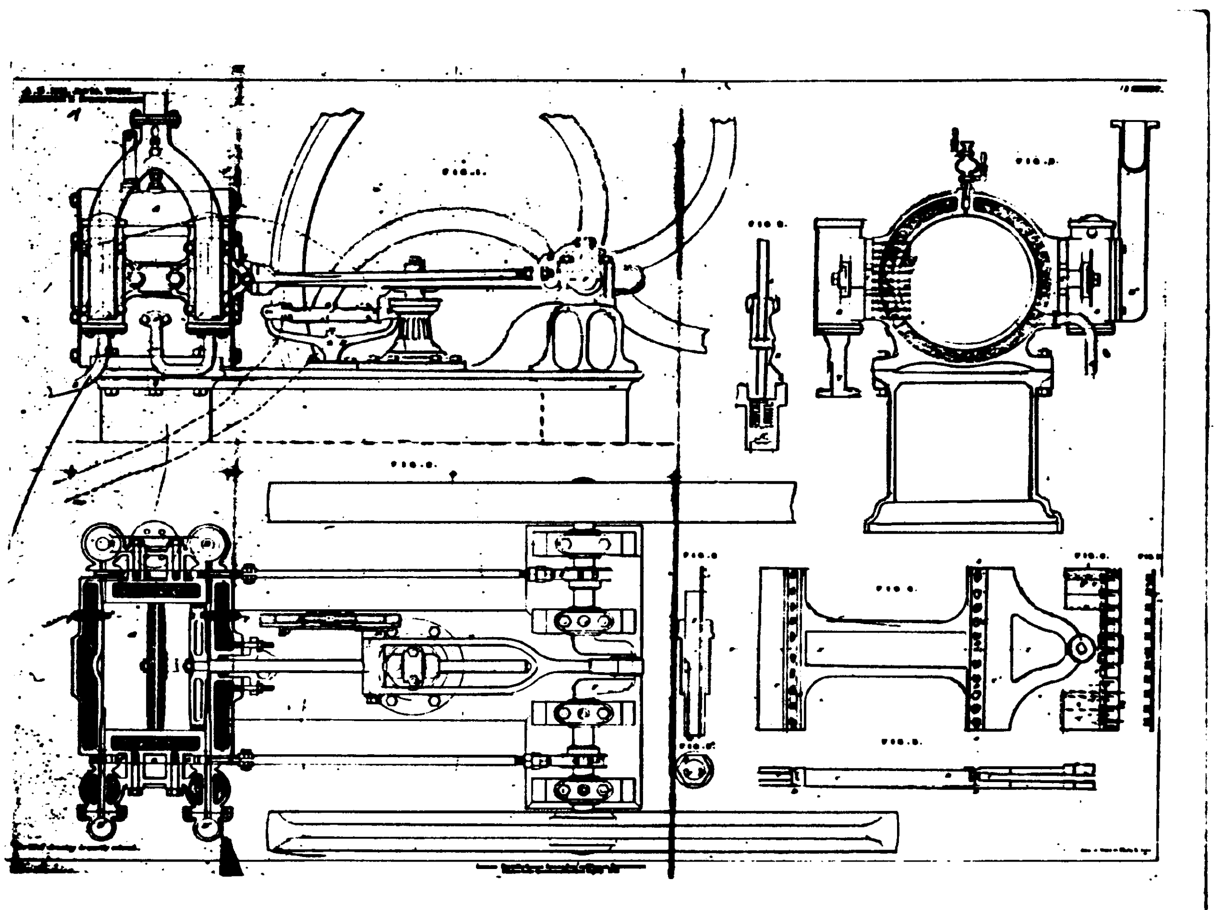


Fig. 4.5 The seond patent of improvement (1861) with sliding distributor and stratified induction system.

vide about 120 to 150 sparks a second. To distribute the high tension spark, various forms of distributor were tried, the first idea, shown in Figure 4.4 consisted of a commutator device which Lenoir called a director. It consisted of an insulated bush fitted onto the main shaft around the circumference of which were three brass strips. Of these three strips, one was a continuous one in connection with the Ruhmkorff coil and two others were connected to each of the igniters placed in the combustion chamber. The latter two strips were placed only part way round the circumference and positioned so that they would communicate with an igniter at the appropriate time to bring about ignition. Subsequent modifications included a slider mechanism (Figure 4.5) which was replaced later still by a modified commutator arrangement.

4.3 The application to industry. Some problems

The first engine by Lenoir appeared in France in the spring of 1860 accompanied by a good deal of publicity; M. Hyppolyte Marinoni of Paris was the builder. It received unqualified praise from the scientific press and technical fraternity alike, with men of high standing and reputation in science giving it their enthusiastic support. Many were purchased as a result of their favourable assessments of its performance and potential, and the ability of an engine to dispense with a boiler or steam-raising equipment for the very first time as this engine did, was seen as a major step forward.

There was also the added advantage that the engine could be erected in any convenient place without the aggravating enquiries that insurance companies carried out before they would allow a steam engine and boiler to be installed.

The high hopes and expectations that attended its inauguration were soon replaced by doubt and despair. Many, having purchased the engine, encountered difficulties, not only with the electrical ignition system, as mentioned previously, but with overheating, fuel consumption and lubrication. The makers, in their enthusiasm, had greatly understated the fuel consumption; seizure of the piston and slides was common which could only be remedied by using vast amounts of lubricant and when the engine was put to work, severe vibrations were experienced when placed under load. Adverse criticsm mounted and many engines were either scrapped or converted into steam engines. Lenoir was acutely aware of the difficulties associated with the running of his engine and his second patent of 1861[5] was an attempt to alleviate them.

The problems facing Lenoir were precisely those encountered by the earlier pioneers mentioned in Chapter Two, namely, those concerned with ignition, overheating and shock. Those concerned with ignition centred mainly on the high tension distributing arrangement; the high voltage spark would prematurely jump the distributor contacts on the commutator and cause pre-ignition. In an attempt to overcome this, Lenoir devised a sliding type distribution system (Figure 4.7). The igniter electrodes often fouled up with carbon deposits and moisture, causing missed or late ignitions and one missed ignition would frequently stop the engine completely. Trouble was also experienced with the primary cells which gave off highly obnoxious smells and required frequent replenishing of the acids. The over-heating problems that arose occurred largely because of the working cycle employed and the failure to allow sufficient expansion of the burning gases after ignition. Cylinder dimensions, for instance, of a half horse power Lenoir engine are given as: diameter 7 inches, and stroke 4 inches* [6], the latter being totally inadequate. To alleviate the over-heating problem, Lenoir tried injecting water into the cylinder, but this short-circuited the igniter points to cause even more erratic running. Some time later, he re-designed the exhaust slide valve by hollowing it out and filling it with water in an effort to solve the heating problem. This idea, which proved worthwhile, was adopted on engines that were made later in England.

By far the most serious problem with the Lenoir engine was the explosion shock and, unfortunately, Lenoir failed to realise that such was an inherent feature of non-compression engines working with a direct action. In attempts to overcome it, he devised an arrangement on the admission slide valve, the object of which was to separate the gas and air into layers by making each pass through a series of small holes, both in the valve itself and also in a grooved plate placed in the port. An enlarged view of this plate is shown in Figure 4.6, which was included in his improved patent of 1861. In suggesting this particular idea, Lenoir had the mistaken idea that the stratified, or layered arrangement of gas and air produced during admission by this grooved plate, would remain so in the working cylinder, and would

*This may well mean the working part of the stroke, ie the full piston travel being 8 inches thus make for a more gradual explosion. He also erroneously believed that by diluting the gas with excessive amounts of air (up to 50% in excess of that normally required for combustion) the explosion shock would be reduced even further[7].

Lenoir's false ideas on combustion had a long lasting effect, but precisely how he came by them is not clear. If he was aware of Bunsen's work on gases which appeared shortly before Lenoir began his work on engines, it is possible that he misunderstood it; it is not too difficult to appreciate how this may have occurred. On the combustion of gases, Bunsen says[8]:

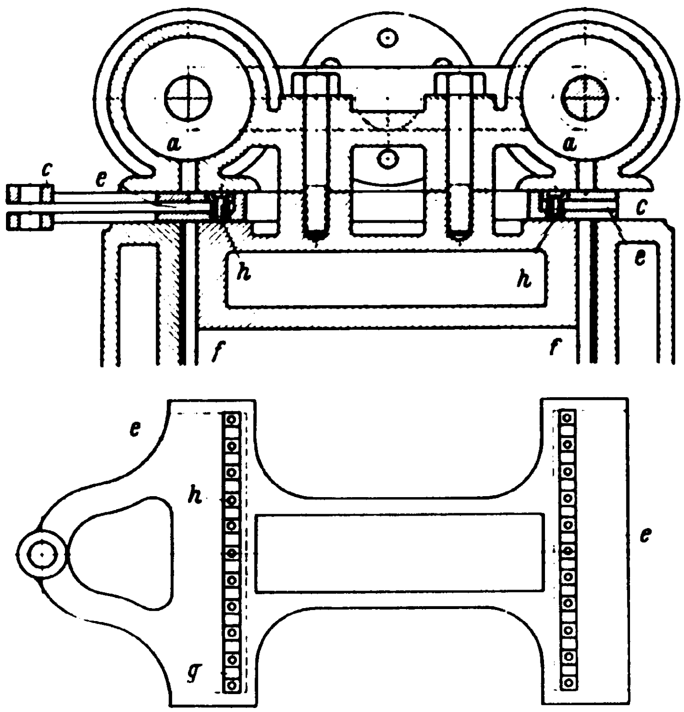
> 'If an explosive gas column is ignited at its upper end by the time the combustion reaches the lower end, a considerable heat is lost by radiation and convection. If the fulminant gas is weakened by neutral gases near the point of ignition, then at that point, there is seen a ball of fire moving slowly away.'

On the explosion of gases:

> 'The explosiveness of a gas is therefore not lessened by the admixture of inferior gases because the temperature is less, but for the reason that the velocity of transmission of the combustion is diminished..'

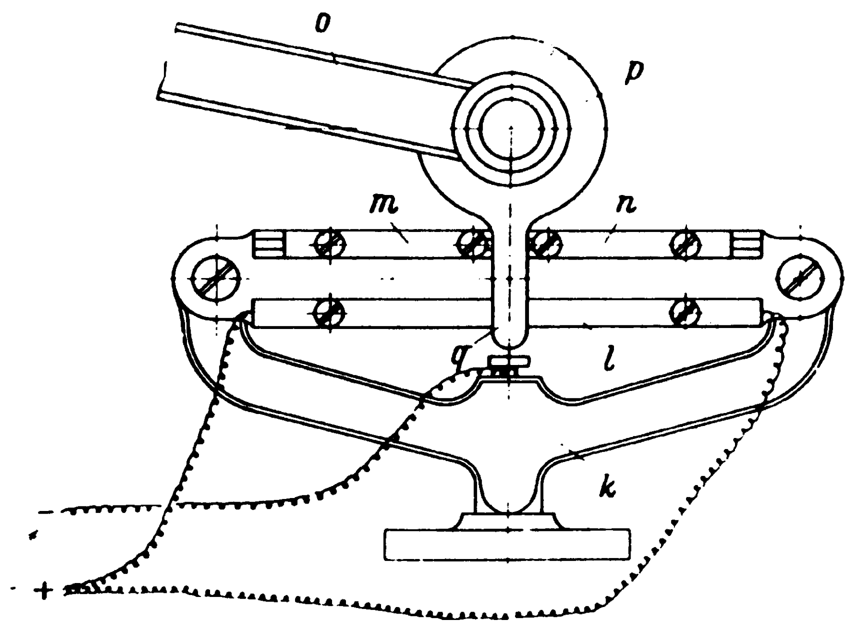
Lenoir was not alone in propagating erroneous ideas; Gustav Schmidt, a respected authority on scientific matters, in attempting to explain the 'Theoric der Lenoir'schen Gasmachine' says[9]:

> 'The heat generated by combustion dilates the steam, carbonic acid, nitrogen and the surplus air that are formed, and thereby drives the piston against the opposite side of the cylinder whereupon a fresh detonation takes place, which ought to be free from any observable recoil in consequence of the overplus of air ....'



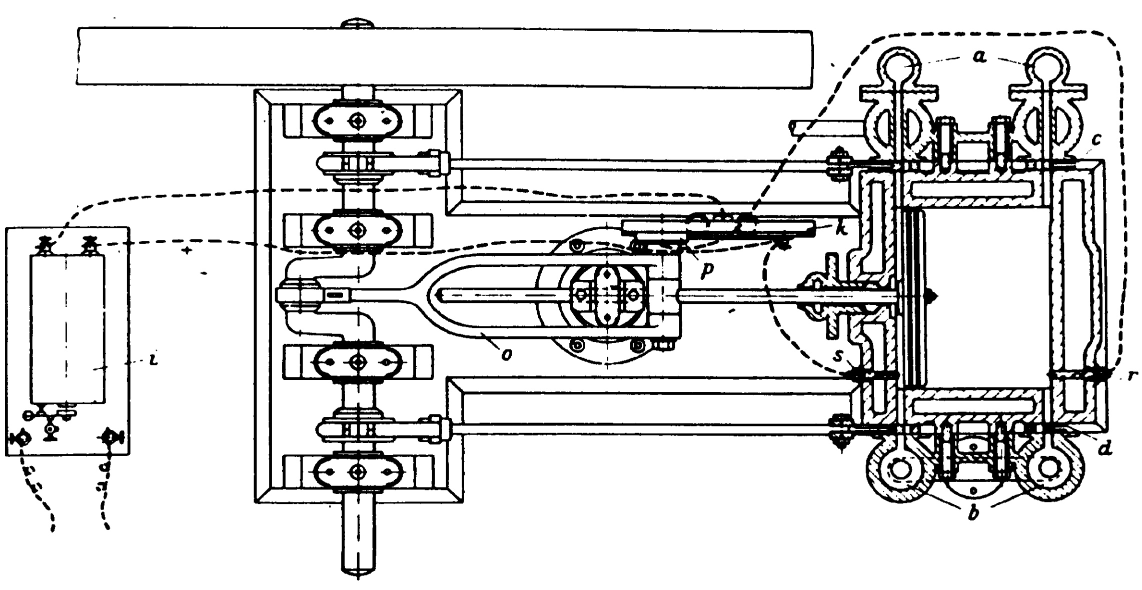
a—Gas supply; c—Slide-valve; e—Slots for air supply;
f—Inlet ports to cylinder; g—Openings for air;
h—Gas supply orifices.

Fig. 4.6 Enlarged view of the slide valve arrangement showing how Lenoir sought to achieve his 'stratified layers' of gas and air.



k—Frame with ground terminal; l—Full length, lower contact strip; m & n—Contact strips for timing the sparking at plugs; p—Slider mount on crosshead; q—Slider contact tongue.

Fig. 4.7 Exploded view of slider type distributor



a—Gas supply; b—Exhaust outlets; c—Intake slide-valve; d—Exhaust slide-valve; i—Induction coil; k—Sliding-type ignition distributor; o—Connecting rod; p—Distributor slider in crosshead; r,s—Spark plugs.

Fig. 4.8 Plan view of engine and electrical ignition system.

At that time, and indeed for some time to come, it was obviously believed that to make an 'explosive' engine into a non-explosive one, a considerable dilution of the gas was necessary. It was not fully appreciated that a great reduction in flame speed would also occur which, in turn, added to the heat problem. Stratification, it was thought, would provide a cushion and attenuate the resultant shock. In a later production of his engine, Lenoir appears to have abandoned the stratification idea entirely.

4.4 Tests and performance. Its introduction into England

In January 1861, Professor Tresca, on behalf of the Conservatoirs des Arts et Metiérs, tested a half horse power Lenoir engine for three and a half hours, a report of which appears in the Journal of Gas Lighting[10]. Speed variations were found to be considerable between 67 to 130 revolutions per minute; gas consumption at 106 cubic feet per horse power per hour was nearly four times that of the four-stroke engines yet to come; large quantities of oil were required for lubrication and missed ignitions frequently occurred. Indicator diagrams, Figure 4.2, showed that upon ignition, an extremely rapid rise in pressure occurred followed by a sharp fall, with substantial variations taking place at the point at which the pressure rise commenced*. Tests in March of the same year, carried out on a one horse power engine showed some improvements with less speed variations and better fuel consumption being recorded.

* These were caused by variations in ignition timing

M. Tresca made the comment that it was six times more costly to run than a similarly powered steam engine, but considered its use to be advantageous in certain applications. The Journal reporting the trial, however, nullified Tresca's opinion, by stating that 'it is still one of the scientific toys of the age in spite of the high promises which attended its inauguration'.

The truth, as usual, lay somewhere between. It was not as good as first made out, but neither did it warrant the sweeping condemnations made against it. Many cases of dissatisfaction with the performance of this engine could be put down to unskilled attendants, who would attempt to run it with excessive loads and incorrectly adjusted gas cocks. They were often over-generous with the oil, but quite the reverse with the cooling water and the running of the engine, more often than not, was in the hands of ignorant and unskilled labour.

In spite of its defects, the Lenoir engine gradually found a place as a useful motive power for a variety of uses. It became accepted, first in France and then, about two or three years later, in England. Its first appearance in England was at the International Exhibition of 1862, but it was not until the 'Lenoir Patent Gas Engine Co.' of 20 Cannon Street, London was formed in 1864 that it really began to establish itself in this country. The Reading Ironworks, Reading formerly Messrs. Barret, Exal and Andrews were appointed builders and the first engine made by them was worked at Messrs. H. Poole & Co., Westminster in January 1865. Between then and March 1866, about fifty engines had been made in sizes of ½, 1, 2 and 3 horse power[11]. Prices ranged from £32 for the smaller engine to £100 for the larger. By the mid-1860's it was claimed that the gas consumption had been reduced to seventy cubic feet per horse power per hour. The involvement of the Reading firm with Lenoir engines began in 1864, after they installed in a Paris bakery, some bread-making machinery, which was to be driven by a Lenoir engine. Apparently impressed, they returned to England and began making it themselves. Prior to this, a few Lenoir engines were already at work in England, presumably imported from France. One is recorded as working at the firm of G.B. Kent and Co., Great Marlborough Street, London in 1863[12] and another at the firm of W.E. Wiley, Birmingham in 1864[13] at which time it stated the price of gas there was 2/6½d per thousand cubic feet*.

By August, 1865 the number of Lenoir engines that were working in France was estimated at between three and four hundred; with something like fifty having been made for use in England by the Reading firm[14]. The most popular users were printers, but Lenoir engines were also applied for sawing stone, polishing marble, cutting chaff, pumping and driving lathes. A half horse power engine was installed during the first half of 1865 in the workshops of the patent museum, South Kensington** and by November 1865, was reported by Mr. F.P. Smith, the Curator, to have made 2,762,184 revolutions - about 450 hours running - without the slightest

* This was probably the cheapest price in the country at that time. The London price in that year was 4/6d per 1000.

** This same engine, made by the Reading Ironworks, can be seen in the Science Museum, London derangement of its parts[15]. One was also available for public inspection from 11.00 am to 1.00 pm and 3.00 pm to 5.00 pm daily at the premises of 40 Cranbower Street, Leicester Square[16]. Another one horse power engine, installed at Petworth House, Sussex about 1865 to pump water for the town, was reported by Dugald Clerk to have worked for more than twenty years and two other engines of one horse power each had worked at the brewery of Messrs Trueman, Henburg and Baxton, London for a similar length of time.

All were found to be 'in excellent order and smooth and perfect in operation .....'[17] In America, a few were built by Messrs, Coryell of New York, but due probably to the high cost of gas there - about twice that in London - and the uneconomical cycle that the Lenoir engine used, none greater than one horse-power appear to have been made.

The numerous successful applications of the Lenoir engine quoted above, illustrate that, provided care was taken, it was capable of doing a useful job of work. It also suggests that its operation was in some way delicate but, since this was the first of its kind, it may be forgiven on that account. However, it fell considerably short of the desirable engine requirements that had become recognised by the mid-1880's*. The indicator diagrams, for instance, show that severe restriction on the in-going charge occurred; the charge also experienced extensive pre-heating as it entered and struck the hot piston. The factor responsible for restricting the gases known as 'throttling' was the action of the eccentrics that were used to operate the slide valve. Their mode of

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* These are discussed in Chapter Nine

action does not permit that sudden opening and cut-off to the moving charge, which is deemed necessary to ensure that the maximum mass enters the cylinder. Consequently, a large 'lead' was required to ensure that the inlet port would be well open by the time the charge began to enter. In the absence of anything better, eccentrics continued to be used until 1888, at which time slide valves were replaced by cam operated poppet valves.

Another major defect of the particular cycle of operation used by the Lenoir engine was the sharp fall off in pressure of the expansion line, which can be seen on the indicator diagram. Little attention appears to have been given to this point at the time of the Lenoir engine and it was not until much later, when the Otto four-stroke diagrams appeared, that a critical comparison was made and an interest taken in indicator diagrams. At this later date (1876) various ideas and theories were offered as explanations to account for the differences between the two expansion curves, but the true reason - the use of compression in the Otto engine, which enabled a greater charge mass to be concentrated in a smaller volume - does not appear to have been appreciated until the 1880's when, largely through the work of Dugald Clerk, it was realised that the combustion chamber of the Lenoir engine, presented an enormous surface area to the burning gases. This caused a rapid cooling and a consequent loss of available energy. The expansion curve in that case would fall greatly below the adiabatic condition.

It is not the intention here to emphasize the deficiencies of the Lenoir engine, but merely to give some indication of the degree of understanding of engine technology that existed at that time. From thermodynamic considerations, it rates none too well, but the most significant aspects of the Lenoir engine are those not directly measurable in material terms. Its very defects, for instance, caused others to strive for something better; the extravagant consumption of gas drew attention to the need to understand more thoroughly the phenomena of combustion and this led eventually to a good deal of experimental work. It prompted discussion and resulted in Gustav Schmidt coming near to the truth when he said about the Lenoir engine:

> 'More favourable results would be obtained with greater expansion and better transformation of the heat into combustion into work, if the gas and air were previous-compressed to two and three atmospheres.' 18

The idea that compression may be a useful aid to engine performance thus became an active topic for discussion in the early part of the 1860's. A Frenchman, Francisque Million, whose proposals are shortly discussed, expressed exceedingly clear ideas as to how it could be utilised and, although he appears to claim exclusive right to originality for suggesting it, (apparently unaware of Barnett's ideas of 1838) he does make some valuable suggestions. About this time, 1862, yet another Frenchman, Alphonse Beau de Rochas* describes in an obscure pamphlet, but with remarkable foresight, the cycle of operations in which an engine could best be made and the conditions that had to be satisfied in order that such a cycle should be as efficient as possible. It is probably more than coincidence that ideas like these were being put

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* The work of Beau de Rochas is discussed in Chapter Six

forward at the time of Lenoir's engine. A strange fact is that Lenoir seems to have disregarded them; he was experiencing difficulties with his engine when these constructive ideas for its improvement were being suggested, he knew Beau de Rochas personally[19], and almost certainly, having regard to his experience with patents, would be aware of Million's work. Lenoir, however, appears to have resolutely pursued his own ideas, using a non-compression cycle.

4.5 Possible external influences. Ideas c.1858

In the closing stages of the 1850's, many notable ideas for gas engines were being expressed, which show great similarity to the construction and operation of Lenoir's engine when it appeared in 1860. No documented evidence to show that Lenoir was influenced by these other suggestions has been found, but the similarity of Lenoir's engine to that of James Robson's working engine of 1858, for instance, is outstanding*. Two Italians, Henri Marquis de Balestrino[20] and Constantina John Baptist Torassa[21] of Genoa, also made suggestions as to how steam engines could be used to run on different fuels. Balestrino describes most explicitly how an explosive mixture could be admitted to each end of a cylinder and exploded by means of electricity (precisely what Lenoir did) from a galvanic battery with, as he says:

> 'a suitable mechanism being employed for making and breaking a circuit'

A year later, Torassa made some detailed suggestions for mod-

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* The work of James Robson of Newcastle is described in Chapter Two

ifying the cylinder of a steam engine in order that:

> 'it could answer for the explosive force of gas'.

Torassa also suggested that:

> 'A mixture of hydrogen and air admitted alternately to both sides of a cylinder of a piston and cylinder arrangement could be ignited by an electric spark and made to explode without damage or noise.'

A similar idea for the electric ignition method used by Lenoir can be found in a proposal by William Henry Fox Talbot, probably better known for his work in photography. In 1840 Talbot suggested two forms of motive power, one using carbon dioxide and another using hydrogen, which was produced by electrolysis[22]. In the latter case, electric ignition was suggested for which means he proposed a commutator and a distributive system similar to that used later by Lenoir.

It would seem, therefore, that at the time Lenoir began his work with internal combustion engines, there was a considerable amount of background work being suggested by numerous individuals. What Lenoir did was to draw all these loose ends together in such a way that the end product, his engine, although far from ideal, provided a reasonable foundation on which a knowledge of its working principles could be built.

Towards the end of the decade beginning 1860, the production of Lenoir engines was down to a handful. About five hundred had been built in total by the English, American and French builders. In England, Messrs Kinder and Kinsey were responsible for improvements to the engine and a notable one was that to the admission slide valve[23]. The idea of a 'strata' of gas and air within the cylinder had, by that time (1867), been completely abandoned and a 'mixing plate' was applied to cause the gas and air to intermingle before entering the cylinder. Provisions continue to be made for an 'overplus' of air to enter. A three horse-power engine working at the Ipswich Gaslight Co. driving the retort exhausters, was fitted with these improvements and was reported by Mr. E. Goddard, the Superintendent of the Gas Works, to be working admirably[24].

Lenoir became a naturalised Frenchman in 1870 and in 1878 received the Montyon Prize de l'Academie des Sciences and a Silver Prize of 12000 francs from the Societé d'Encouragement and the Legion d'Honneur in 1881 for his work in telegraphy[25]. In 1883, he patented and made a single cylinder, single acting engine which used compression and worked on the four-stroke* principle[26]. Electric ignition was again used and in 1887, a liquid fuel version of it propelled a vessel on the Seine, touring between Le Havre, Tancouville and Paris[27]. Lenoir also built a motor car and shortly before he died in 1900, he recalled the following story which was supposedly corroborated by a former workman who was a foreman employed by Lenoir[28]:

> 'In 1863, I built a motor car in which we went to Jonville-le-pont in September. It took an hour and a half to get there, about the same to return. The engine was about one and a half horse-power and made one hundred revolutions with quite a heavy load.'

For this achievement he was awarded the Silver Medal de l'Automobile Club.

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* Otto's four-stroke patent was not recognised in France, its having been established in the French Courts that Beau de Rochas had priority

On 4th August 1900 at Verenna-St-Hildar, Lenoir died. He lived long enough, therefore, to see many of his ideas, however imperfect they were, taken up and successfully applied by others.

4.6 The compression engine of Francisque Million 1861

Paris was alive with ideas for engines in the early part of the 1860's. Million's proposals[29] shows that he clearly understood the basic principles required by an engine and it can best be described as a combination of those by Wright of 1833, which used separate gas and air pumps, added to the cylinder arrangement of Lenoir's engine. Figure 4.9 shows the arrangement of Million's engine. In making his ideas known, Million recognised that the work put into working such pumps, which were merely 'charging pumps' was negative work, since they contributed little to the performance of the engine. He, therefore, preferred to consider his pumps as 'compressor' pumps and maintained that an engine employing them could be made smaller and would be able to develop greater power in proportion to their dimensions as a result of the engines greater operating pressures. Apparently, quite unaware of Barnett's similar and previous claims to the use of compression, Million states:

> 'In the engine above described, the mixtures are intoduced under pressure into the motive cylinder..... I claim the exclusive right to the principle upon which this engine is constructed and operated whatever may be their pressure.'

In constrast to the general ideas at that time, Million preferred a homogenous mixture in his cylinder and provided

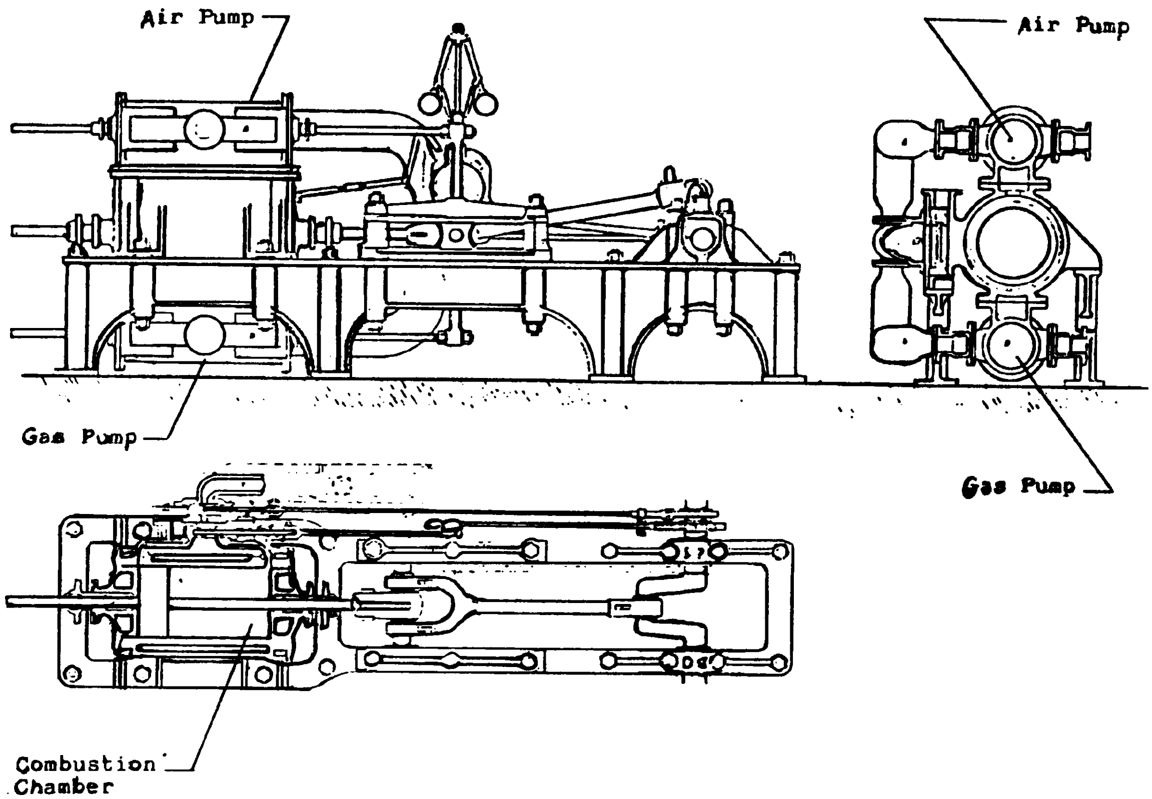

Fig. 4.9 Compression engine of Francisque Million 1861 using separate charging pumps for gas and air.

wire gauze in the inlet supply pipe to achieve this. Ignition was by electric spark obtained from a Ruhmkorff induction coil. In designing his engine, Million had incorporated the suggestions of Gustav Schmidt with regard to compression and mentioned earlier in this chapter, but no evidence of his ever building one of his engines has been found. Beau de Rochas, whose work is fully discussed in Chapter Six (section 6.4.1) combined all these ideas in his pamphlet of 1862 and presented them in a manner which was to form the basis on which future engines were to operate; but their practical application had yet to wait a further fifteen years.

4.7 The Hugon engines

Pierre Constant Hugon was a Director of a Parisian gasworks who developed an interest in gas engines in 1853. A total of twelve patents were issued to him in France and four in England[30]. His enthusiasm led him, in 1867, to claim that he was the original inventor of the Lenoir engine and describes the reasons why he abandoned his work with that type of engine:

> 'as it needed electricity and required so considerable a quantity of grease as to cause the cylinder, either by its own expansion, to stop the engine or to create such an amount of residue as to clog and impede its working, these and many other deficiencies convinced me that the application of gas was imperfect.' 31

Hugon went on further to say that 'The complicated and delicate arrangement of electrical batteries would be an insuperable objection in a workshop'. If this comment had been made seven years earlier, when Lenoir's engine first appeared,

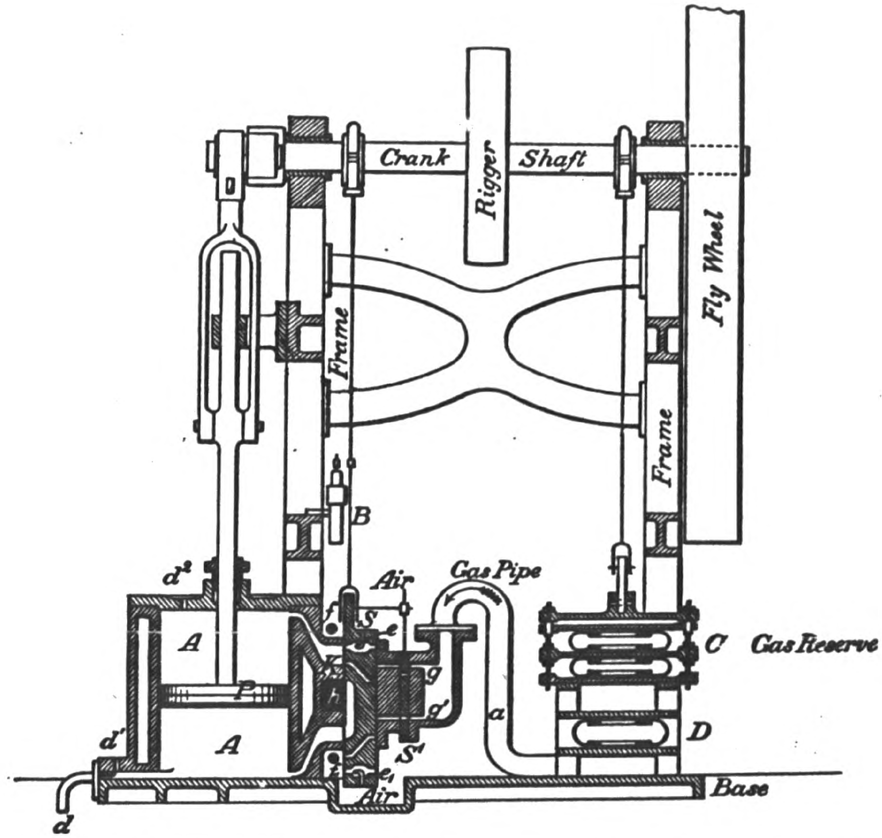

Fig. 4.10 Vertical Hugon engine made by Thos. Robinson and Co. Rochdale, England. Flame ignition

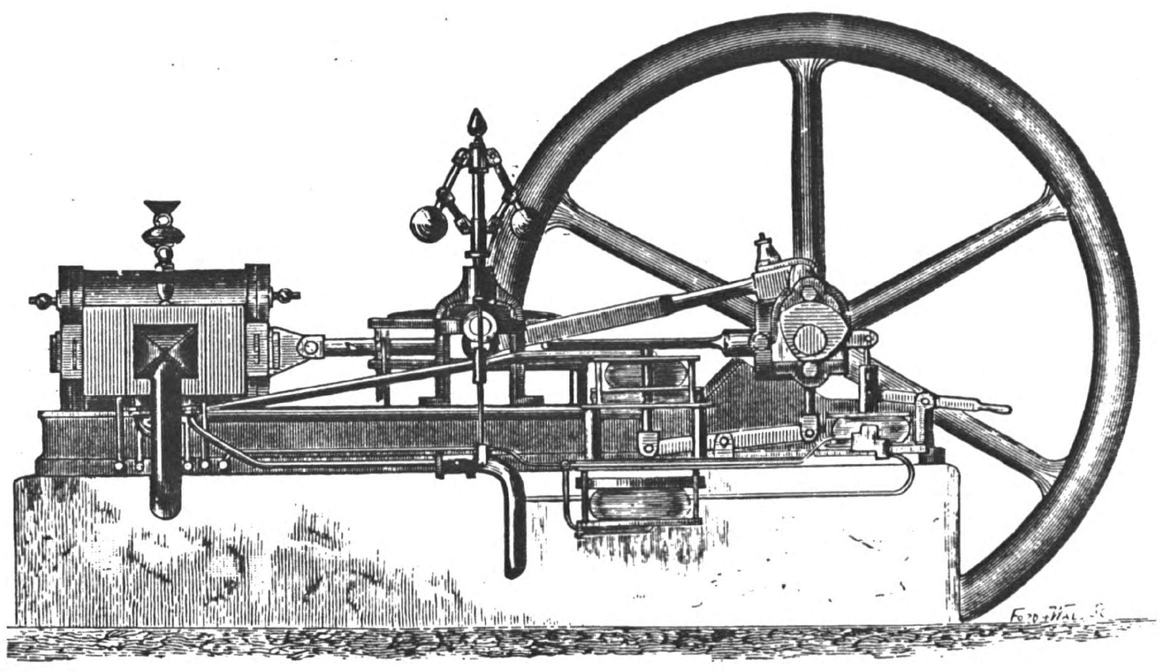

Fig. 4.11 Horizontal engine by Hugon. Flame ignition.

it would have been more credible, but it came at a time when the difficulties of electric ignition were already well appreciated. To his credit, Hugon did develop a method of flame ignition using the slide valve, which at that time, provided a distinct advantage over other forms of ignition and was used in various forms until 1888, when incandescent methods of ignition were used in Great Britain.

The first English patent by Hugon for a gas engine was in 1860[32], and consisted of a U-shaped tube, filled with water. The explosive force was transmitted to one column of the limb, the water being used to absorb the explosive shock. The working stroke occurred by using the vacuum produced on cooling of the products and allowing atmospheric pressure to act. An unsuccessful attempt to launch this engine as a commercial proposition was made in 1863[33] following a second patent but, although the gas consumption was something like a half that of the Lenoir, it failed to gain popularity.

From this financially unrewarding but practically worthwhile experience, Hugon developed his vertical engine, Figure 4.10 in 1865. It was a non-compression engine, working on a similar cycle to the Lenoir engine, but by this time Hugon had devised a highly reliable flame ignition method. Patents were taken out in England, France and America[34]. Its appearance coincided with the general air of dissappointment in the performance of the Lenoir engine and, consequently, Hugon's engine quickly found acceptance. By 1866, the Hugon vertical engine was a worthy rival to the Lenoir[35]. Messrs. Edward Casper of Poultry, London were the agents and it was manufactured by Messrs. Thomas Robinson of Rochdale[36]. Trials of this engine carried out by Professor Tresca in

Paris during 1866 over a five-hour period recorded the following results[37] :

Speed (rev/min)	53
Maximum cylinder pressure (16/in^2)	48
Air/gas ratio	13.1
Exhaust gas temperature (°C)	186
Water jacket temperature (°C)	42
Brake horse-power	2.02
Gas consumption (cu.ft/bhp/hr)	92

The gas consumption is seen still to be high, but the cost per thousand cubic feet of gas was steadily being reduced throughout the country by this time. This fact, together with its reliability and regularity of ignition, were the factors responsible for its limited success. A half horse-power engine would cost £60 and a four horse-power, the largest vertical made, would cost £150. A three horse-power engine had a stroke of 11.8 inches and a cylinder bore diameter of 13 inches. A further test was conducted by M. Achille Cazin of the Lycée de Versailles in 1866[38].

Hugon translated the mechanics of his vertical engine to a horizontal single-cylinder version, Figure 4.11 sometime in 1867. The cylinder and associated slide valves were simply placed in a horizontal position. The flame ignition system Hugon used, continued to give good service and its success probably set the seal for future ignition systems. Figure 4.12 shows the general arrangement of Hugon's flame systems. When ignition was required, the slide valve into which the flexible supply pipes were connected, slides to the right to close the port 1 to atmosphere, and then to open the explosion port 3 (as shown at the opposite end of

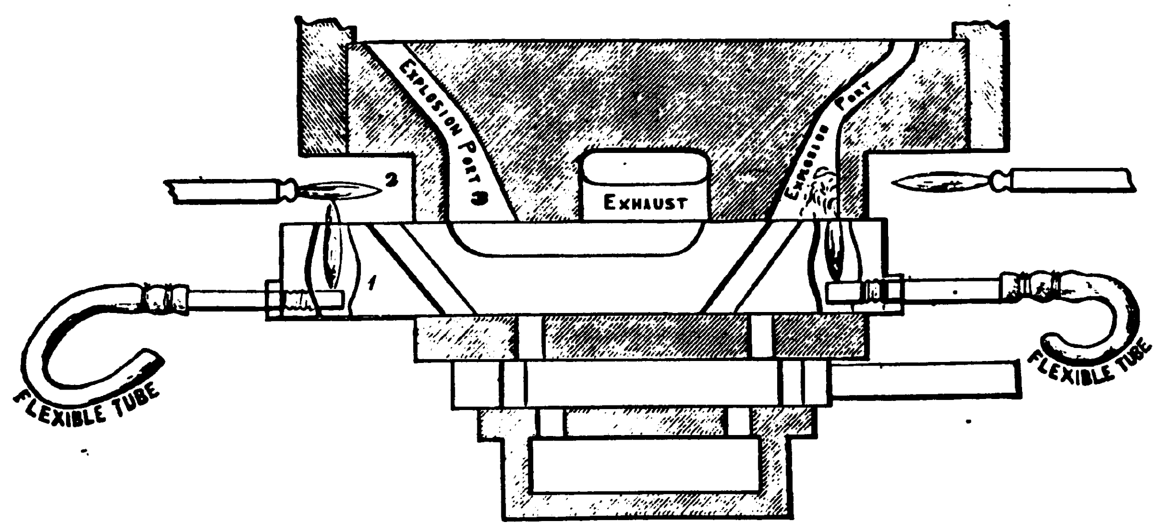

Fig. 4.12 Slide valve and flame ignition system of the Hugon engine

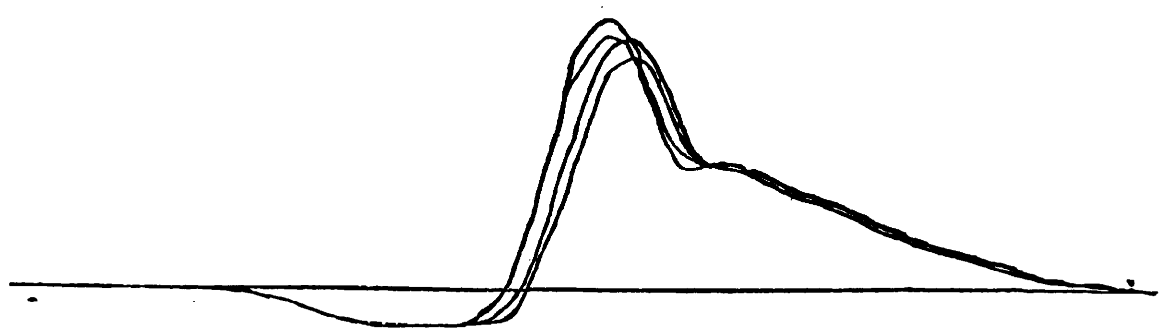

Fig. 4.13 Pressure-Volume indicator diagrams, Hugon engine.

the slide). The explosive mixture which, at that time, fills the explosion port, is thus ignited and the flame spreads into the cylinder itself.

A problem first encountered with the ignition system was that on explosion, some burnt products of combustion would find their way back into the gas supply pipe. The solution first used was to supply the gas to the valve at an elevated pressure created by small bellows. A better idea, however, was introduced by a Mr. S. Ford of the patent office Museum, London on a half horse-power engine installed there about 1868. This consisted of a light check valve placed in the gas pipe, which intercepted the rush back of burnt gases .

The supremacy of Hugon's horizontal engine proved to be short-lived in that it barely had time to establish itself, before the Otto-Langen Atmospheric engine appeared in 1867. The success of the latter, as will be seen in the next Chapter, was almost immediate and it drove all others off the market.

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4. French Patent is dated 24 January 1860. English Patent 335/1860 is dated 8 February and registered to J.H. Johnson, Patent Agent. An American Patent 31772/1861 followed on 19 March

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22. English Patent 8605/1840

23. English Patent 499/1867 (The address given by Kinder and Kinsey is that of the Lenoir Gas Engine Co.)

24. _Journal of Gas Lighting_ Vol. 17 (1868) p.141

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26. English Patent 5315/1883 to J.H. Johnson, Patent Agent. (The Otto Four-Stroke Patent of 1876 was not upheld in France)

27. Payen _op cit (3)_ In 1965, a 6 horse-power Lenoir engine using liquid fuel worked on the Waterway between Paris and Charenton for two years.

28. Ibid

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CHAPTER FIVE

THE FIRST COMMERCIALLY SUCCESSFUL ENGINES

By the middle of the 1860's it was still a fact that a commercially acceptable engine had not been produced. France had made a significant contribution with the Lenoir and Hugon engines and there were signs that the latter had some chance of success; but the fuel consumption of both was high and many technical problems yet remained to be solved. Interest in the possibility of motive power using combustion, however, had become much more widespread. America was awakening with ideas of its own and the industrialised nations of Europe also were becoming increasingly aware of the advantages to be gained by the use of an engine that could be started and stopped at will. One such nation in Europe, of which, up to now had made no significant contribution in the field of engine technology, was Germany, but this situation was about to be dramatically changed by the appearance of a highly successful engine working on an old idea - an atmospheric engine - by N.A. Otto and E. Langen.

At the time of its first public appearance in Paris at the Exhibition of 1867, few people, if any, could have had any idea - especially after listening to its clatter and watching its ungainly action - of how this engine was to influence future developments. After several tests during the Exhibition, totalling many hours, the 'Otto and Langen' atmospheric engine was awarded a Gold Medal and almost immediately Otto and Langen were inundated with orders and inquiries. In the ensuing years, this particular engine, which has the distinction of being the first ever to be made in large numbers, had a pronounced effect upon many trades in industry by making available to them a prime mover which was economical and reliable. Numerous examples of the Otto and Langen atmospheric engine have survived and can be seen at most National and Provincial Museums throughout Europe and America. Until now, however, little or nothing has been known of its origin. The institutions just referred to have been unable to describe either the events which made the engine technically possible or its contribution to industry and the effect it had upon the society that put it to use. The opportunity to fill this gap has been taken and after describing the events which led up to its appearance in 1867, its technical progress and economic contribution, both in Germany and England, is recorded. This is followed by details of how it came to be introduced into England and the chapter closes with a description of other engines that were introduced during the period under consideration.

5.1 N.A. Otto and his early experiences with engines A partnership with E. Langen

Nicolaus August Otto (1832-91) was about twenty-nine years of age when he developed an interest in engines. There is little in his early life, either at school* or in his youth, which indicated his inventive talent and, at the time of his first involvement with engines, was employed as a travelling grocery salesman for the firm of C. Mertens and Co. Most of this time was spent covering the territory along the German side of the Belgian-French border, where quite possibly he

* Otto's school report shows him to be above average

became inspired by news of the Lenoir engine. Like many others before him, Otto's thoughts first centred around the idea of an engine that would be independent of a piped fuel supply and could thus be used for propulsion (his days spent travelling the countryside using a horse and carriage may well have been influential in this respect). An application made in Prussia to patent a device which was a form of carburetter[1] was turned down on the grounds that it constituted nothing new*, but by this time Otto had become acquainted with a Cologne instrument maker, Michael Zons[2], who had a small workshop and between them they built a model of the Lenoir engine[3]. They were pleased to discover that it worked, but promptly ran into the same problem encountered by Lenoir - that of explosive shock - which made the running of the engine erratic and irregular. All attempts by Otto and Zons to overcome the problem proved unsuccessful**.

In May 1862, Otto gave up his job with C. Mertens and began to spend more time in the workshop with Zons and during that year, they are reported to have made a four-cylinder arrangement with two pistons in each cylinder, shown in Figure 5.1, but after a while gave up the idea[4]. The failure to solve the shock problem led Otto to seek alternative sources of inspiration. In 1862 he travelled to London to the Great Exhibition, but apart from the Lenoir engine and some cumbersome hot air engines, there was nothing that would point the way out of his difficulties. The only consolation to him

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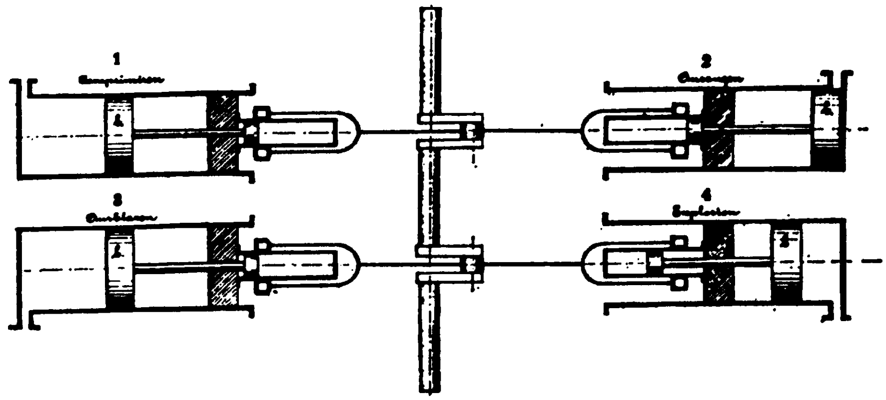
*Prior to July 1877, patents in Germany were granted by individual states. Those in Prussia were vetted by a technical committee

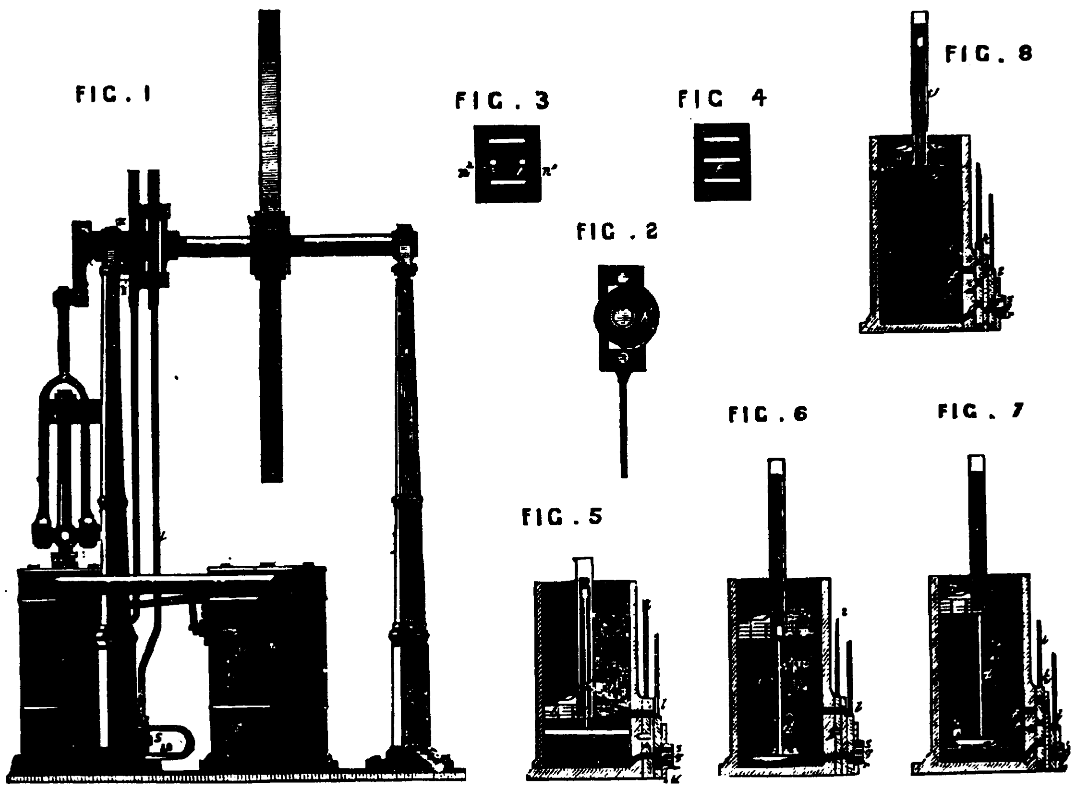
**Otto was of the mistaken belief that a weak mixture (excessive air) would alleviate the problem. Lenoir had similar views was that he had not been outpaced by anyone else with a superior idea.

5.1.2 Otto's first engine

About the same time that Otto was experimenting with Zons, discussions of the theory of the Lenoir engine were taking place[5]. There is no evidence to suggest that Otto was aware of them; he quite possibly was, having an eye on technical matters, since about this time (1862) he appears to have abandoned any further attempts with direct acting non-compression (and possibly compression) engines. In March 1863, his first engine rattled into life. This was a form of 'Atmospheric' motor, Figure 5.2, with the transmission shaft, crank and flywheel fitted on top of a high column. A patent application in Prussia was again refused, but was granted in England and France[6]. The fact that he had no protection in Prussia, placed Otto in a dilemma; foreign patents were difficult to exploit profitably and yet he needed to start production to gain both experience and financial return. Despite the risk of rivals copying his design, Otto did make a few engines. These, however, did not achieve any notable success. The working of Otto's first engine, although quite unlike the later successful atmospheric engine of 1867, incorporated certain similar features, such as the creation of a partial vacuum and the use of a slide valve.

The working cylinder of his first engine contained two pistons, one to act as a 'shock absorber' which fitted into the hollow section of the second, which was the working 'power' piston, (the combination was a form of dash-pot





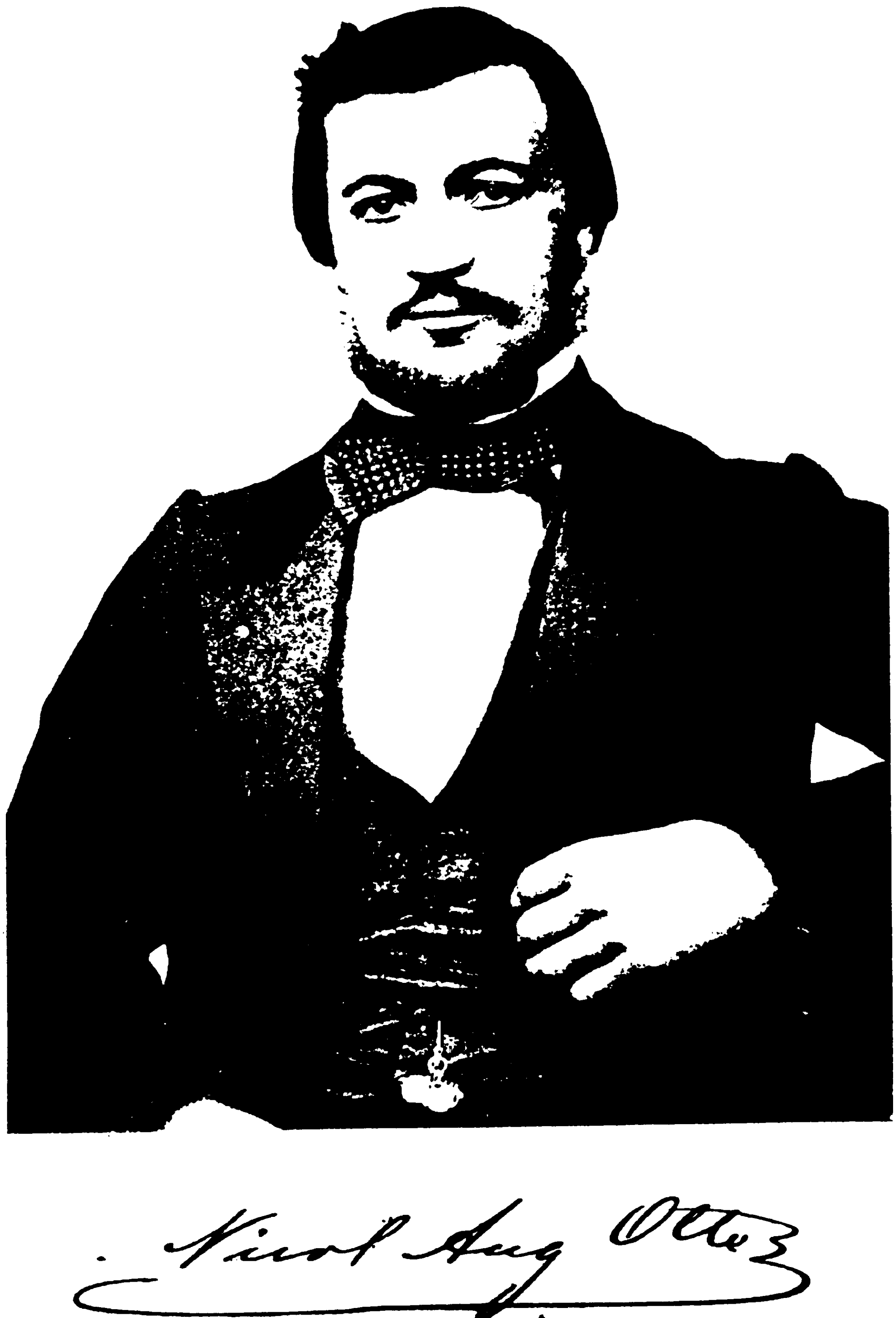
Upper
Fig. 5.1 The four cylinder four-stroke engine using compression, that Otto claimed he made in 1862.

Lower
Fig. 5.2 The first Atmospheric engine of 1864.

arrangement). The cycle of operations began with the two pistons at their lowest position. On turning the flywheel, the power piston was raised, and when near the top, the second piston was also raised, drawing in a mixture of gas and air through separate ports. Air trapped above the power piston would then be forced out and allowed to exhaust through valves which closed as the piston reached the top. Ignition, by electric spark, beneath the shock absorbing piston, caused it to rise rapidly, compressing the air between the two pistons, forcing it through holes and simple disc valves in the top piston, into a tank or reservoir. The air was not allowed to exhaust, but was maintained, the pressure being utilised to act on the upper face of the power piston as it descended to perform the working stroke.

On being thrust upwards after ignition had taken place, the shock-absorbing piston would almost meet the power piston, but the dash-pot arrangement cushioned the ascent to prevent actual contact. In this position a partial vacuum was formed beneath the pistons and the excess of pressure on the upper face forced the two pistons downwards.

A year after the patent for this engine, Eugen Langen, who became a partner of Otto, attempted to introduce this engine into England after a small number had been made in Germany. These attempts were unsuccessful and are described in more detail later in this chapter.



NICOLAUS AUGUST OTTO UM 1865

Fig 5.3

5.1.3 N.A. Otto and Co.

After three years experimenting, Otto had become desperately short of money. His savings, together with a small inheritance and money borrowed from his brother, had virtually gone. He had long since forfeited his share of the family house and land and was attempting to pay for expensive machinery and tools out of his own pocket. It was into this depressing but potentially promising situation that Langen, an engineer and business man, stepped. A partnership which proved to be life-long began and so, also, did a world industry.

Eugen Langen (1833-95) had the benefit of schooling at the Karlsruhe Polytechnikum, which was followed by an engineering apprenticeship and, later, managerial experience, in his father's steel forging plant*. Precisely how he became aware of Otto's work is not known, but on 9th February 1864 Langen had the first glimpse of Otto's creation in a tiny workshop on the Gereonswall, near the Rhine[7]. He needed little encouragement to become involved. Within a few weeks, Langen had raised sufficient funds to form a company and on 31 March 1864 the firm of N.A. Otto and Co. was formed. Premises in the Servagasse near the Rhine were obtained, which were old grain lofts converted to workshops**, and a labour force, made up of locksmiths - skilled men capable of working from drawings - was recruited. Work began on making engines according to the 1863 patent. They were found to work reasonably well in the workshop, where skilled atten-

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*One of the Langen's family interests. Others were sugar refining and banking

**Langen, in recalling these early days, tells of how dust fell between the floorboards onto machinery below tion was available, but proved unable to withstand the neglect afforded them by operatives who were ignorant of the basic need for lubrication and a moderate loading. Consequently, Otto spent a good deal of time visiting customers to put right the results of their maltreatment and Langen, who expected to have to do no more than take care of finance and business, found himself increasingly involved with technical problems. He attempted to enlist the help of his former student friend, Franz Reuleaux, then Professor of the Technical Institute, Zurich, but Reuleaux declined. Langen also attempted to introduce this engine into England by writing to a fellow German, Ludwig August Roosen-Runge, who was in business in Manchester, but this also came to nothing*. Otto and Langen had very much to fight their own battles at this stage.

5.2 The Atmospheric Engines 1866-67

At some stage during the three-year period leading up to the Paris Exhibition of 1867, Otto abandoned work on his first type of atmospheric engine and turned his attention to another that had already been brought to a workable form by the two Italians, Barsanti and Matteucci (see Chapter Two, section 2.6). In 1866 Otto, having made improvements, obtained a patent[8] for this later engine, shown in Figure 5.4, which he managed to get working during the same year. Langen tried to introduce this engine into England also, but once again was unsuccessful. A probable reason for its failure was that some difficulty was experienced with the electric

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*This is fully discussed later in the chapter

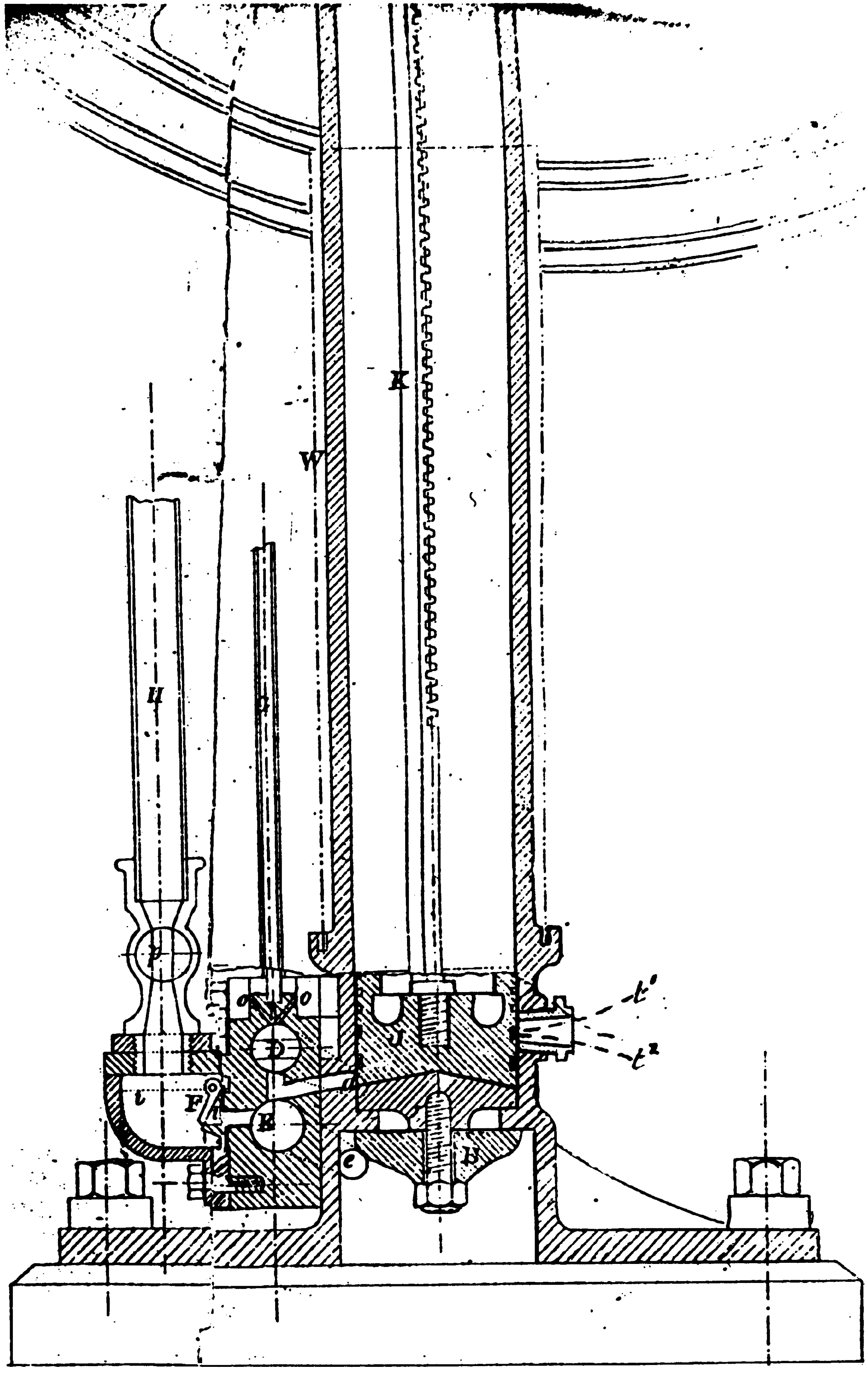

Fig. 5.4 Atmospheric engine, 1866, using electric ignition.

ignition system, which was proving most unreliable[9].

The similarity both in principle and design between Otto's 1866 version of the atmospheric engine and that of the Italians of 1857 cannot be ignored. C.D. Abel, the patent agent in London who obtained Otto's patent, informed Otto of the Italians' patent[10], but nowhere does Otto acknowledge the work of the Italians. The German version, however, incorporated many notable mechanical improvements and it was on the strength of these that the vigilant Prussian technical committee saw fit to grant a patent.

The engine exhibited in Paris in May 1867* showed that many improvements over the 1866 version had been made. Quite evidently Otto had spent the intervening period overcoming the practical difficulties that had arisen earlier. Notable of these improvements was that the electric ignition system had been replaced by a flame method and a slide valve, ingeniously adapted from the Hugon engine, was used. Also included was an improved drive mechanism (with which the Italians experienced great difficulty). Although, as stated earlier, the principle of operation of the German engine was identical to that of the Italians, it should be mentioned at this point that Otto never laid claim to its mode of action. The claims of his patent relate only to the mechanical improvements which he introduced and which enabled him to overcome the acknowledged weaknesses of the Italian engine.

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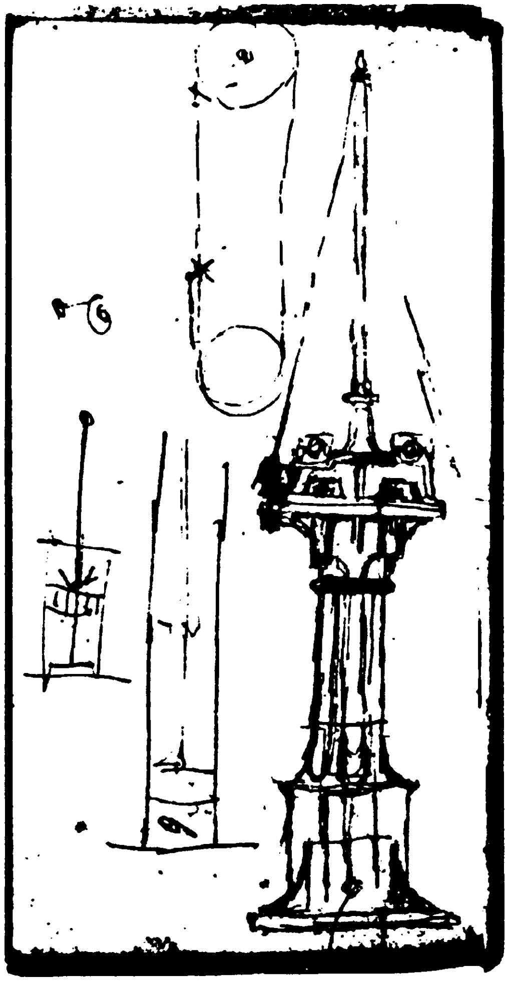
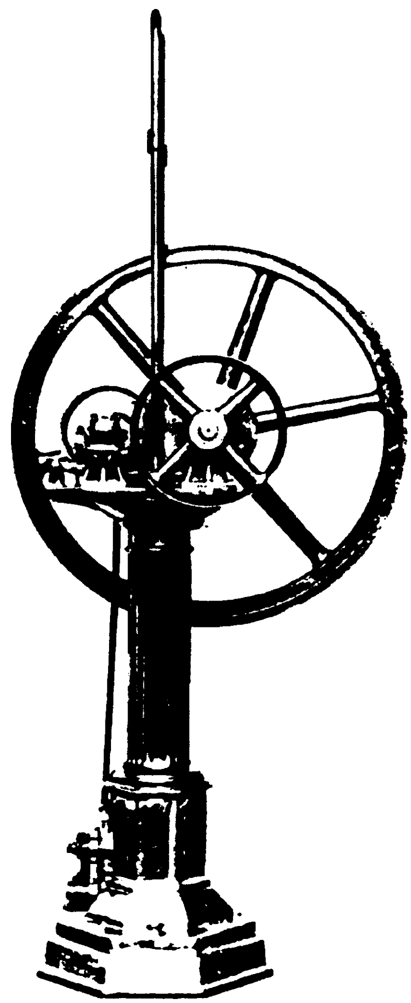
* This same engine, in working order, is now displayed in the Werkmuseum of the Klöckner-Humboldt-Deutz AG. Cologne. KHD is a direct descendant of the firm N.A. Otto and Co. founded in 1864

Fig. 5.5



Handskizze von Eugen Langen zum Motor

Fig. 5.6
A hand-sketch of the
Atmospheric engine of
Eugen Langen



Der auf der Pariser Weltausstellung 1867 gezeigte Motor

Fig. 5.7
Engine No. 1 exhibited in Paris 1867

5.2.1 The working principle, description of operation and special mechanisms required of the Otto-Langen atmospheric engine

The name 'atmospheric engine' by which this and other similar engines became known, is rather misleading, since it does not adequately describe the process inherent in its working. Atmospheric pressure is utilised to produce the working stroke - hence the name - but before the pressure exerted by the atmosphere can be put to such profitable use, there is caused in this engine, an explosion beneath a piston, the force of which thrusts the piston upwards some considerable distance. A partial vacuum is created beneath the piston as the latter ascends, thus allowing atmospheric pressure to act upon the upper area of the piston. The partial vacuum is created by the momentum of the piston or, more precisely, by the energy imparted to it by the explosive force. For many years after the introduction of this engine there was a widespread but erroneous belief that the vacuum resulted from a rapid cooling of the gases by the cylinder walls. An examination of the indicator diagrams obtained from these engines, however, Figure 5.20 shows clearly how, as the piston ascends, a pressure equal to that of atmosphere occurs first and as the piston continues to rise, the pressure falls below that of the atmosphere.

Confusion with regard to names or titles which supposedly are meant to describe the principle of the working of engines is not uncommon. They can be explained simply as a lack of appreciation of the scientific principles involved. Such misunderstanding seemed not to impair the technological development of the Otto-Langen engines, principally because its basic principle of operation was simple. The main problems associated with this engine were of a mechanical nature and these are later described.

The distinguishing feature of the Otto-Langen engine from the Lenoir and Hugon was its 'free piston', free, that is, in the sense that it was not attached via a connecting rod to a crankshaft*. When impelled upwards by an explosion, the piston, B, Figure 5.11, and the toothed rack A, attached to it, rises freely and does not turn the driving shaft. This is done on the downward stroke. To accomplish this, four special mechanisms are required; a free wheel or 'clutch' arrangement; eccentrics; a slide valve and a governor (the latter was not absolutely essential).

The free-wheel, or frictional driving clutch, Figure 5.12, proved to be a most difficult design component and throughout the entire career of this engine, had to be continually modified to withstand the heavy demands placed upon it. It consisted of an outer gear, D, which was meshed to the piston rack and, in the space between this gear and the shaft were a series of rollers and wedges, I. On the upward thrust of the piston, the gear D would rotate clockwise (when viewed as shown), the wedges I, which were lined with leather, being lifted clear of the disc, G. During the downward and driving stroke, the gear D would force the rollers into the narrower end of the space in which they were placed and, in turn, would force the wedge I into contact with the disc

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*The working 'free piston' engine was often referred to as 'indirect acting' as opposed to a 'direct acting' engine, such as the Lenoir, in which the explosive force was directly communicated via piston and connecting rod, to the crankshaft

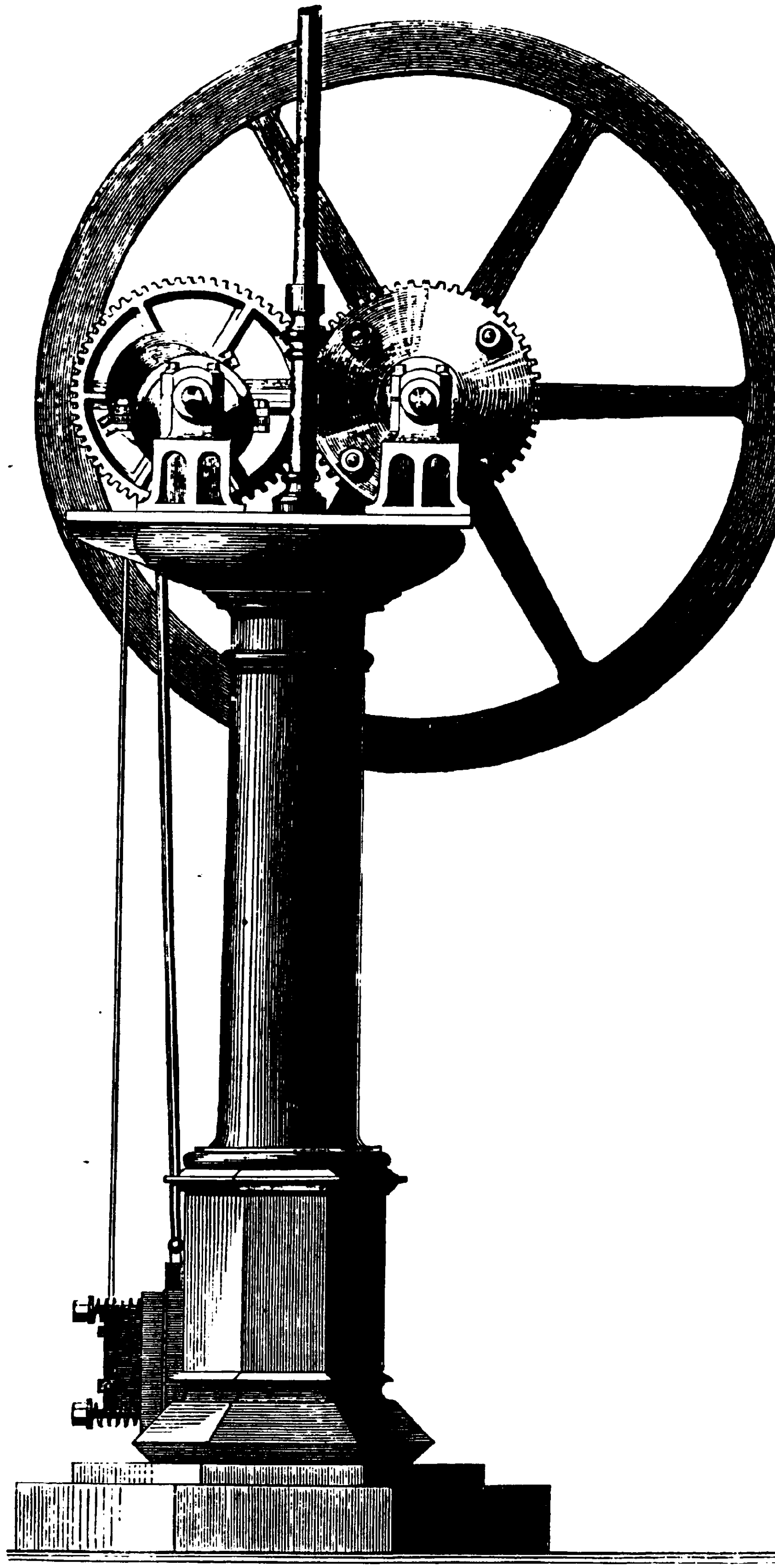

Fig. 5.8
Engine exhibited in Paris 1867. Two slide valve operating rods are shown.
(Engraving in The Engineer, 1867)

G keyed to the main drive shaft E. The original design of this clutching arrangement is thought to be the work of Langen and was used much later in the 'free-wheels' on some automobiles.

The use of eccentrics to operate the slide valve which admitted air and gas brought about ignition was in keeping with general practice at that time. In the Otto-Langen engine, eccentrics were also used to raise the piston which drew in gas and air to begin the cycle. Because of the nature of the working cycle used on the Otto-Langen engine, the throttling effect to the air as it entered, (an inherent defect resulting from the use of slide valves) experienced on the Lenoir and Hugon engines, was almost non-existent. This gave good filling of the cylinder and, ultimately, a more thermally efficient engine. On later versions of engine, eccentrics were replaced by a much simpler system consisting of a roller, mounted on the end of a crank to raise the piston. A second crank was used to raise and lower the slide valve.

The governor proved to be another difficult design component and many versions of it can be seen in patents and on engines that still survive. For three or four years following its introduction, the form of governing used on the Otto-Langen engines was to simply restrict the exit of the exhaust gases. This has the effect of retarding the descent of the piston on its working stroke with consequent longer intervals between firing strokes.

To prevent the exhaust gases leaving freely, a light valve in the exhaust pipe was operated by a rod connected to a cen-

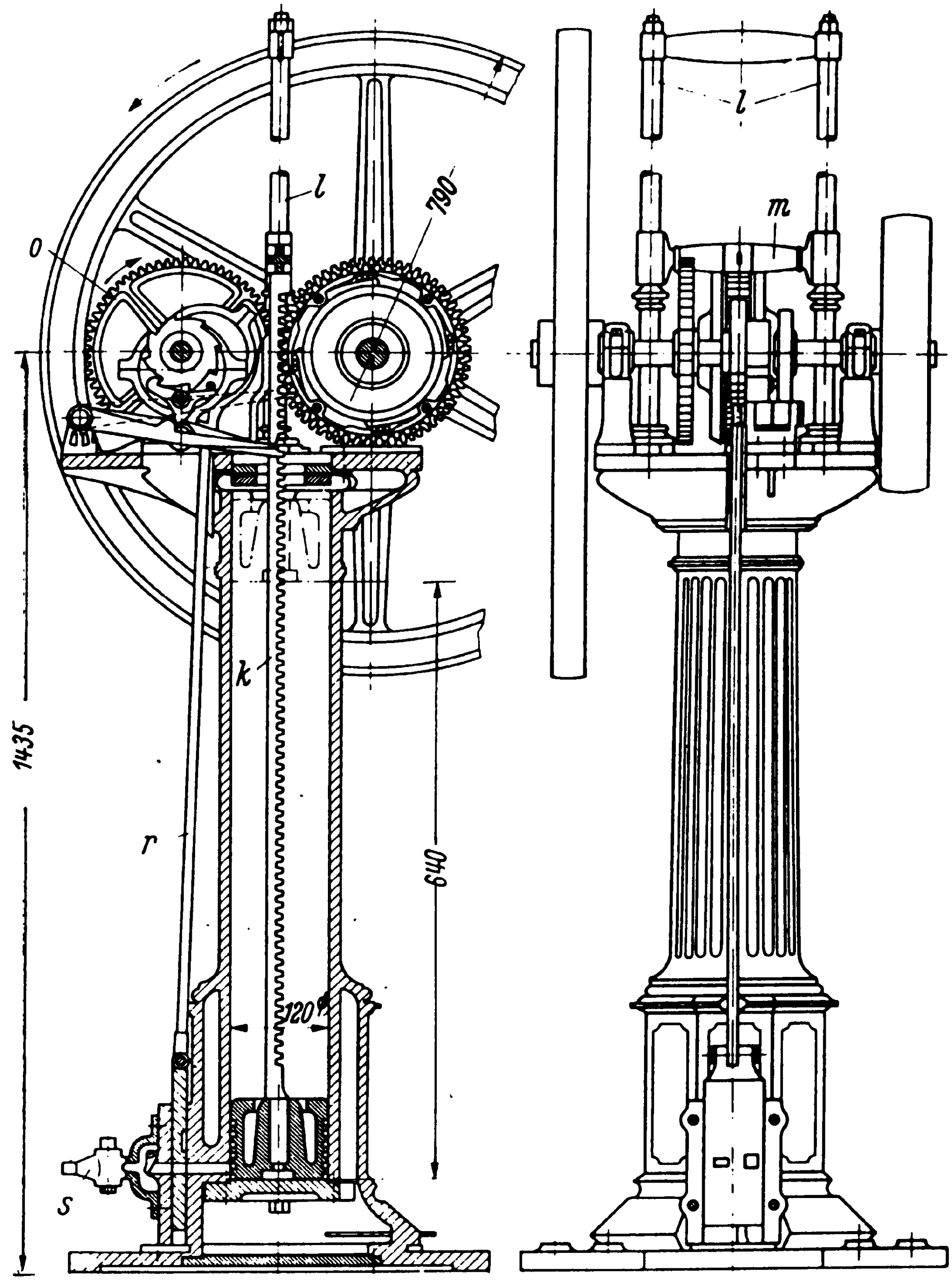

Fig. - 5.9
Sectional view of the German engine with modified slide valve operating rod.

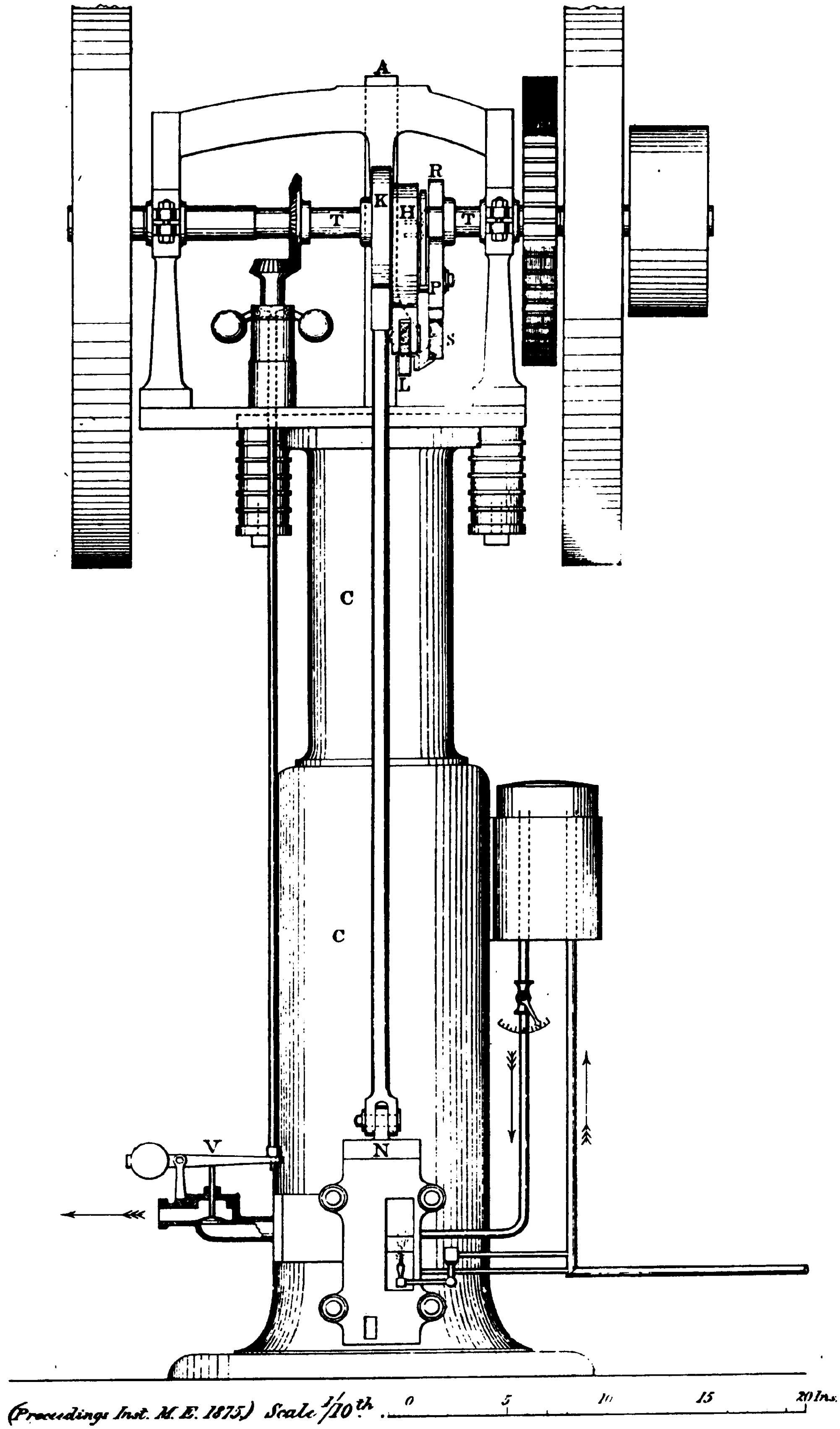

Fig. 5.10
English (Crossley) version of Atmospheric engine.
Engines up to two horse-power had only one flywheel

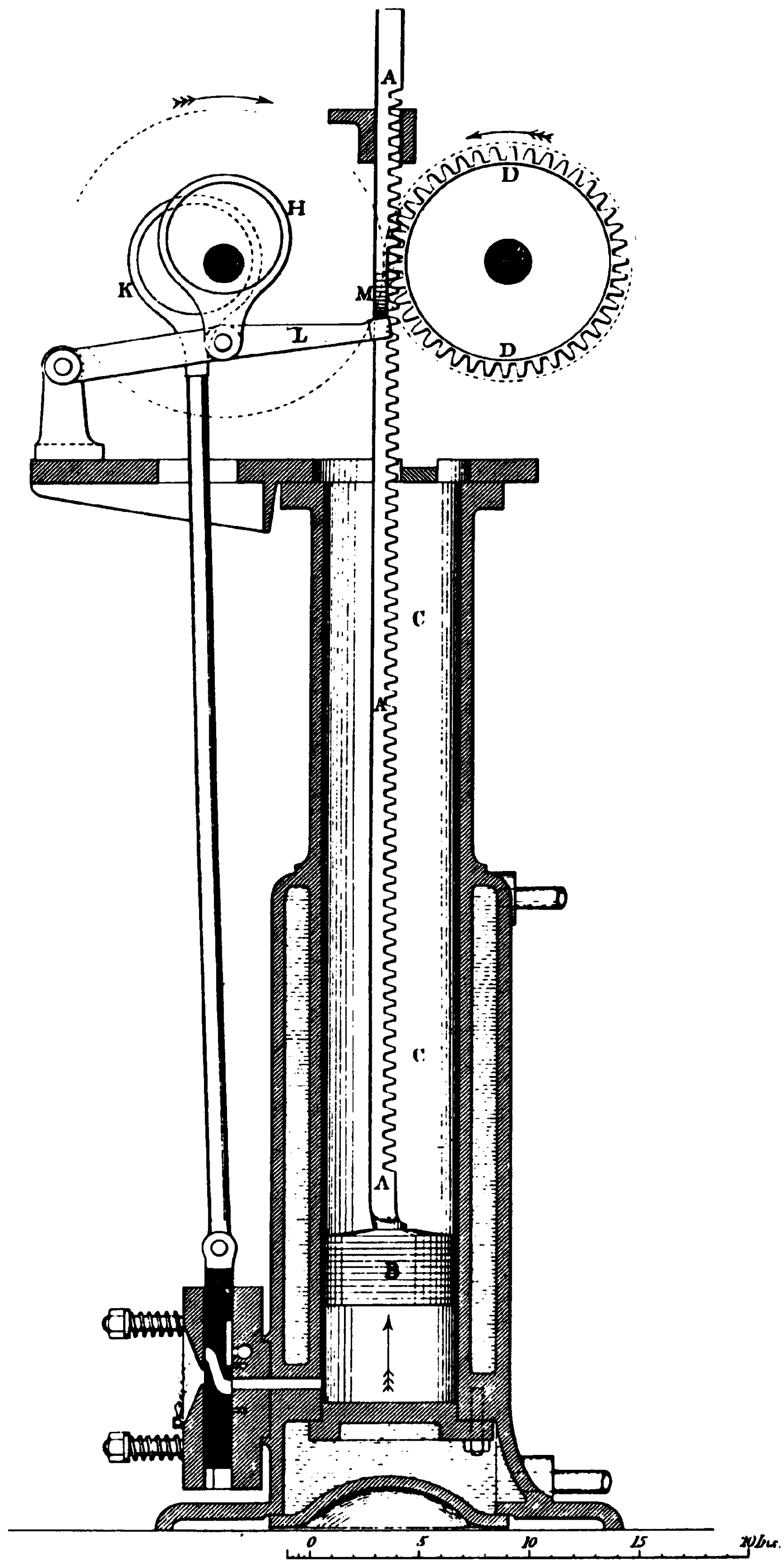

Fig. 5.11
Sectional view of Crossley Atmospheric engine.

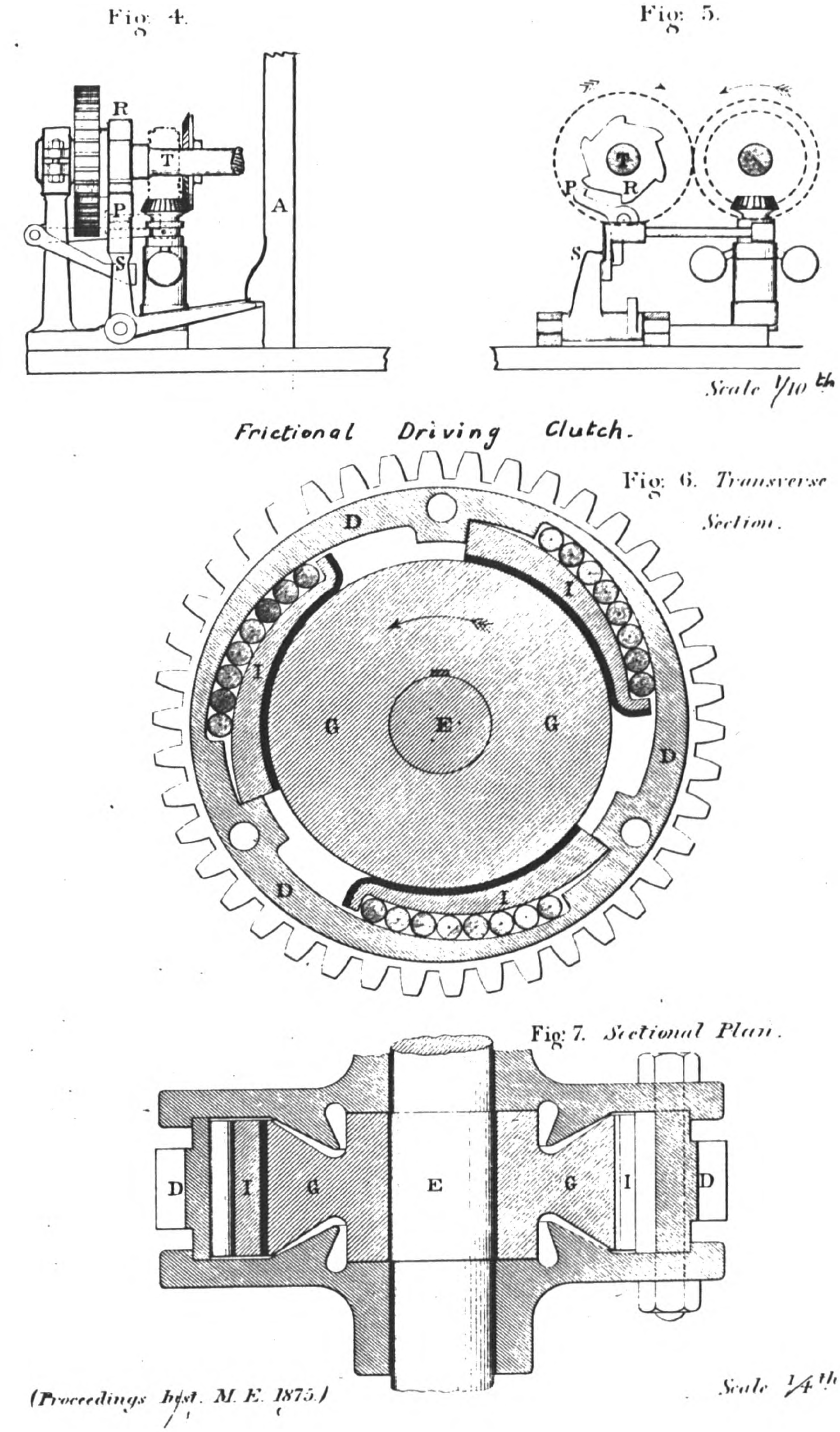

Fig. 5.12
Frictional Driving Clutch and governor arrangement, Crossley Atmospheric engines.

trifugal or fly-ball governor, Figure 5.10. Half horse-power engines were not always fitted with governors, instead a hand-operated gas-cock was fitted into the exhaust pipe, which could be adjusted to give the desired effect.

Governing by restricting the exit of the exhaust gases worked well enough when the engines were in good condition and the piston a good fit in the cylinder, but after some time in service the cylinder, having become worn, would allow exhaust gases to leak past the piston and downward movement of the latter would be largely unchecked. The engine would then gather speed and eventually control would be lost.

5.2.2 Recognition at the Paris Exhibition A Gold Medal Award

The outward appearance and mechanical operation of the engine shown in Paris was quite unlike that shown in the 1866 patent, see Figures 5.4 and 5.7. In fact, at the time of the Exhibition, the engine had not been patented. A patent issued three months later shows the features of the Exhibition engine and includes many improvements that had been made in that short period[11]. The slide valve, for instance, was operated by one rod and not two as on the Exhibition engine*, Figure 5.8); a centrifugal governor had become optional and water was made to circulate the base of the cylinder as well as its lower portion.

* The two rods were respectively used to admit gas and air. The Paris engine (now in KDH Museum Cologne) now has only one rod and must, therefore, have been modified before its sale in 1868 to a manufacturer in Milan

All these improvements were probably found necessary from the rigorous tests to which the engine was subjected during the Exhibition. These extended over several days and involved periods from one to three hours[12]. Visitors to the Exhibition gazed in disbelief at the mechanical contraption that was pounding away in the engine section of the North German States. A sign in French said simply:

> 'Gas engine, Otto and Langen system offering industry a one to three horse-power motor. Cheaper to operate than the steam engine.'

The Prize Awarding Committee of the Exhibition at first ignored the engine, but the hopes of Otto and Langen were raised when Franz Reuleaux - a student friend of Langen and a member of the Committee - persuaded them to carry out tests on the engine for economy of fuel. (The Lenoir and Hugon engines that were exhibited were excused this particular test, having been subjected to it during previous exhibitions). To the amazement of all but Otto and Langen, the atmospheric engine was found to consume less than half the gas of a Lenoir engine. Immediately there were protests; Lenoir refused to believe the result and suggested a hidden gas pipe was used; and Matteucci, the surviving Italian of the Barsanti-Matteucci partnership wrote and protested that the engine was a flagrant breach of their 1857 patent. There was, of course, no hidden pipe and no action was taken with regard to Matteucci's claim. The engine was awarded a Gold Medal.

News of the success of the new engine quickly spread; within weeks, Otto and Langen received more orders than they could cope with. Much work had yet to be done on the engine before it became a saleable and dependable product, but the tests carried out at the Exhibition by acknowledged experts had demonstrated its potential. The reaction of industry was immediate. At last there was now an engine that was not likely to cost a fortune to operate.

5.3 Developments 1867-74

5.3.1 Re-organisation of N.A. Otto & Co. Langen, Otto and Roosen

The success of the engine at the Paris Exhibition of 1867 brought to Otto and Langen, an all too familiar problem. Faced with mounting orders and enquiries, they lacked the capital necessary to expand and buy new machinery. An attempt to alleviate the difficulty was made when Langen took on a third party to the firm, Ludwig August Roosen-Runge, in March 1869. Roosen was a wealthy businessman, originally from Hanover, but, for several years prior to 1869, had been a partner in a firm, Roosen and Cornelsen, Civil Engineers, with premises in South King Street, Manchester*. The firm, N.A. Otto and Co., now became Langen Otto and Roosen and there is little doubt that the injection of Roosen's money enabled the firm to overcome their difficulties at that time and continue in business. Later that year, the firm moved to Deutz, a suburb of Cologne, situated on the bank of the Rhine and Langen obtained even more financial aid from his brothers.

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*Roosen was instrumental in bringing Otto's atmospheric gas engine to England in 1869. The events which led up to this are fully described in section 5.5

By the end of 1871 nearly five hundred engines had been sold by the German firm alone - the same number as the Lenoir and Hugon combined had managed to sell in twice that time. At first it was made in sizes of ¼ to 2 horse-power and proved itself easily adaptable for driving machinery in most of the smaller manufacturing industries. In workshops it was being used to drive lathes, grinding machines and saws.

The printing trade, with its numerous small establishments, found the atmospheric gas engine, with its small occupation of floor space, instant start and clean operation, of great advantage. A one horse-power engine was able to operate several presses, folding and stitching machines. In the textile industry, it was used to operate spinning and weaving machinery; gas works used it to drive exhausters, scrubbers and washers and the food industry used it for sugar manufacture, bread-making and coffee-roasting. The engine was used mainly to relieve the drudgery of manual labour, especially in the printing trade and in warehouses which used hoists - work that was usually done by relay teams of men and boys. In other situations, it was bought to entirely replace a steam engine; soon proving its superiority in running costs over the latter.

Agents and licensees soon began to appear throughout Europe. The Crossley Brothers* of Manchester were the first, beginning manufacture in 1869 and becoming sole licensees and agents in 1870. They were followed by Ed. Sarazin of Paris; C. Bloss of Barcelona; Langen and Wolff of Vienna and the

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* The contribution by the Crossley Bros. of Great Britain is fully discussed in section 5.6

Schleicher Brothers of Philadelphia.

5.3.2 Gottlieb Daimler and Wilhelm Maybach The Gasmotoren Fabrik - Deutz

The demand for engines exceeded all expectations and, despite the numerous injections of capital, it soon became clear that the firm, Langen, Otto and Roosen was unable to cope. Major re-organisation was needed and Langen considered selling the company on receiving an offer from a group of men from Hanover. In this group, however, was an Englishman, Frederick William Turner, an Engineer who was familiar with the working of gas engines and Langen, who apparently knew and trusted Turner, sought the latter's advice. Turner* at the request of Langen, drew up plans for building extensions. This was at the beginning of 1872, which proved to be a highly significant year for the German firm. On 5th January of that year the firm again changed its name to the Gasmotoren Fabrik, Deutz (GFD) and about this time, negotiations with Gottlieb Daimler (1834-1900) began, regarding his role as Technical Director at GFD. Turner seems to have taken exception to Daimler's criticisms of the plans that had already been made with Langen and the Englishman's brief spell at Deutz appears to have ended about this time. As will be seen later, Daimler possessed a particularly aggressive nature, which eventually resulted in his dismissal, but, as well as a wealth of technical expertise which he had accumulated from the principal industrialised cities of Europe[13],

* Details of Turner's involvement at Deutz were extracted from an assorted collection of letters in the Klöckner-Humboldt archives. File No. VI/2B

Fig. 5.13
Gottlieb Daimler (1834-1900) and
Wilhelm Maybach (1846-1929)

he took to Deutz his protegé, Wilhelm Maybach (1846-1929), a brilliant designer. The combined efforts of these two men left a lasting impression on the work that was done at Deutz.

After serving an exacting apprenticeship with a firm of gunsmiths, Daimler worked at the firm of F. Rolle and Schwilque, near Strasbourg which built railway cars, goods vans, bridge components and various types of machinery. In 1856, the factory began building locomotives and Daimler was made a foreman at the age of twenty-two. This was followed by a period of study at the Stuttgart Polytechnic Institute where he learned the rudiments of physics and chemistry, engine design, engineering drawing, economics and English. He left the Institute at the end of 1859. By this time, it was becoming clear to Daimler in what direction his destiny lay. Like Otto, he was stimulated by the Lenoir engine, but, as yet, was not to realise his ambition of working on problems associated with engine technology. After a short stay in Paris, Daimler travelled to England in the summer of 1861, first to Leeds where he worked in the engine shop of Smith, Beacock and Tannet and then to Manchester in the famous firm of Roberts and Co., which made textile machinery, machine tools, screw propellors, steam engines and locomotives. This was followed by a spell in the Whitworth tool factory in Coventry, returning to Germany early in 1863 to work at the Maschinenfabrik Straub in Geislingen as a designer working on tools, mills and turbines. Later that same year, Daimler took over the managements of the Brüderhaus Engineering Works where he later became aware of the talents of Maybach. Daimler's last job before moving to Deutz was technical manager of the Maschinenbau-Geselleschaft, Karlsruhe.

All too well aware of his abilities, Daimler drove a hard bargain with Deutz with regard to his salary and share of the profits. His contract of employment was confirmed on 11 March 1872, but it was not until 1 August 1872 that he began work and business arrangements settled[14]. He was also provided with a house by the Gasmotoren Fabrik. The first task at Deutz was to re-arrange equipment and methods of production and to prepare plans for expansion. Daimler set about it with enormous enthusiasm. He brought factory workers from Württemburg and changed what previously had been a handcraft operation into an organised manufacturing process. Within a few months, Daimler had produced a substantial amount of re-organisation at GFD and amongst his recommendations was that Maybach assume the role of chief designer. Maybach took up his appointment in July 1872. He was endowed with a superb and natural ability for design. He received his schooling in an orphanage known as the Brüderhaus which was a component of the Wernersche Anstalten group founded by a Lutheran theologian, Gustav Werner in 1839. At the Brüderhaus, training involved both theoretical and practical aspects concerned with engineering and it was during this time that Maybach's talents came to the notice of Daimler. Before joining the firm at Deutz, Maybach had also worked under Daimler at the Karlsruhe Maschinenbau and during these years of association, there had built up between these two men a great deal of mutual respect and affection. They became close friends and when Daimler was forced to leave GFD in 1882, it was inevitable that Maybach would follow him. The continued partnership was destined to make a valuable contribution to engine technology*.

For just over four years, the basic design of the 1867 patent for the atmospheric engine remained unchanged, only minor modifications being made. The initial Prussian patent, granted in 1866, however, was due to expire in 1874 and the only way to secure a new one was by incorporating new features in design. This was Maybach's first job at Deutz. By the end of 1873, his work was completed and the English patent of February 1874[15] (Figures 5.14 and 5.15), displays in full measure his abilities as a designer. Figure 5.15 shows that the bottleneck shape used up to that time had been replaced by one of a tapered, cylindrical appearance; the water jacket now extended over the whole length of the cylinder and was intended to be of such a capacity, that there was little need for a circulating system. Significant mechanical improvements were also made to the governor which, instead of operating a restricted valve in the exhaust pipe, now simply prevented the piston from being raised to begin the cycle; a dove-tailed guide for the piston rod appeared, the friction clutch was made larger and a considerable simplification to the main drive shaft and countershaft was made, replacing entirely the former complicated system of ratchets and levers.

The ownership of this patent, (Figure 5.14), became the centre of a great dispute between Daimler and Langen with arguments dragging on for months[16]. Daimler possessed a particularly aggressive nature which, on numerous occasions had brought him into conflict with Otto. Langen came close to

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* See Chapter Seven, section 7.12

A.D. 1874, 18*th February*. N° 605.

Gas Motor Engines.

LETTERS PATENT to Charles Denton Abel, of No. 20, Southampton Buildings, Chancery Lane, in the County of Middlesex, for the Invention of "IMPROVEMENTS IN GAS MOTOR ENGINES."—A communication from abroad by Gottlieb Wilhelm Daimler, of Muelheim on the Rhine, in the German Empire, Civil Engineer.

Sealed the 21st April 1874, and dated the 18th February 1874.

PROVISIONAL SPECIFICATION left by the said Charles Denton Abel at the Office of the Commissioners of Patents, with his Petition, on the 18th February 1874.

I, CHARLES DENTON ABEL, of No. 20, Southampton Buildings, Chancery Lane, in the County of Middlesex, do hereby declare the nature of said Invention for "IMPROVEMENTS IN GAS MOTOR ENGINES," to be as follows:—

This Invention relates to improvements in gas motor engines of the kind described in the Specifications of Letters Patent granted to me on the 12th February 1866, No. 434, and on the 3rd August 1867, No. 2245, being communications to be from E. Langen, and N. A. Otto.

Fig. 5.14
Improvement Patent of 1874 issued to Daimler, but featuring Maybach's design improvements to the Atmospheric engine.

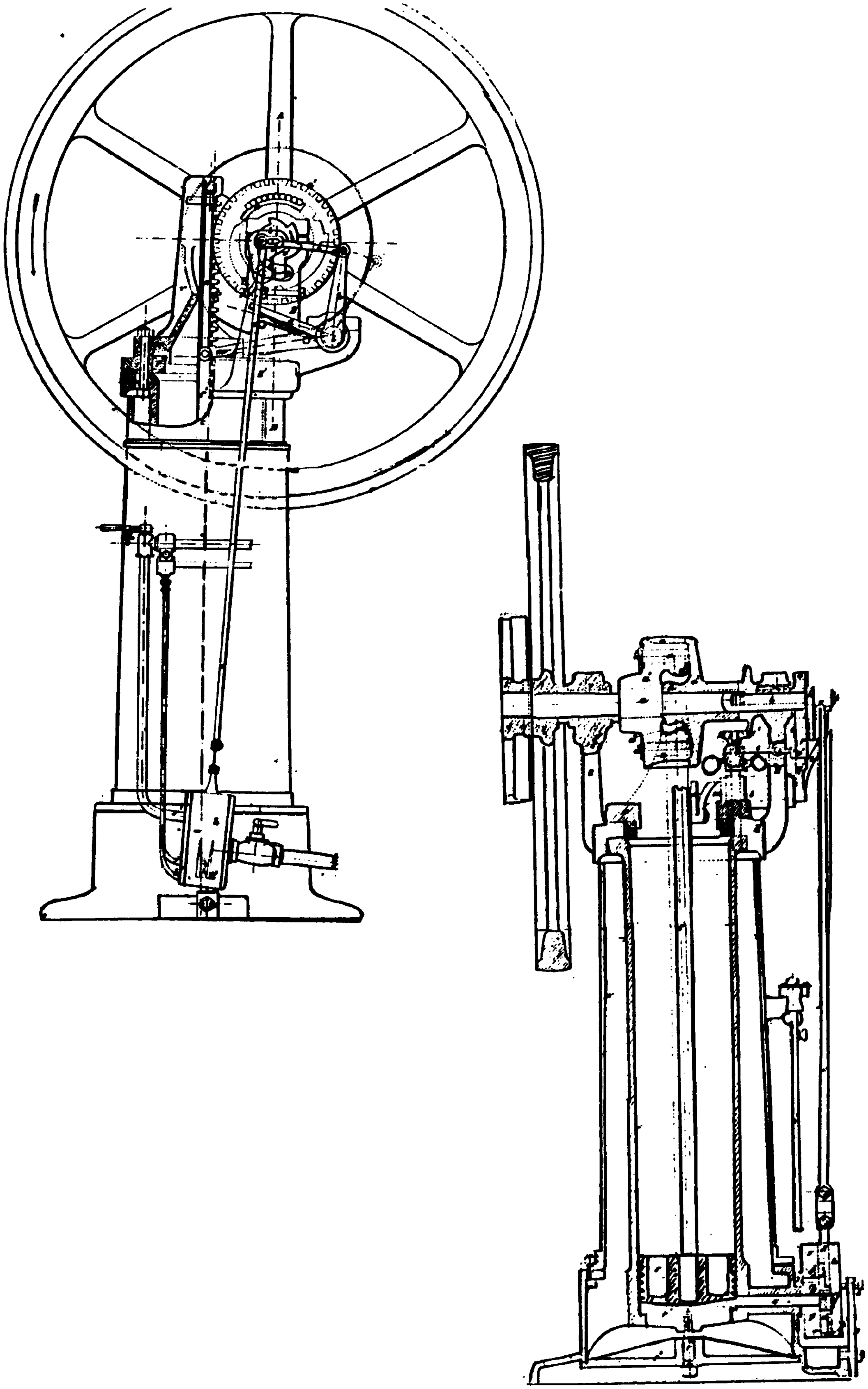

Fig. 5.15
Improved German design according to Maybach
(English patent 605/1874)

dismissing him over the issue of the patent and refused to accede to Daimler's demands for sole ownership and all consequent profits resulting from it.

A compromise was eventually reached whereby Daimler's name appeared on the patent, but Deutz retained all rights. To bring about the deal Daimler was offered shares to the value of 1000 marks - well below their true market value- which he accepted. When Daimler eventually broke away from Deutz, it was the money from these shares which helped him to finance his ideas on high speed petroleum engines (see Chapter Seven, section 7.12).

5.4 Experimental work at the GFD

By the year 1872, the Otto and Langen engine had become an essential component of many industries in the industrialised countries. The feeling of resignation, detectable from reading journals about the mid-1860's, that direct-acting engines (with or without compression) possess inherent and insurmountable defects - possibly prompted by the bad performance of the Lenoir engine - was beginning to subside. A previous stalemate situation had now changed to one of more promise. There was still a limit to the power which the atmospheric engine could give and there was still also the hurdle of making it independent of a piped fuel supply to overcome. In 1873, these were seen as the main problems requiring attention and since, at that particular time, demand for the engine exceeded plant capacity, there was every reason for embarking upon development work.

The internal arrangements at Deutz at that particular time were that experimental work was Otto's province, Daimler ensured that production ran smoothly and Maybach draughted out design improvements. Langen was the general overseer and more often than not, the peace-maker, smoothing out the differences that erupted between Otto and Daimler. On the experimental side, Otto had done some work with hot-air engines in 1871 but had abandoned it.

He later tried to incorporate a crank drive to replace the free piston principle of the atmospheric engine and attempted to utilise a hydraulic system of power transfer to reduce the noise that occurred when the engine was in action, but none of this work produced any notable success and neither did another attempt to put two atmospheric engines side by side, driving a common shaft. A joint effort, involving Otto and Maybach was also made to run the atmospheric engine on liquid fuel. For this Maybach designed a primitive form of carburettor in which air was made to pass through the fuel, becoming heavily laden with inflammable vapour as it did so. Ignition, however, was by a naked flame and explosions and fires were a constant risk. A few liquid fuel atmospheric engines were reported to have been made, but their safety of operation could not be guaranteed[17] and they were abandoned.

Attempts to raise the power ceiling were marginally more successful; three horse-power engines being the absolute limit. Any attempt to increase this brought about severe vibrations of the floor for several feet around the engine and a noise level that was quite intolerable. Daimler's contribution was to devise a single-cylinder horizontal engine with three pistons. It used the atmospheric principle of operation, the difference being that it was double-acting, patents in England and America being taken out in 1875[18]. The basic aim with this engine was to increase power output and reduce recoil shock, but the mechanical complication was so extensive that even Maybach was unable to produce a satisfactory design. The three-piston arrangement consisted of a "power' piston and two 'free' pistons, one placed each side of the power piston. A very long connecting rod joined the power piston and the crankshaft. Ignition of the charge between the two pistons at one end of the cylinder would thrust the pistons apart, the free piston becoming temporarily latched in its extreme position. A partial vacuum would be formed in the cylinder, allowing atmospheric pressure then to act upon the second free piston (now unlatched) forcing it and the power piston along the cylinder to produce the working stroke. The description of its operation which is given in the patent is extremely vague and it is quite obvious from this that Daimler had not succeeded in working out the mechanical details. It never really progressed beyond the drawing-board stage and no engineer, after studying the proposals, would be surprised.

5.5 The introduction of the Otto-Langen engine into England

The Otto-Langen atmospheric engine started a major national industry in England - the process of its introduction until now has never been clearly recorded. About all that was known is that the Crossley Bros. of Manchester began its manufacture sometime during 1869. A study of documents and the original agreements, contained in the Archives of the Klöckner-Humboldt-Werkmuseum, Deutz has shown that negotiations to introduce German gas engines into England actually began in 1864. These original agreements (given in Appendix Two) written in the German language have been translated[19], together with other relevant correspondence. The result is a substantially complete picture of how a small number of individuals worked together to make available for Great Britain a motive power unit that fulfilled a long-felt need[20].

5.5.1 First correspondence between Germany and England

A few months after the formation of N.A. Otto and Co. in March 1864, Eugen Langen wrote a letter, dated 25 October 1864 to Ludwig August Roosen-Runge, of Roosen and Cornelsen, Civil Engineers, 22a South King Street, Manchester[21]. Langen was eager to introduce Otto's first gas engine into England and wanted Roosen to find an engineer who would accept one and demonstrate it. Langen and Roosen apparently were already acquainted*. Roosen's reply on the 3 November 1864 was one of willingness to help and requested information on the engine regarding its size, weight, space occupied and price from Antwerp. In a further letter, dated 29 November 1864, Roosen revealed to Langen that he thought an attempt to introduce the engine at that time might prove difficult.

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* From the numerous items of correspondence it would appear that Langen had met Roosen in England, but no direct reference to this was found. Another possibility was that Roosen could have arranged the supply of machine tools for use in the Langen sugar factory.

His reason for saying this becomes clear later in the letter, when he reveals that there was great interest at that time in small turbines, which were proving popular. Langen then seems to have given up the idea of sending Otto's first engine to Manchester and almost a year later, on 28 November 1865, wrote to Charles Denton Abel, a patent agent and consulting engineer (also a German) asking him to accept a one and a half horse-power engine of Otto's first type. Nothing fruitful resulted from this correspondence either, and Langen appears then to have dropped the idea for the time being.

The reference by Roosen in his letter to the use of small turbines is interesting and it may not be out of place at this point to briefly relate the results of some searches that have been made by the author on the topic. Roosen, in his letter, gives no indication as to what type of turbine he had in mind or for what purpose they were being used. A good deal of correspondence, however, related to the use of water turbines can be found in 'The Engineer' beginning about 1861 and much discussion on the topic is contained in subsequent volumes. They are described as of the 'vortex' type capable of working from a small head of water. Numerous designs are shown with Messrs Williamsons of Kendal making a substantial contribution of saleable units. A moving figure behind the abundant discussion is Professor James Thomson (brother of Sir William Thomson, later Lord Kelvin) who appears largely responsible for the design.

Water turbines also featured fairly extensively in the International Exhibition of 1862[22] but judging from the descriptive account given to them, would seem not to have been regarded as a potentially promising source of power supply at that time.

It was whilst interest in Great Britain centred on water turbines, that Otto was developing his ideas on the second of his atmospheric engines, based on the Barsanti and Matteucci design (see section 5.2) and on 5 February 1866, Langen again wrote to Abel telling him of Otto's latest engine, but once more, nothing positive resulted. As stated previously, it is highly likely that the difficulties being experienced with the electric ignition that Otto was attempting to use on this engine, had some bearing on its failure to reach England.

5.5.2 <u>The first engine in England</u>

These numerous unsuccessful efforts by Langen to introduce these early German gas engines into England were not as negative as they appear at first sight. Roosen was a wealthy man, had a keen eye for business developments in engineering and was not without influence in Manchester. Abel, as a patent agent, was also likely to be extremely useful and both men had now been alerted to what was going on in Germany with regard to the development there of small motive power units. Since nothing significant in this respect was happening in England, they would very likely be following developments with interest. When Otto's much improved atmospheric engine was awarded the Gold Medal at the Paris Exhibition of 1867, therefore, enthusiasm became difficult to contain. Negotiations between Roosen and Langen resumed once more, this time with Roosen asking for an engine to be sent over and, in March 1868, Langen wrote saying that he would be prepared to send one, should Roosen succeed in finding someone with suitable premises who would receive it. A reply to Langen, dated 4 April 1868, reveals that Roosen was, in fact, having difficulty finding someone but was in contact with a Mr. Butterworth who had premises nearby[23]. Butterworth apparently was a little apprehensive about the idea, so a Mr. Routledge[24] and Roosen were to arrange the storage and demonstration. The engine was to be sent via Antwerp to Messrs Lofthouse, Glover & Co., Hull, with full instructions for erecting and starting.

Events at this stage, however, are a little unclear. According to a letter written by Roosen to Langen in mid-June, Butterworth did not receive the engine. It is not entirely certain, in fact, that it arrived in England. The tone of the letter is one of annoyance on the part of Roosen, who suggests that Butterworth should be compensated for the trouble and inconvenience to which he had been subjected.

5.5.3 The original agreements between N.A. Otto of Cologne L. Simon and Son of Nottingham and Crossley Bros. of Manchester

The uncertainty as to what happened to this engine, which was, or would have been, the first German engine to arrive in England, thus becomes a matter for speculation. There is a strong possibility that it may have been diverted to Nottingham for what is certain is that a few months later, on 3 December 1868 an agreement between the firm Louis Simon and Son of Nottingham and N.A. Otto was signed, authorising Simon's to be responsible for the sale of Otto and Langen atmospheric gas engines in Great Britain and Ireland. This agreement, and the subsequent ones, have been translated from the original German copies contained in the Archives of the KHD Museum and are given in full in Appendix Two of Volume Two.

The first agreement involving Simons, shows what arrangements were made to begin the sales and the manufacture of the Otto-Langen engine in Great Britain. The most relevant clauses were Nos. 1, 2, 3, 13, 14 and 16. Clause 1 authorised Simons to become responsible for the sales activities and Clause 2, that Roosen and Cornelsen would safeguard the interest of Simons in the Manchester district[25]. Simons, in fact, were only buyers of engines from Cologne and were not allowed to manufacture them as seen in Clauses 3 and 13. A possible explanation of what happened to the diverted Butterworth engine can be extracted from Clause 14:

> 'We will deliver to London*, one half horse-power engine, where you will install it to drive your bronzing machine so that potential customers can see the engine working ...
>
> 'We will retain ownership of it and reserve the right to decide on its sale ...."

The most significant Clause of this agreement, and one which has the most far-reaching effects, is seen to be No. 16 which outlines the action to be taken should the demonstration of the engine in London prove encouraging. Under the terms laid down, Simons were obliged to find someone who would either buy the invention or manufacture it against a royalty, but the sentence which is untimately responsible for

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* Simons had premises in Southwark Street, S.E. London

a complex arrangement involving Crossley Bros., N.A. Otto and Simons is that which promises to safeguard the sales activities of Simons when eventually a manufacturer (in that case, Crossleys) was found.

> '....... in any case (whether a buyer or manufacturer is found) we will safeguard your sales activities, enabling you to continue as sole sales agent.'

Some intriguing questions now arise as to why Simons should act in this particular capacity. Why did they not manufacture thé engine themselves? How, in fact, did Simons become involved in the first instance?

The last question is somewhat simpler to answer than the first. Louis Simon was a German who had been forced to leave Berlin and his position of editor of a newspaper, because of his outspoken views against the Government[26]. He settled amongst the German fraternity of Nottingham and founded a business in metallic printing*. There are, therefore, two reasons to suggest how Simons came to be involved: the rather obvious one of nationality and the second was their involvement in printing. Printers, it may be remembered, were amongst the most popular users of the atmospheric engine. The reason why Simons did not themselves make the engine was probably because, primarily, they were not a manufacturing concern. They were engaged in printing on metals and, as such, would be concerned only with the process of driving their machines. Langen, in choosing a printing firm to launch his engine,

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* The firm, still in existence, is now Richard Simon and Son, (Richard being the son of Louis) and manufacture a range of drying, cooling, flaking and chilling machines as well as industrial weighing machinery. The present firm has no record of its early history.

must have been aware, both of the needs of that particular industry and the effect upon future sales of the engine, should it have proved acceptable.

The London demonstration must be assumed to have been a success, since a manufacturer - Crossley Bros. - was found which gives rise to yet another pertinent point as to how Crossleys came to be chosen. Attempts to establish this by searching the archives of KHD failed to show any positive link between any of the parties so far mentioned. Some correspondence between Crossleys and Langen took place in June 1869 as indicated by a brief reference to this fact in a subsequent letter of a much later date, However, this initial correspondence between Crossley and Langen which may well be the first written contact, has so far not been found.

There is every likelihood, of course, that there was a verbal contact between either Roosen or Cornelsen and Crossleys. Crossley Bros. had built up an excellent reputation for workmanship and their premises, then in Great Marlborough Street, Manchester, were less than ten minutes walk to those of Roosen and Cornelsen. All these features, the proximity of the parties concerned, the reputation of Crossleys and the awareness of Roosen and Cornelsen of what was going on in the world of engineering, contribute to the suggestion that consultation between Roosen and Cornelsen and Crossleys took place.

5.6 The Crossley Brothers of Manchester and their contribution

5.6.1 From first Agreement to sole agents

The Crossley Brothers were in business as engineers, machinists, millwrights and iron founders, making hydraulic presses, pumps, steam engines, cotton presses, cotton gins and machinery for the manufacture of india rubber products. The firm was founded in 1867 and at the time they began to manufacture the atmospheric gas engine in 1869 already had a patent or two to their credit[27]. The partnership consisted of Francis William (1839-97) and William John (1844-1911) both of whom had served engineering apprenticeships. Frank - as he became known - served his at the works of Robert Stephenson, Newcastle-upon-Tyne and William with Sir W.G. Armstrong & Co. at Elswick. It was Frank who became concerned with designing and draughting out the ideas, while William took care of the accounts. In the very early days of the firm, their main interests was in making machinery for the flax and rubber industries. Frank Crossley had developed a system of producing rubber thread, which was adopted by all leading manufacturers in the country and his second patent, for improved machinery used in the scutching of flax was also very successful[28].

Internal combustion engines, however, must have seemed a much more promising field. Crossleys involvement signalled the end of a thirty-year period during which the initiative, shown by the early pioneers of Great Britain, had not been used to advantage. It also heralded the beginning of a new technology in which they were destined to play an influential part. A copy of the first agreement between Crossley Bros. and Langen, Otto and Roosen dated 20 August 1868, is shown in Appendix Two. This describes the arrangement whereby Crossleys were allowed to inspect and test a half horse-power engine* sent from Germany and destined for a Mr. Sydney Smith. After the test, they were then to decide if they wanted to become a manufacturer. It may be noted that the terms of the agreement enabled them to manufacture and sell only to Simons of Nottingham, a provision being made that at some future date they might become an agent for sales in Great Britain. Mr. Smith received his engine at the end of September 1869**. Crossleys decided to produce the engine and the terms of the agreement were implemented.

Significant clauses are seen to be those which outline the conditions with which Crossleys had to comply. Only three months after seventy-five engines had been sold could they become the sole agent and manufacturer. This was obviously protecting Simon's interest as promised in the December 1868 agreement, but a peculiar situation then developed by which Crossleys made engines, but could not sell them (only to Simons) and Simons sold engines but could not make them. As sales agents, Simons would receive payment from customers, deduct their commission and forward the balance in due course to Crossley Bros. This was an arrangement clearly not to the liking of Crossley Bros. since, judging by a letter dated 22 September 1869, Frank Crossley expressed his dissatisfac-

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* The engine sent over from Germany was No. 154. Kelly's Trade Directory 1869 shows a Sydney Smith of Smith and Barnes, letterpress makers, Longford Terrace, Stretford

** Letter from F.W. Crossley to Langen, Otto and Roosen - 22 September 1869, KHD Archives, Deutz tion at having to provide a number of engines in demand, yet wait a length of time to receive payment for them from Simons. He later consulted privately with Simons and an agreement was entered into enabling Crossleys to become sub-agents for Simons[29].

The formal contract establishing Crossley Bros. as the sole manufacturers and sales agent for Great Britain and Ireland, excluding the British Colonies, was signed on 12 and 15 June 1870. Why two contracts, substantially the same, were drawn up is a little mystifying. The first, between 'Langen, Otto and Roosen and Crossley Bros.' was signed by Crossley Bros. and the second, between Crossley Bros. and Langen, Otto and Roosen,' was signed by Langen, Otto and Roosen. A feasible explanation is that, after drawing up the Clauses, Langen, Otto and Roosen posted the draft to Manchester (12 June 1870 was a Friday), it would be received on Monday, upon which Crossley's would copy out the Clauses in total, sign it and return it to Cologne*.

The remaining Clauses of this contract, which define the terms under which Crossleys were to work, are briefly summarized as follows:

They were restricted in the production and sales to the United Kingdom and could not sell any gas engines other than those of Langen, Otto and Roosen. All engines produced were to be in strict accordance with the measurements and materials specified in the drawings provided by Langen, Otto

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*A similar technique was adopted by Crossley's in their pri- agreement with Simons 29, F.W. Crossley requests acknowledgement of his terms by 'repeating the Clauses in Extense'.

and Roosen. No modifications were to be made without permission. A name plate saying LANGEN AND OTTO PATENT was to be displayed in a prominent position with each engine being given a serial number. No number was to be used twice and the sales of engines were to be recorded in a special book which was to be available for inspection at any time.

5.6.2 The distinctive engines of Crossleys

So began an era for Crossleys, who proceeded to bring about a revolution in small prime movers in Great Britain. By the year 1876, an estimated 1300 had been trundled across the cobbled floor and through the stone archway (still standing) of the small work shop in Great Marlborough Street. Their contribution to its technical improvement was outstanding, for, of their own volition, they registered patents of improvements and introduced countless simplifications, which did a great deal to reduce the offensive noise of this engine. Although there was a profitable exchange of ideas between Crossleys and the Deutz firm, there was a distinctive difference in appearance between the English and German engines. Notable of these was the absence of the ornate Grecian Column design of the first German engines and the use of a simple gasometer to replace the flexible bladder used by the Germans to prevent pulsations affecting the mains gas supply.

The first Crossley patent, Figure 5.16, related to the atmospheric gas engine, was registered in 1874[30]. A number of similarities between this and the German (Daimler) patent of February 1874 are shown, such as the cooling arrangement, the dove-tailed guide and cylinder shape, but numerous modifications, peculiar to the Crossley engines are included. Notable of these is the improved governor action, the use of a crank to raise the piston at the start of the cycle and the use of two flywheels. A description of an engine similar to this is given in 'Engineering' of December 1875 in which it is stated that it is now the engine manufactured by Crossley Bros[31]. Between September 1874 and December 1875 a second engine patent[32] was taken out by Crossleys, Figure 5.17. Its main claim was for the use of an air spring or cushion, which was used to check the ascent of the piston, should it experience a particularly forceful explosion. The air spring also served to force the piston back down the cylinder by simply using the trapped air on the upper side of the piston, which was slightly compressed. Two other notable differences are seen on this engine; the piston rack is placed at the back of the engine and only one shaft is used on which is mounted the governor and clutch assembly.

Figure 5.18 shows an enlarged view of the single-shaft arrangement by Crossleys and it is obvious from this that a serious attempt had been made to simplify the mechanical complexity of the atmospheric engine. A close examination of its intended working, however, reveals it to be of unsatisfactory design. The mechanism for raising the piston to draw in a new charge had been completely re-designed. Instead of the crank, which had been used previously, a large piece of metal, referred to as a 'stop' (letter E, Figure 5.18) was contacted by a roller, which rotated with the shaft.

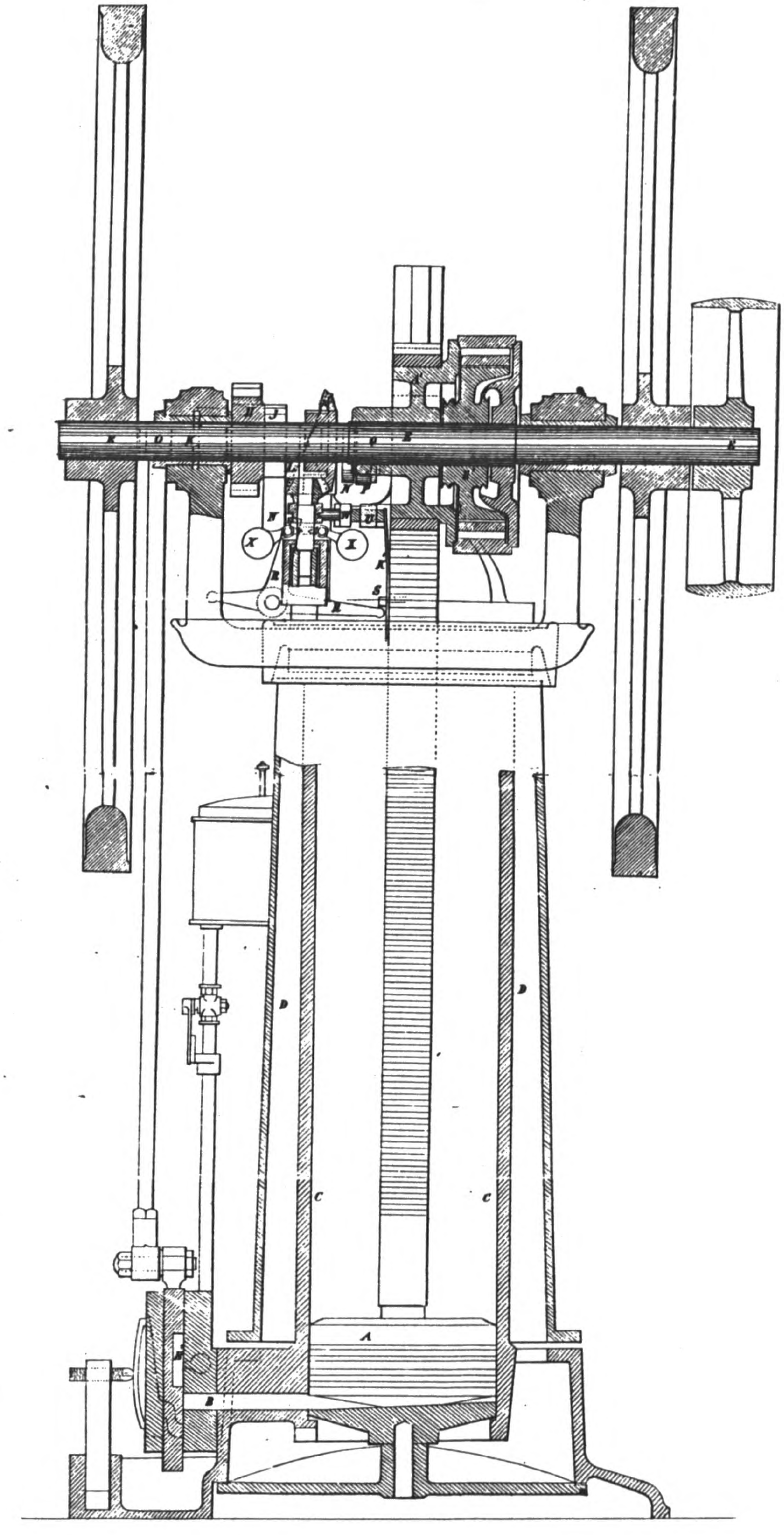


Fig. 5.16
Design features of the first Crossley patent 3205/1874. Slide valve now positioned at the side.

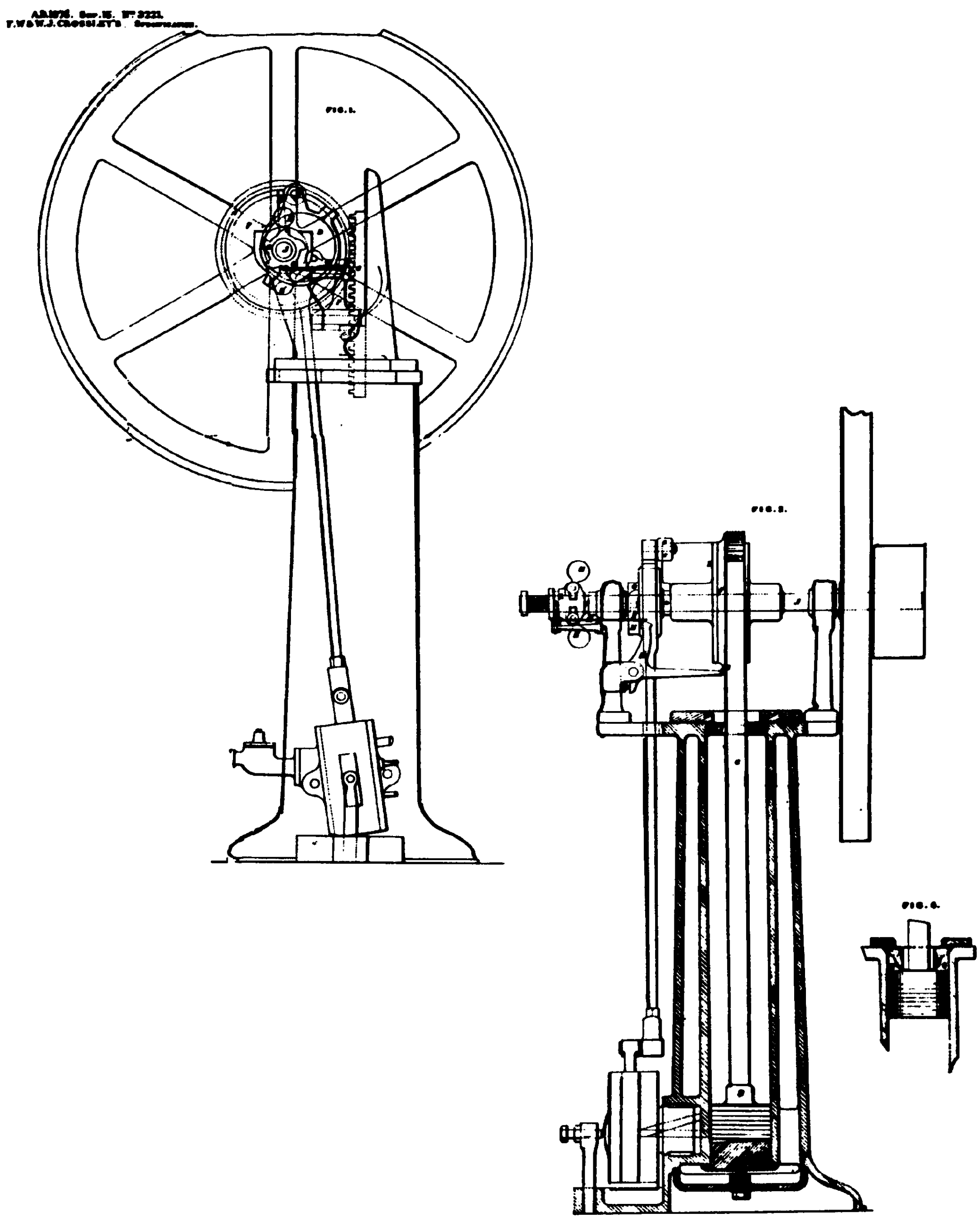


Fig. 5.17
Second Crossley Patent 3221/1875
Piston rack is situated at rear, air buffer is used; piston is raised by a roller and stop arrangement and a single shaft used (German idea)

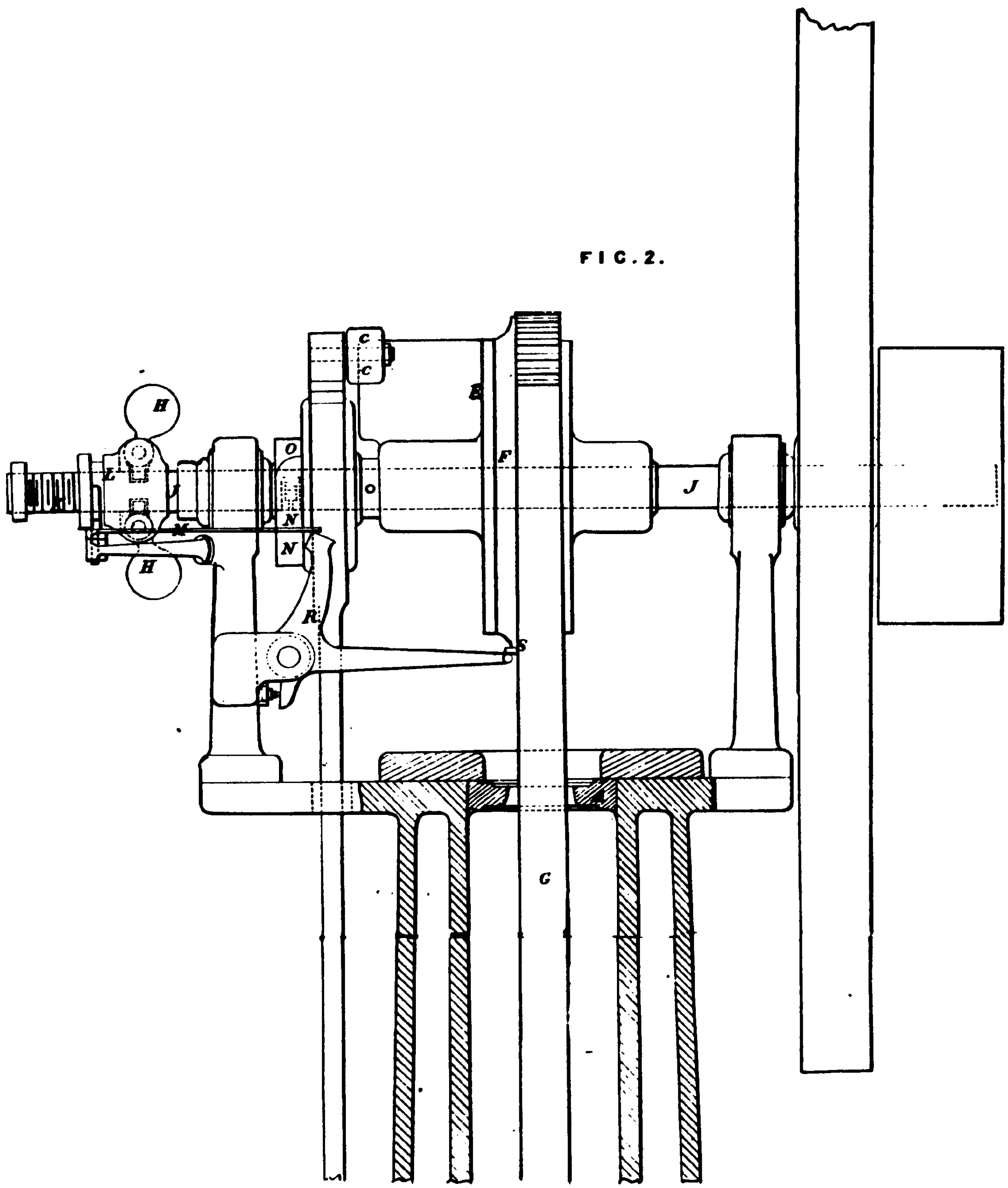


Fig. 5.18
Enlarged view of single shaft arrangement of Crossley patent 3221/1875

The length of the stop, one end of which was fixed to the friction clutch housing, meant that a considerable force would be exerted upon it when hit by the roller and it would not be too difficult to imagine that a high rate of wear, with a possibility of fracture, would soon take place. This particular design appears not to have been used, but certain features of it, such as the lever system of the governor, can be seen on the engine as described in the December edition of 'Engineering' 1875 and shown in Figure 5.19. This latter design appears to be almost the final one, featuring what would appear to be a sensible combination of proven design. It reverts to twin fly-wheels and the second countershaft. A crank is used once more to raise the piston and the governor of the earlier engine is used, but is not placed at the end of the shaft.

The third and final patent by Crossleys related to the atmospheric engine was taken out in January 1876[33] and describes what is probably the first-ever starting handle applied to an internal combustion engine, Figure 5.22. A lever, with a toothed segment on one end, is geared with a small pinion fixed onto the crank which operated the slide valve. To start the engine, the lever was pulled downwards, so as to rotate the pinion and, in turn, the crank, thus raising the piston to draw in a fresh charge. The engine shown is stated by Crossleys to have been presented to Henry Ford, and is now exhibited in his Museum in Detroit. It is almost certainly one of the last engines of this type ever made by Crossleys. The starting handle was an optional extra and was fitted to the three horse-power engines.

5.7 A summary of the progress of the Otto-Langen engine

Although only seven patents were taken out in England for the atmospheric engine - four by the German company and three by Crossley Brothers - countless modifications, often not reflected in the patents, were continually introduced. The technological progress that took place was remarkable; the engine was transformed from a noisy and objectionable contraption to a tolerable, economical and versatile machine that was made acceptable and useful to an enormous variety of industries. The following is a summary, in chronological order, of its progress, including significant events from the formation in 1864 of the firm N.A. Otto and Co.

March 1864	Otto and Langen signed agreement, forming the firm N.A. Otto and Co.
8 Feb 1866	Prussian patent for the first atmospheric engine with electric ignition
12 Feb 1866	English patent/434 to C.D. Abel. Prior to this Abel had informed Otto of Barsanti and Matteucci
May 1867	A much improved version shown at the Paris Exhibition. Single flywheel; guide rods for the piston rack; cooling at lower part of cylinder only; Grecian column appearance; slide valve positioned 90° to main shaft and operated by two rods; governed by restrictor valve in exhaust pipe. Awarded a Gold Medal.
3 Aug 1867	Second English patent/2245 to C.D. Abel. Improvements to clutch and slide valve porting and method of operation. Water Jacket now cast integral with cylinder and extended to beneath the base of the cylinder.
3 Dec 1868	Agreement between Louis Simon and Son, Nottingham and N.A. Otto and Co.
March 1869	N.A. Otto and Co. became Langen, Otto and Roosen
20 Aug 1869	Agreement between Crossley Bros. and Langen, Otto and Roosen
25 Oct 1869	Revised agreement between Louis Simon and Son

and Langen, Otto and Roosen incorporating engines made by Crossley Bros.

12 June 1870	Formal contract between Langen, Otto and Roosen and Crossley Bros. establishing Crossley as sole manufacturing and sales agents
15 June 1870	Reciprocal contract to that of 12 June
24 May 1870	Termination of arrangements with Langen, Otto and Roosen and Louis Simon & Son.
January 1872	Formation of Gasmotoran-Fabrik, Deutz A.G. Otto made technical director, Langen becomes general manager
July 1872	Wilhelm Maybach appointed design engineer
August 1872	Gottlieb Daimler becomes production manager at Deutz. Maybach assigned the task of redesigning the atmospheric engine to reduce manufacturing costs and simplify its operation.
February 1874	Third English patent/414 (provisional only and not proceeded with. Daimler's name appears on the patent
18 Feb 1874	Fourth English patent/605 to C.D. Abel. A communication from Daimler to Gasmotoren-Fabrik, incorporating the improvements by Maybach, features include: elimination of bottle-neck shape, cooling water extended over entire length of cylinder, capacity now such that circulation unnecessary, governor acts to prevent raising of piston instead of valve in exhaust, a single shaft used on which the clutch and slide valve eccentric are mounted, slide cover held on by bolt acting on blade spring, dovetailed guide for piston rack, inlet and exhaust passages simplified. Dispute between Daimler and Langen delays production of the improved engine until November 1875.
18 Sept 1874	First Crossley patent on atmospheric engine No. 3205 to F.W. Crossley. Included many features of Daimler's patent, with the following additions: (i) use of countershaft parallel to main drive shaft on which is placed a crank to raise the piston (ii) governor acts to cause retardation of arrest of piston rack (iii) two flywheels are used
27 July 1875	Mr. F.W. Crossley read a paper before members of the Institution of Mechanical Engineers at the Manchester Town Hall 'On Otto and Langen's Atmospheric Gas Engine and some other Gas Engines'. The engine described was the pre-1874 version.

15 Sept 1875	Second Crossley patent/3221 to F.W. & J.W. Crossley. A combination of the German single-shaft arrangement and Crossley governor design, mounted on extreme end of drive shaft and works by preventing piston being raised and slide valve being moved when speed becomes excessive, piston is raised by a 'roller and stop' arrangement, single flywheel, air spring or buffer for checking ascent of piston.
31 Dec 1875	'Engineering' page 514 decribes the atmospheric engine then being made by Crossleys, the design is that of the 1874 engine, ie two flywheels and a second shaft, but the governor action is that of the 1875 patent.
12 Jan 1876	Third and final Crossley patent/132 to F.W. Crossley. Engine design identical to that described in 'Engineering' 1875 but equipped with starting handle. Used in the 3hp engines and fitted as an extra if required.

5.7.1 Production figures

(i) By the German firm[34]

1867	7	1872/73**	245
1868	46	1873/74	348
1869	87	1874/75	589
1870	118	1875/76	635
1871	197	1876/77***	222
1872*	141	1877/78	4

*From January to July

** Beginning of GFD

*** 4-stroke engine

(ii) Crossley Brothers, Manchester[35]

The figures are given in the Prospectus as follows:

Up to June 1876: 12 quarter horse-power; 314 half horse-power; 421 one horse-power; 343 two horse-power; 40 three horse-power. Manufacturers in France, Belgium and Italy made between them about 170 engines to June 1876

Prices

Quarter horse-power	£58
Half horse-power	£75
One horse-power	£98
Two horse-power	£135
Three horse-power	£170

One horse-power being considered the equivalent of four strong men

5.7.2 Comparative running costs of gas and steam engines, 1872

A written guarantee was supplied with each engine to the effect that it would not cost more than 1 pennyworth of gas per horse-power per hour.

Figures supplied by a printing firm in Birmingham give a comparison between two small steam engines, each of one horse-power, that were replaced in 1872 by a two horse-power atmospheric gas engine, which did identical work[36].

Cost for year 1872

Steam engines

	£	s	d
Coal	76	0	2
Water	4	8	7
Oil	1	5	0
Wages	26	0	0
Repairs	2	0	0
	£109	13s	9d

Gas engines

	£	s	d
Gas	14	9	5
Water	2	2	0
Oil	2	10	0
Wages	5	6	0
Repairs	12	0	0
	£36	7s	5d

The large repair bill on the gas engine was due to the need to fit a new clutch which, at first, was not strong enough. A further instance was quoted in which a gas engine of the horizontal type - possibly Lenoir or Hugon - was using gas to the cost of £3 per week. This was cut down to 7s.10d. by installing an Otto-Langen engine.

5.7.3 Dimensions and weights[37]

Horse-power	¼	½	1	2	3
Diameter of fly-wheel (inc)	34	48	48	60	60
Diameter of base	22	25	30	36	36
Diameter of driving pulley	10	12	12	27	27
Revolutions per minute	100	95	95	95	95
Number of piston strokes	40	36	32	30	30
Approx. gross weight (cwt) (water + fly-wheel + pulley)	9	21	32	44	50

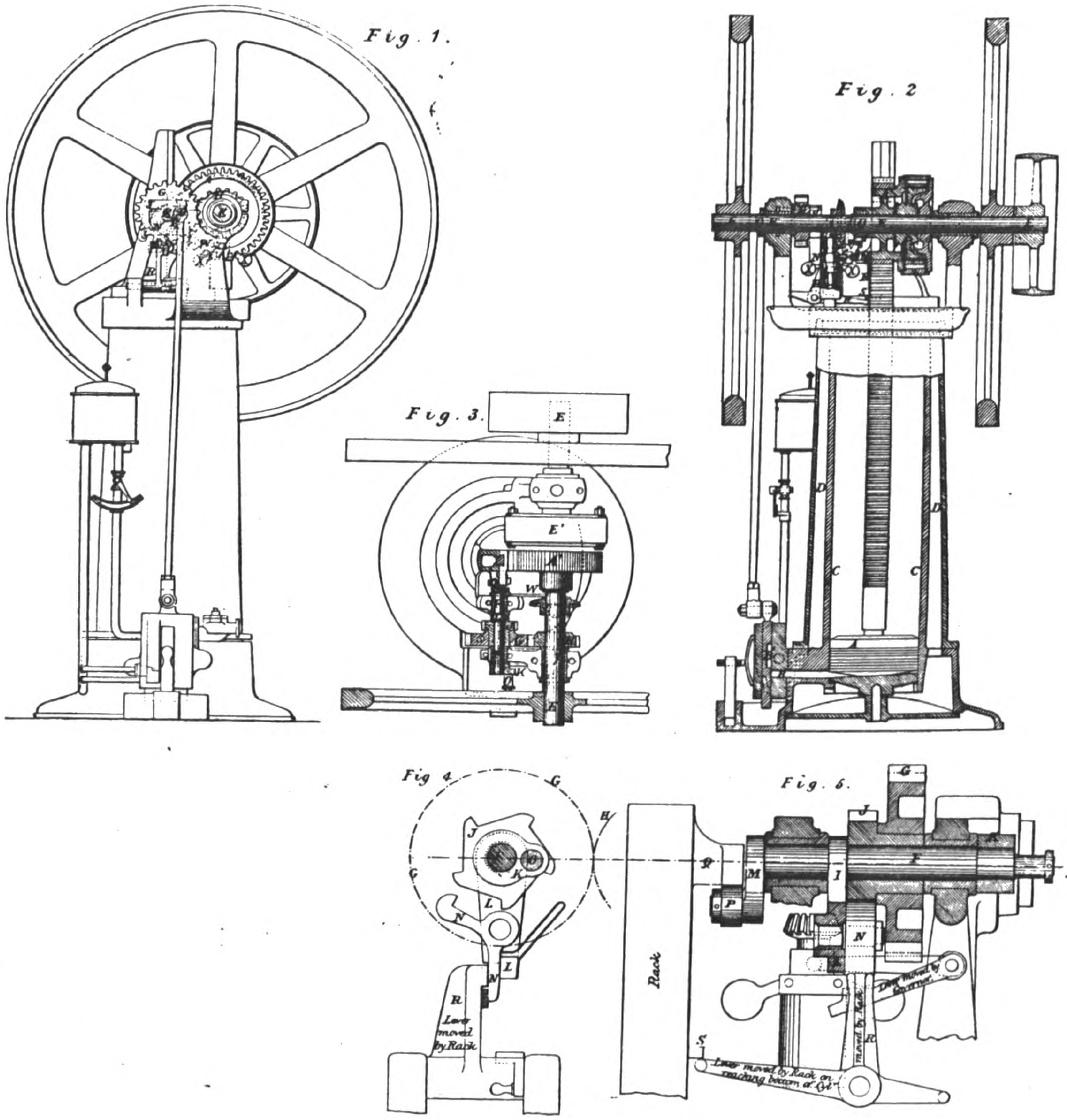


Fig. 5.19
Final design of Crossley Atmospheric engine.
A working version of this engine is exhibited
in the North Western Museum of Science and
Industry, Manchester.

ATMOSPHERIC GAS ENGINE. *Plate 27.*

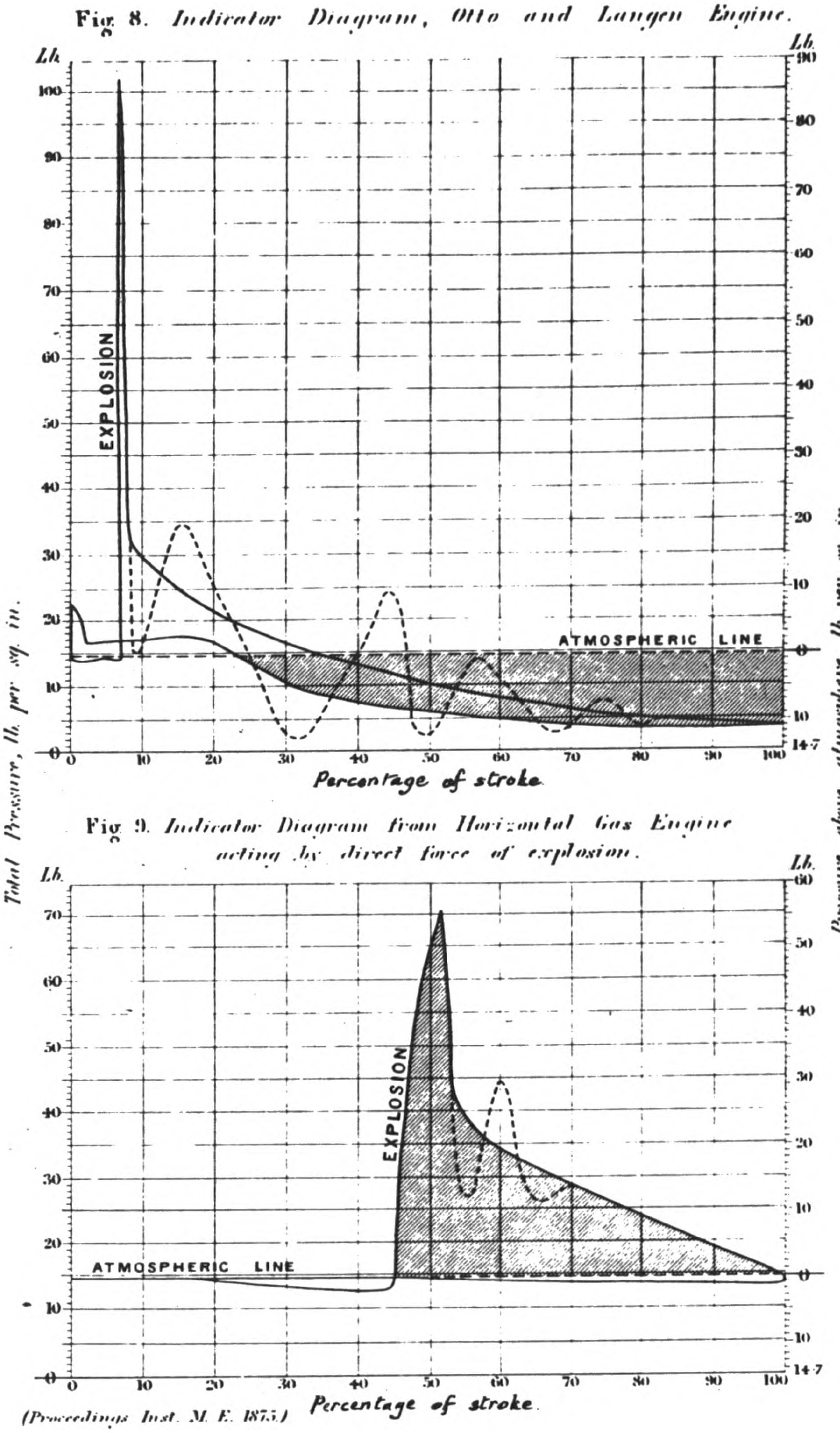


Fig. 5.20
Comparative indicator diagrams of Otto-Langen engine (above) and the Lenoir engine.

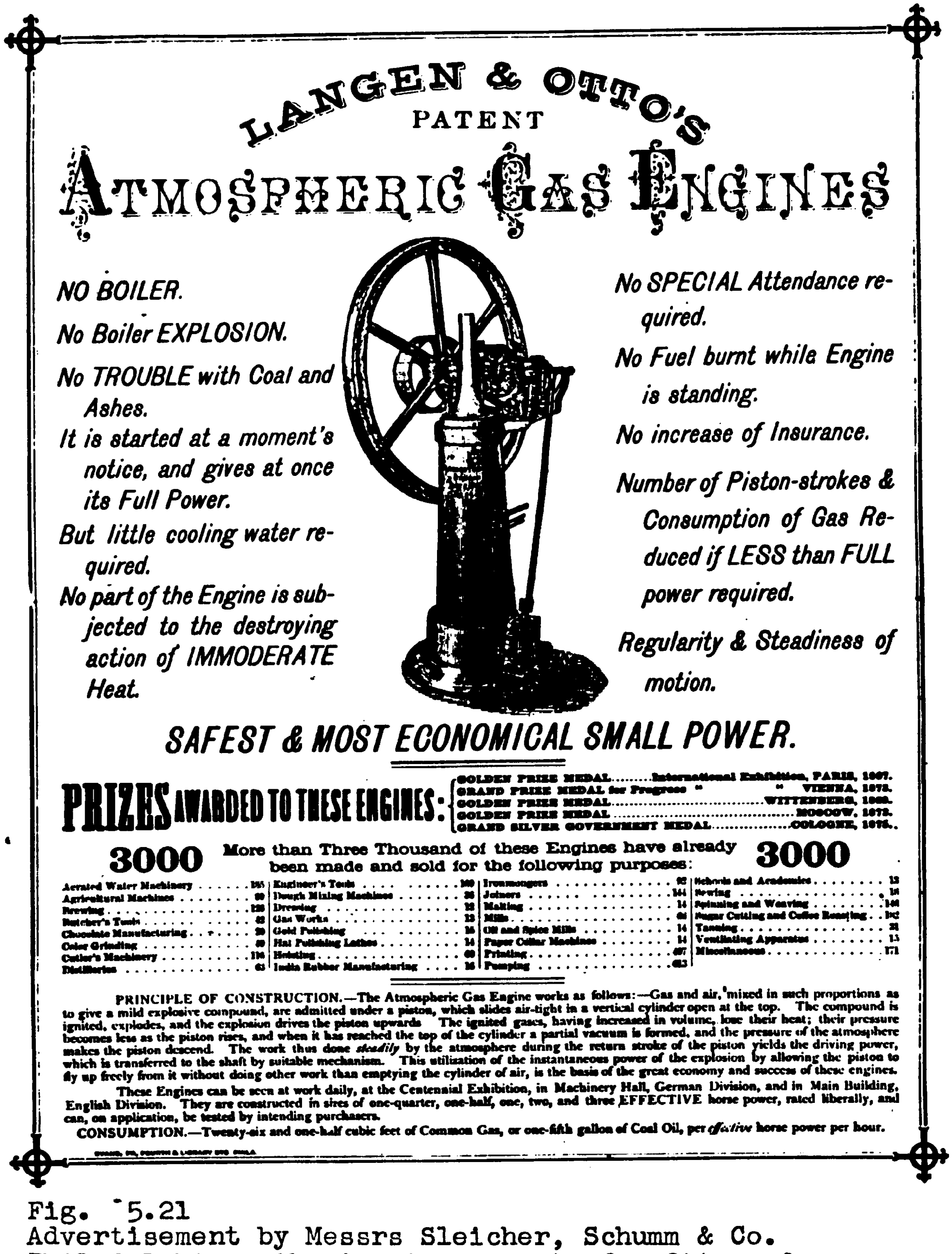
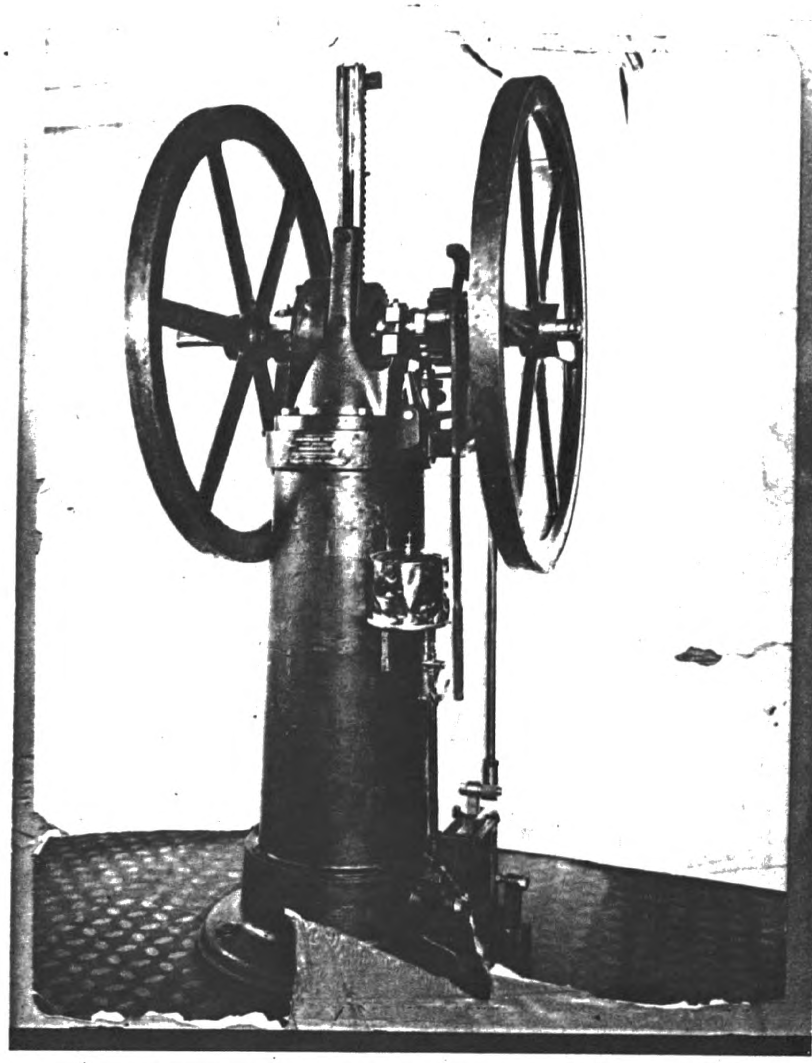


Fig. 5.21
Advertisement by Messrs Sleicher, Schumm & Co. Philadelphia, the American agents for Otto and Langen engines. Note the applications of the engine



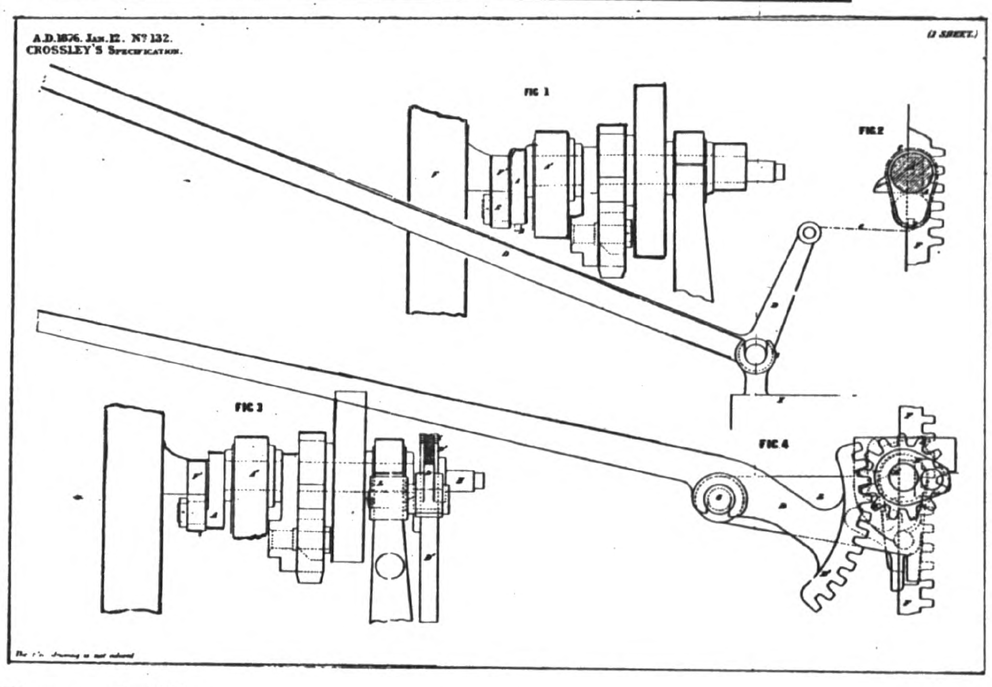


Fig. 5.22
Final Crossley patent No. 132/1876 for the Atmospheric engine, showing a starting handle

An estimated thirteen hundred of these noble engines were built by Crossleys * and a handful have survived in Great Britain. The oldest and the first atmospheric engine ever made by Crossley Bros. is exhibited in the Science Museum, South Kensington, London and is of the 'bottleneck' shape shown in Figure 5.

The second oldest, No. 379 also a half horse-power model, is now in the Department of Mechanical Engineering of the University of Nottingham **. Another half horse-power engine, No. 487 which is in remarkably good condition, is exhibited in the Royal Scottish Museum, Edinburgh. A one horse-power engine, No. 1224, is shown in the North Western Museum of Science and Industry, Manchester and represents one of the last type ever made. The engine in Nottingham and that shown in Manchester are in running order, the latter being demonstrated daily to the public. The first engine made by Otto and Langen and awarded the Gold Medal at the Paris Exhibition of 1867 is now displayed in the Klöckner-Humboldt-Deutz Werkmuseum, Cologne and is also demonstrated daily to the public. It produces ½ hp at 80 rev/min.

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*The first four-stroke engine to be built by Crossleys was No. 1300

**For the privilege of being able to examine this engine thanks are expressed to Professor A.G. Smith of the University of Nottingham

5.8 Other engines 1870-76

For ten years following its introduction, the Otto-Langen atmospheric engine had virtual monopoly of the market for engines up to three horse-power; for any other to break into this strongly-held field and establish itself would have been exceedingly difficult, but three engines, each with a different working principle, did precisely this. One was an atmospheric engine by Frederick Gilles of Cologne; the second was the Brayton engine from Philadelphia and the third, the Bisschop, (or Bisschoff) engine, a small engine made in sizes up to four man-power.

5.8.1 The Gilles engine of Cologne

Frederick Wilhelm Gilles was a former employee of the Gasmotoren- Fabrik-Deutz who, in 1874, left to set up his own business making engines only a short distance away from GFD. The Gilles engine[38] was an atmospheric engine employing two pistons. No attempt was made to increase power output over that of the Otto-Langen, but the purpose of the two pistons - one of which was free and the other connected to a crank - was a direct attempt to reduce recoil shock and noise. The working piston is labelled A, Figure 5.23 and the lighter, free piston, B, both being contained in the same cylinder. When both pistons were in their lowest position, ignition by gas flame occurred, the free piston being rapidly forced up and held in that position by a latching mechanism worked by an eccentric positioned on the crankshaft. Atmospheric pressure would then force up the working piston, turning the crank to perform the working stroke.

The Gilles engine was built by the Maschinenbau Humboldt AG, with a few being built by Simons of Nottingham, during 1877 (see Figure 5.24). It was a commendable design and worked well, being exhibited in Paris in 1878, but the timing of its release onto the market was unfortunate. Otto's 'New Motor' of 1876 proved a much too formidable competition and Gilles was forced to retire from the scene. A Gilles engine is exhibited in the KHD Werkmuseum, Deutz.

5.8.2 The Brayton 'Ready Motor'

Probably the most serious contender to Otto's supremacy during the first half of the 1870's was an engine by George Bailey Brayton (1839-92) of America. It possessed several outstanding features, such as a higher power output than the Otto-Langen, the use of compression and operated on a constant pressure cycle making it totally free from recoil shock. These were potentially important advantages compared to the Otto-Langen and a successful utilisation of them, almost certainly would have had a severe detrimental effect upon the latter's sales. As events turned out, Brayton, like many other inventors at the time, experienced ignition difficulties which, ultimately, forced him to abandon his gas engine. He converted it to a liquid fuel engine, however, and became notably more successful.

Brayton's work with internal combustion engines began c.1857 while still in his youth. He experimented with a turpentine and alcohol mixture as a fuel and eventually produced the 'Brayton Ready Motor' Figure 5.25, which worked by compres-

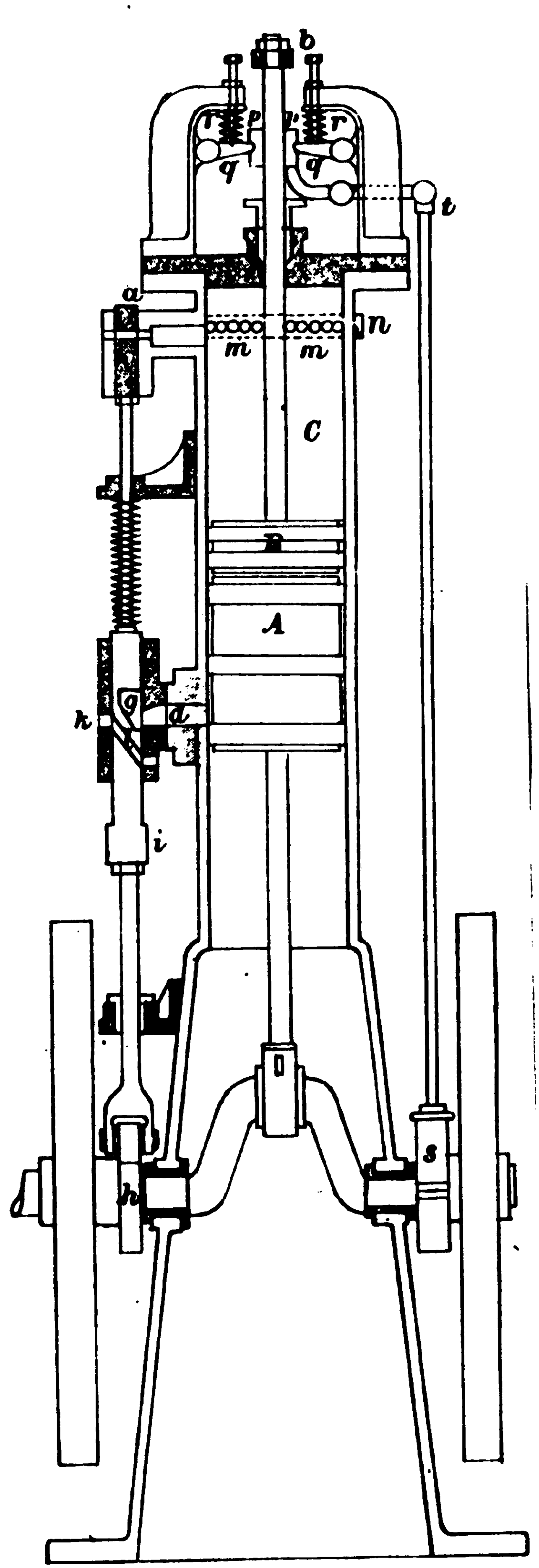


Fig 5.23 The Gilles engine of Cologne
Made by L. Simon and Son, Nottingham in 1876/77

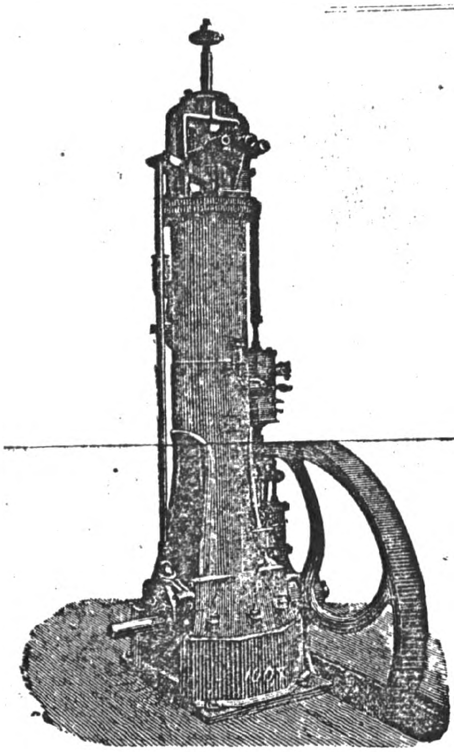
JANUARY, 1877.

THE

Improved Atmospheric Gas Engine.

GILLES' PATENT.

THIS Motor was introduced only six months ago, and the facts that already one hundred are at work in Germany, giving complete satisfaction, and that the present demand has exceeded the most sanguine expectations, are the best evidence of the established superiority of GILLES' PATENT ENGINES over all other similar ones.



Some of the advantages of these Engines, as compared with Steam or other Gas Engines, are:—

They require no boiler, no fire, no electricity, no water; there are no coals to get in, and no ashes to remove.

No Water is required to keep the Cylinder cool; and, as no unpleasant heat is evolved, the engines can be put up in any workshop.

They require little floor space; and, as the driving pulley is at the bottom, no foundations are needed.

They work almost Noiselessly, and require no skilled attendant.

They can be started at full power or stopped in a moment, by simply lighting or turning off a gas jet.

There is no danger of any kind in their use, explosions being impossible; and the rate of insurance is not increased where they are put up.

Taking the price of gas at 4s. per 1,000 cubic feet, the cost of working the engines does not exceed One Penny per horse power per hour. Less gas is used when the engines are not working full power.

The piston being directly connected with the driving crank, the motion of these engines is continuous and regular.

The working parts are simple, and not liable to get out of order. There is very little wear and tear, and the best materials and workmanship are used in their construction.

Prices of Engines, delivered at Nottingham:

$\frac{1}{3}$ H.-P.	$\frac{2}{3}$ H.-P.	1 H.-P.	$1\frac{1}{2}$ H.-P.	2 H.-P.	4 H.-P.
£65.	£85 10s.	£110.	£127.	£146 10s.	£300.

FURTHER PARTICULARS AND TESTIMONIALS ON APPLICATION.

Terms Cash. Packing Cases to be paid for or returned. Printed Instructions for working accompany each Engine. If required a competent Engineer will be sent at 12s. per day, Railway Fare extra.

ONE OF THESE ENGINES MAY BE SEEN IN OPERATION AT THE "PRINTERS' REGISTER" OFFICE, ST. BRIDE STREET, LONDON. E.C.

Sole Licensees and Manufacturers for Great Britain and Colonies, LOUIS SIMON & SON, Nottingham.

LONDON:

JOSEPH M. POWELL,

Manufacturers of Printing Machines and Printing Materials,

ST. BRIDE STREET, LUDGATE CIRCUS, E.C.

Fig 5.24 The Gilles engine as advertised in Gt. Britain 1877.

sing air and gas into a separate cylinder and then passing the mixed charge into the working cylinder, igniting it as it entered[39]. For ignition, Brayton designed a special grating valve, which worked on the principle of Davy's Safety Lamp, ie. continuous combustion being maintained at constant pressure on the engine cylinder side of the valve, but was unable to pass back through the grating against the direction of mixture flow. The grating valve is shown in Figure 5.26. The engine was able to give one firing stroke per revolution of crankshaft; early engines were single-acting, but later ones beginning about 1876, were double-acting.

Attempts to use gas as a fuel instead of a liquid were not wholly successful. After a time in service, the grating valve would cease to be effective and a blow-back of the ingoing and more ignitable gaseous mixture would take place, severely contaminating the contents of the reservoir. An explosion would occur which, although not dangerous, would stop the engine and the reservoir would have to be purged of the now burnt gases. The inconvenience of this almost certainly caused Brayton to concentrate his efforts using liquid fuels - a light oil, probably a form of kerosene. From its introduction 1875, the liquid fuel version survived with various modifications for fifteen years. With the use of liquid fuels, the blow-back problem was eliminated by forcing the fuel through a ring of felt placed in an annular groove, using air pressure.

A feature of the Brayton petroleum engine was its smoothness and steady running, making it suitable for driving dynamos[40]. Messrs Simons of Nottingham introduced it into England in

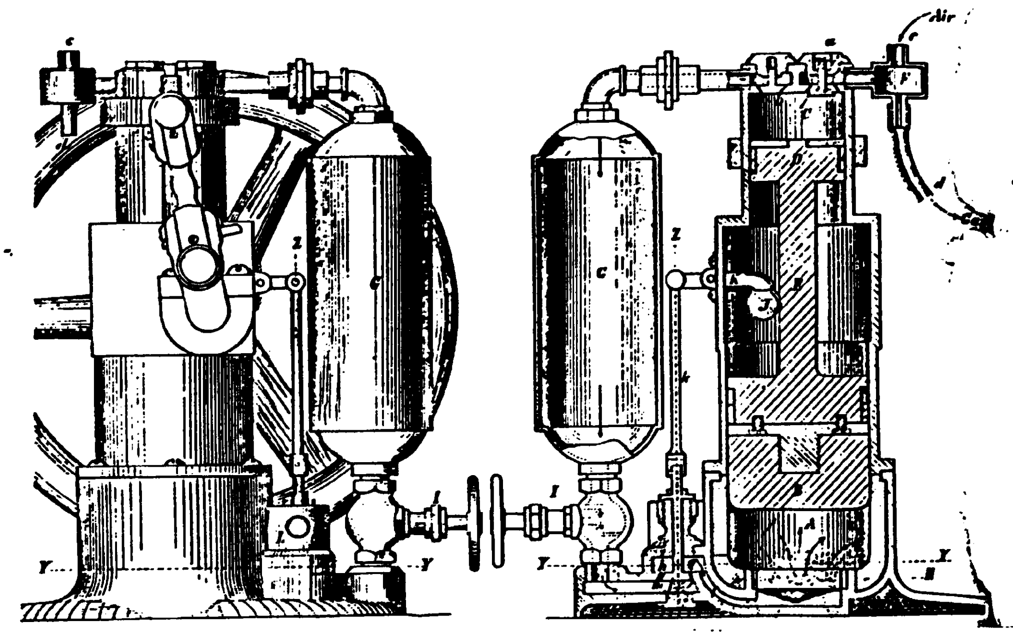


Fig 5.25 The Brayton Gas Engine of 1872
(From the English Patent No. 432)

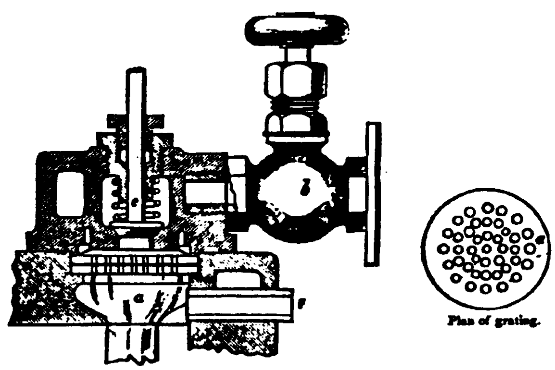


Fig 5.26 Grating valve used on the Brayton engine to prevent "blow-back" into the gas reservoir

1878 and added a modification of doubtful utility - the addition of steam into the working cylinder. Many official tests were conducted upon it[41], which show a rather heavy fuel consumption and a large amount of negative work expended on pumping the mixture into the working cylinder. In addition to his inventive talent, Brayton possessed an enterprising nature. A number of companies were formed to manufacture and sell his engines and a constant stream of ideas came forth. He built a number of marine engines in the late 1870's, a double-acting ten horse-power engine early in 1877 and from then until well into the 1890's made many modifications to cater for particular requirements. The last liquid fuel engine made was based on a patent of 1890[42] and was reported on in 'Engineering' of 1892[43]. Ever-mindful of developments, Brayton attempted to use an incandescent method of ignition, which by then had become well-established. Instead of simply heating a tube, however, Brayton placed coils of platinum wire in the end and raised it to incandescence by a separate blow torch. Upon starting, the heat of combustion was sufficient to keep the platinum at a temperature sufficient to ignite the vapour and air mixture.

The extent of Brayton's work covered forty years, from before Lenoir to Diesel. Sometime, c.1890, he came to England to work in Leeds on a new idea for an oil engine and is reported to have died, aged fifty-three, while actually working on it.

5.8.3 The Bisschop engine

Proof that a need existed for a small motive power unit, even when the Otto-Langen was in demand, is seen by the popularity and numbers of Bisschop engines that were sold in the United Kingdom alone. Made in sizes of one to four man-power, an estimated one thousand were in use in 1880 and nearly two thousand by 1885[44]. This little engine held its own for nearly thirty years, driving such things as small printing machines, chaff-cutters, sausage-making machines, boot and shoe machines, lathes, organ-blowers and coffee-grinding machines. (See Figure 7.12 of Chapter Seven).

It was originated by a Frenchman, Alexis de Bisschop in 1872 and was essentially a non-compression engine, which utilised directly the explosive force exerted on the piston. Figure 5.27 shows two sectional elevations (a) and (c) at right-angles to each other and (b) is the flame-ignition system that was used.

The simplicity of construction and operation was the chief appeal of the Bisschop engine; it required no cooling water, used no piston rings, no lubrication was needed on the cylinder (the gas used at the time, it was claimed, contained lubricant properties - this was probably the tar element) and occupied very little floor space. From Figure 5.27 (c) A is the working cylinder, B the piston with a long connecting rod (the piston being a loose fit in the cylinder to accommodate expansion) and C is a cross-head arrangement to which the connecting rod (small c) is attached. Diagram (a) shows the crank arrangement. One end of a long lever, E, is connected to the cross-head and the other to the crank, F.

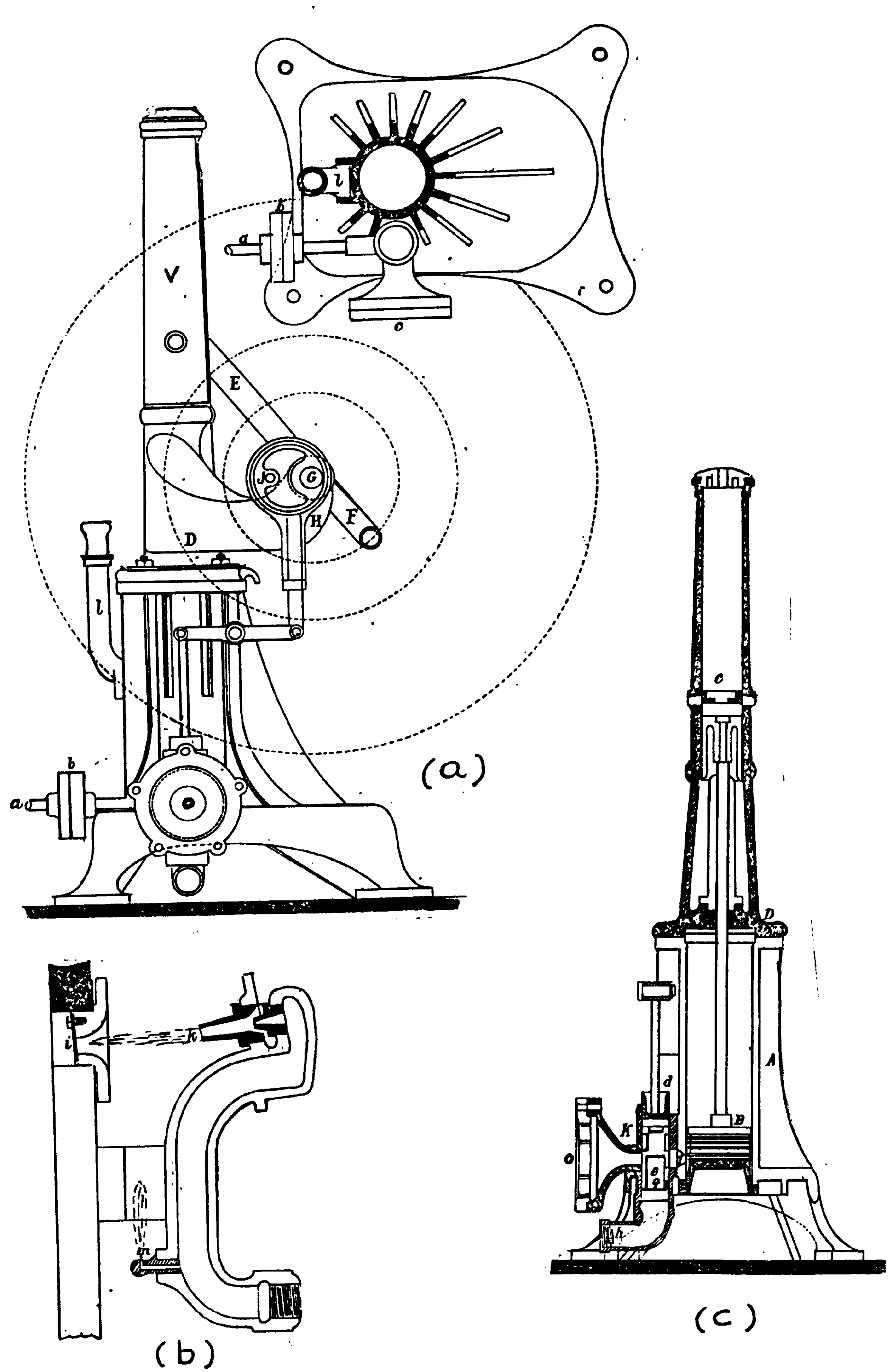


Fig 5.27 Sectioned views of the Bisschop engine manufactured by Messrs Andrews of Stockport from 1878.
Lower left (c) is the flame ignition system used in the Bisschop

To allow for the vertical movement of the piston and connecting rod, the vertical column, V, is slotted. The flywheel was mounted on the shaft, G, which was a forging of the crank, F. The shaft, G, was held in a casting, H, together with an eccentric, J, which controlled the admission of gas and air.

When working, the momentum of the flywheel raises the piston drawing in a mixture of gas and air. After about a third of the stroke, ignition occurs through the small hole, i. (b) in the cylinder wall. A long flame issuing from k, the igniting flame, would be extinguished at ignition, a secondary flame was thus provided at m, which re-lit the igniting flame. As the piston ascended on its working stroke, a new charge was admitted at the base after the exhaust products of the previous stroke had been expelled. Since no cooling water was employed, the heat that was generated was dissipated by large ribs placed round the periphery of the cylinder.

The first English patent granted to Bisschop was in 1872[45], but the manufacture of the engine in Great Britain did not begin until 1878 by J.E.H. Andrews of Reddish, near Stockport, who became impressed by its performance at the Paris Exhibition of that year[46]. (A fuller description of how Andrews and Co. Ltd. came to be involved is given in Chapter Seven, section 7.5.2). Andrews made many notable improvements of their own and the Bisschop as made by them, became immensely popular among the small traders. The reason for its popularity was undoubtedly its simplicity in construction and ease of operation, being easily operated 'by any boy or girl'

Fig 5.28 Advertisement for the Bisschop engine (from Kelly's Trade Directory of Manchester, 1881)

(Figure 5.29). Fuel consumption was acknowledged to be high, but for the small power motors that were made - up to two man-power - this was quite happily tolerated.

The Bisschop was manufactured in Germany by Messrs Buss, Sombart and Co. of Magdeburg and Berlin, who instigated many improvements of their own. It is interesting to note that in the very early years of its life (1872-1878) the patent claims by Sombart and by Bisschop refer to 'an arrangement of gases within the cylinder'. This involved a locally separated introduction of the air and gas as it entered the cylinder and the provision - so claimed - of a particularly rich gas near the ignition source. It may be remembered that this idea was first suggested by Lenoir (who later abandoned it), but Bisschop was as equally adamant as Otto was later, that such an arrangement of gases within the cylinder was responsible for the silent operation of the engine. Indeed, Bisschop may well be said to have pre-empted Otto's thoughts on the matter when, in his patent[47] of 1875, Bisschop states:

> '....... the explosive gases always arranging themselves according to their specific weight .... it may be noted that the noise of the explosion is very much lessened by this arrangement."

After stating the working of the engine, it is clearly expressed that 'an elastic cushion is formed' to take up the recoil and diminish the noise'.

References - Chapter Five

1. Gustav Goldbeck. Gebandigte Kraft (Munich 1965) p.23
2. Ibid pp.23-26
3. Arold Langen Nicholaus August Otto, der Schopfer des Verbrennungsmotors (Atuttgart 1949) p.27
4. Goldbeck op cit (1) pp.27-28 This aspect of Otto's work is highly controversial. It features later in patent trials related to the four-stroke cycle.
5. Gustav Schmidt. 'Theorie det Lenoir'schen Gasmachine' Dinglers Polytechnisches Journal CLX (1861) pp.321-37
6. English Patent 2098/1863 to R.A. Brooman, Patent Agent French Patent 59991/1863
7. Goldbeck op cit (1) p.40
8. English Patent 431/1866 of Feb. 12 to C.D. Abel. A Prussian Patent was also obtained
9. Goldbeck op cit (1) p.46
10. Friederich Sass. Die Geschicte des deutschen Verbrennungsmotorenbaus von 1860 bis 1918 (Berlin 1962) p.26
11. English Patent 2245/1867 of Aug. 3 to C.D. Abel
12. KHD Archives, Cologne. 'Test on Otto-Langen Engine' The dates of the tests were: May 10, 15, 16, 17, 18, 23, 25, 1867
13. Friederich Schildberger. Gottlieb Daimler, Wilhelm Maybach and Karl Benz (Daimler-Benz Aktienesellschaft, Stuttgart 1970) p.11. The author also acknowledges the help given by staff of the Daimler-Benz Museum, during his visit in July 1977.
14. Ibid p.21
15. English Patent 605/1874 of Feb. 18 A provisional patent issued sixteen days earlier appears to have been ignored
16. Eugen Diesel From Engines to Autos (Chicago 1960) p.54 Diesel states that the dispute was not settled until late 1875 with production of the newly-designed

engine being held up until then

17. Ibid p.54

18. English Patent 71/1875 American Patent 168623/1875

19. The author acknowledges the assistance given by Herr Hans Jürgen Reuss, Head of Archives, KHD, Werkmuseum, Cologne.

20. K.A. Barlow. 'The Internal Combustion Engine - Its Introduction into England' Diesel Engineering (1978)

21. At that time, Manchester, in common with many other industrialised cities in Britain, possessed a strong contingent of German engineers and business men. Roosen was one of the latter and Cornelsen was the engineer, but almost nothing is known about him.

22. 'Record of International Exhibition, 1862' pp.238-42

23. 'Kelly's Trade Directory' for Manchester of that year shows a James Butterworth, Engineer of 13 Albert Street, Lower King Street, (now King Street West)

24. Ibid William Routledge of Routledge and Ommanney, New Bridge Foundry, 12 Adelphi Street, Salford (at the same address was a James Farmer. The firm of Farmer Norton is now in Adelphi Street)

25. A prospectus for the Otto-Langen engine issued by Simon includes the name of 'N. Cornelsen & Co.' Book VI 2B KHD Archives

26. Information given to the author in a conversation by Mr. Jack Simon, a great-grandson of Louis Simon, the founder of the firm which is still in existence

27. English Patent 1193/1867 for the machining of rubbers; 1553/1868 for 'Breaking and Scutching' apparatus

28. Crossley Premier Engines Ltd., Manchester 'Crossley Brothers Ltd., Pioneers, Progress, Leadership' Pub. No. 2295a/062

29. KHD Archives, Cologne The letter from F.W. Crossley to Simons is dated 27 October 1869

30. English patent 3205/1974 of 19 September

31. Engineering Vol. 20 (1875) p.514

32. English Patent 3221/1875 Sept. 15 to F.W. & W.J. Crossley

33. English Patent 132/1876 to F.W. Crossley

34. Sass op cit (10) p.54

35. Crossley Premier Engines Ltd. 'Prospectus of Atmospheric Gas Engines' (June 1876) p.5

36. F.W. Crossley 'On Otto and Langen's atmospheric Gas Engine and some other Gas Engines' Proc. Inst. Mech. Eng. (July 1875) p.213

37. Prospectus op cit (35) p.9

38. English Patent 1520/1876 registered under the name of Wirth of Humboldt Manufacturing Co. An American Patent 1797B2/1876 was also taken

39. William Siemens in England had already suggested a similar idea in 1862 (patented 2143/1862). Brayton, however, produced a working form of it

40. Dugald Clerk. The Gas and Oil Engine (London 1902) p.163 A Professor, Draper, is stated to have found the engine invaluable in his investigation into the existence of non-metallic bodies in the sun's atmosphere

41. Clerk op cit (40) pp.157-164

42. English Patent 11062/1890 which was the basic design Patents of improvements were 6138/1894; 6523/1895 and 12287/1895

43. Engineering Vol. 54 2 (1892) p.88

44. Commerce (Dec. 28 1898) p.1247 The article gives an informative account of the firm, Andrews, who made the Bisschop engine

45. English Patent 1594/1872 of 25 May Granted to William Edward Newton - Patent Agent

46. Commerce op cit (44)

47. English Patent 4342/1875

CHAPTER SIX

THE FOUR-STROKE ENGINE

6.1 The moving force

The need for an alternative form of engine to that of the atmospheric became very strong, and was felt at Deutz long before one became a reality in 1876. Evidence of this is given by the attempts, discussed in the previous chapter, which were made to increase the versatility of the Otto-Langen engine, reduce its mechanical complexity and raise the power ceiling of three horse-power. None of these, however, were successfully overcome and it was inevitable that sooner or later something better would have to be found. The impetus to get things moving came from Langen's friend and adviser, Franz Reuleaux who wrote to Langen on the 12 July 1875.

In this letter, Reuleaux revealed to Langen the work of one of his former pupils, a Finnish engineer named Stenberg, who had developed a ten horse-power hot air engine; Reuleaux was sufficiently impressed to ask Stenberg to meet Langen with a view to producing it, but Stenberg never got the opportunity. The Sachsenberg brothers of Rosslau heard of it and signed a contract with Stenberg for fifteen years[1]. Reuleaux then immediately alerted Langen, urging him 'to act quickly and secretly' ..... 'the troubles with Daimler must be forgotten' ..... 'you must develop the high pressure machine'. Four days later there came a further warning from Reuleaux, this time pointing out the Lehmann hot air machine at Leipsig. There is no doubt that by this time Reuleaux was concerned for his friends in Cologne and also sorry, since unwittingly it was he who had assisted Stenberg to obtain a patent. Otto's first reaction to this was to revive his own hot air engine experiments of 1871, but he was sharply rebuked by Reuleaux who insisted that any new idea must be for a gas engine. The race was well and truly on, with but a few months in which to achieve results. Otto was virtually on his own; relationships with Daimler - who in any event was engrossed in the problems of his three piston atmospheric engine - had become so strained that he and Otto were no longer on speaking terms.

The development of the four-stroke engine - Otto's eventual answer to the problem - can be divided into two periods. One immediately prior to 1876[2], which covers its formative years, and the second after 1876, when attempts were made to explain the theory of its action. This latter point was the cause of immense controversy, and gigantic legal battles concerned with the understanding of the four-stroke engine took place in patent litigation trials.

In covering the first period, the experimental work which enabled Otto to produce a working engine is related, together with the theories as to its working, which he held at the time it was patented. To assist in this particular evaluation, the author has been privileged in being allowed to make a detailed study of Otto's original experimental engine[3] and the results of these findings will be given.

The second point, related to the theories which Otto propagated in an attempt to explain the action of the four-stroke engine are discussed in section 6.1.2. Otto believed that the success of his engine was due to a particular arrangement of the air, gas and exhaust residuals in the working cylinder.

Such ideas held for many years before eventually being proved false, but by that time, they had greatly influenced developments with internal combustion engines. The chapter concludes with a critical apprisal of the claims of others to have originated the four-stroke engine.

6.1.1 Otto's early experiments and ideas related to the four-stroke engine

In November 1875, four months after Reuleaux's warning letter, Langen assigned to Otto an engineer, Franz Rings. By May, 1876, following the combined efforts of Otto and Rings, the first four-stroke engine was running and indicator diagrams had been obtained. This remarkable achievement is one that has been totally ignored by historians of technology. The opportunity to discuss this aspect of Otto's work will now be taken and related to the author's findings resulting from his own examination of the prototype engine.

In attempting to establish how Otto was able to produce his four-stroke engine so quickly, three possibilities exist. One, that prior to Reuleaux's letter some experimental work had been done by Otto and which now became highly relevant; two, that Otto had some conception of what he must do and having thus thought it out needed only to overcome the practical problems. The third, really the means which permitted the realisation of the first two, is that he was able to utilise components of other engines and previous experiments, thus minimising the time required for preparing drawings, producing castings and machining.

With regard to the first of these possibilities, Otto was by no means noted as a careful recorder of his experimental work, a feature of his character he was later to regret. Consequently, details regarding his work associated with the four-stroke engine prior to 1876 are sparse. About the most helpful indication of his early work is given in a deposition made by Otto before an official examiner in May 1885, which was admitted as evidence for the patent trial of Otto v Steel held in that year[4]. In this sworn statement he recalls his work in 1861 with a model of a Lenoir engine and how he encountered the familiar 'explosion shock' problem which occurred in engines of that type. Otto believed that this shock was the result of using incorrect mixture properties and carried out experiments using various quantities of gas and air. He was unsuccessful in trying to obtain a smooth-running engine and during 1862 or 1863 (he wasn't quite certain) Otto claims that he carried out some experiments in which he used compression*. These also were unsuccessful (although he commented on the extraordinary power that resulted when compression was used) and from this point appears to have given up these attempts, turning his attention to the atmospheric principle of working. In giving this brief resumé of his experimental work, Otto is quite adament that prior to 1876, he had not tried admitting air first and then gas and air afterwards. This was an extremely important and highly significant feature of his four-stroke patent, since it had a great bearing on his attempts to establish his

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*In patent trials held in Germany, Otto claims that about 1863 he and a mechanic, Michael Zons, built a four-stroke engine. The validity of his claim is discussed later in this Chapter.

priority as the inventor of the four-stroke engine.

Otto further claimed, that during 1876 he made an engine which operated according to the Lenoir method of working, but with his own special arrangement of air and gas admission. This worked quite well, he said, and so also did another experiment which admitted air at atmospheric pressure, but with the gas at an increased pressure, created by external pumps. Neither of these, however, worked as well as his present machine (the four-stroke engine which used compression) and he never sold any that worked on the principle he had just described. This much is about all that is known of Otto's early work and up to the time of Reuleaux's letter, would appear to have been of little direct help to him in his work on the four-stroke engine. On the credit side, he had accumulated fourteen years' experience in engine design, of fuel and air control methods and of mechanisms, all of which he would be able to put to good use.

The second point mentioned, regarding a pre-conceived idea, requires a detailed knowledge of Otto's theories related to the admission and combustion of the charge within the cylinder. As well as being complex, these are confusing and a discussion of them will be delayed for the moment. At this stage, it will be sufficient to say that from the available evidence, it seems highly unlikely that Otto began his work on the four-stroke engine with any clear conception in this respect.

The third possibility, that the original or prototype four-stroke engine was built largely from existing parts, is promising. In discussing this, the author will take advantage of the results of his own investigation and detailed examination of Otto's original test engine on which he has been privileged to work.

The drawings of the four-stroke engine displayed in the English patent 2081 are indescribably bad *, but are substantially representative of the experimental engine shown in Figure 6.1 and now exhibited in the Werkmuseum of Klöckner-Humboldt-Deutz AG., Cologne. It has a single cylinder with a bore diameter of 161 mm and stroke of 300 mm, mounted on a cast iron base in which several holes are drilled; many of these holes are large, from 50 mm to 225 mm and their presence is largely unexplained. A lateral shaft driven at half engine speed works a slide valve situated at the end of a very large combustion space of volume 3805 cubic centimetres. The compression ratio is thus 2.6 : 1. The main purpose of investigating this experimental engine was to determine the exact mode of operation of the admission slide valve, in order to ascertain just how closely it agreed with that described in the patent. Such a comparison would provide a valuable assessment to be made of how Otto intended his engine to work. The results of this aspect of the examination will be discussed, but, first, some observations of an intriguing nature will be described, which have a bearing on the origins of the experimental engine, of how Otto carried out his experiments and the techniques he used, which also goes some way to explain how, in a matter of a few months, he was able to produce a successful engine.

Beneath accumulated layers of paint, it was noticed that the

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* See Appendix Four of Volume Two

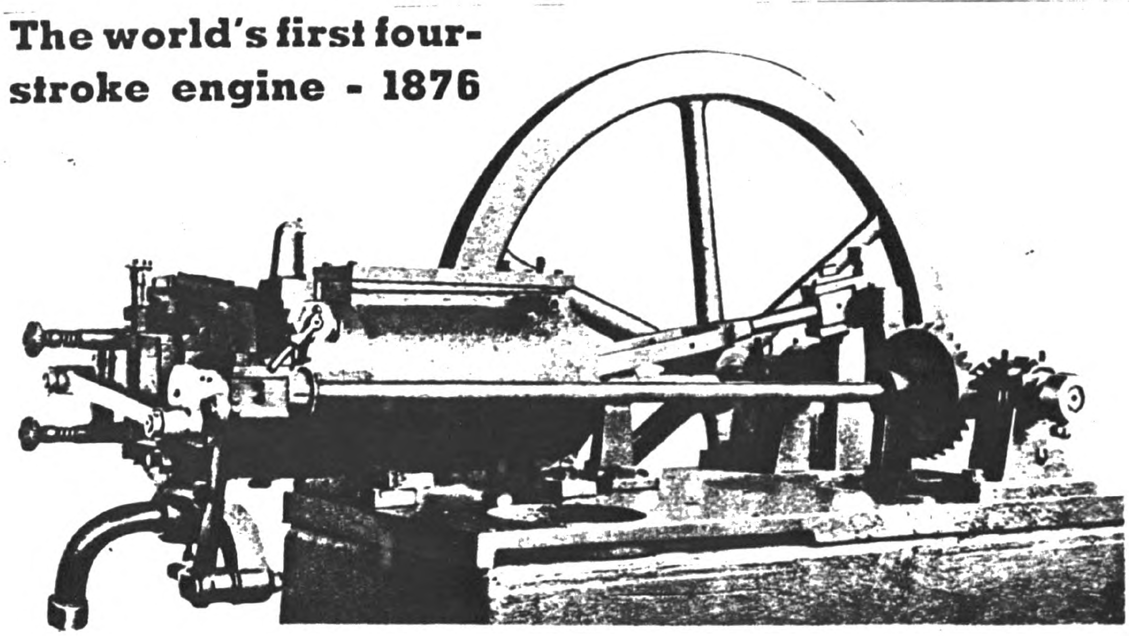

Fig 6.1 Otto's four-stroke experimental engine now exhibited in the Werkmuseum, Klöckner Humboldt Deutz, Cologne. The first trials on this engine were carried out during May, 1876

cylinder portion and the combustion chamber portion were in two separate parts. The quality of the cylinder casting is poor and there is a widely held belief in Germany that it was formerly used as a steam engine. As a result of his investigations related to the engine and to Otto's original notebooks, the author must disagree with this hypothesis; the reasons being as follows:

Although holes are placed in the cylinders (which may be thought to have admitted steam), their position does not coincide with that which would make the engine a double-acting, or even a single-acting, type of steam engine. Secondly, a steam engine cylinder would not require the extensive water jacket, which can be seen on the experimental engine and lastly, there is nothing to indicate how any slide valve admission gear has been attached.

On the other hand, there is quite clear evidence to suggest that the cylinder portion had, at one time, been used for some other purpose. There is, for instance, a large circular hole 21 cm diameter, in the baseplate; a number of bolts at the breech end of the cylinder are not utilised, that is, only four, half of the total number, are used to hold on the breech end, or combustion chamber. There is also a reduction in the width of the baseplate for nearly two-thirds of its length and lastly, the presence of two holes 10 mm diameter, drilled at the uppermost point of the cylinder. One of these is at the centre stroke position and the other is near the bottom, or outer dead centre position.

On the question of the origins of this engine, there is, therefore, a good deal of mystery. No in depth research to discover how Otto managed to bring about his four-stroke engine has been carried out until now and it was with this fact in mind, that pains were taken to establish Otto's thoughts and how he put them into practical form.

Of the various possibilities which exist to show how the four-stroke experimental engine began its days, by far the strongest evidence can be found in the work done by Otto c.1873. This was concerned with hot air engines, but probably because nothing fruitful became of these ideas, little attention has been given to this aspect of Otto's work. In september 1873, Otto sent to Berlin a vertical working model of a hot air engine in support of a patent application. The model was subsequently returned and placed in Otto's museum, but for some reason unknown, it was removed and destroyed during the 1930's. It was referred to as 'A new atmospheric kraftmaschine' and was produced in response to Reuleaux's repeated requests to get something better than the noisy and complicated vertical atmospheric gas engine that was proving popular, but could not be developed further. The new engine possessed acknowledged deficiences, such as high fuel consumption and small power output, but was in fact granted a patent in Berlin in January 1874 for three years. Several other patents from various German states quickly followed. It is from the description of the working and drawings contained in these that it proves possible to link up these ideas related to the hot air engine with the physical evidence as presented by the experimental four-stroke engine.

Although mainly concerned with a vertical application of the new atmospheric motor, the patent description also refers to a horizontal version, the drawings of which are as close as ever it is possible to be to the design of the prototype four-stroke engine. With reference to this horizontal version, Otto suggests that

> '....... it is possible to design the engine without the slide*. In this case, the piston acts via a connecting rod directly onto a crankshaft. But such an engine must operate at a higher speed and the cooling must be effected at the correct time by an earlier inlet ....
>
> 'This system allows the most simple design and may be used for stationary engines as well as locomobiles.'

From a careful study of the description of operation that is given in the patents, it becomes possible to make positive deductions with regard to the intriguing features, visible on the prototype four-stroke engine and referred to earlier. The large hole in the base plate, for instance, would be used to supply the heated air. Quite a large heat source would be required, which would be positioned in the base foundation. (Original photographs show a hollow cast-iron construction on which the engine is supported.) The cut-out portion of the base-plate is of adequate size to accommodate a flywheel and is also correctly situated relative to a vertical cylinder placed on the base plate. The small holes drilled into the highest point of the cylinder can also be explained. In a letter from Franz Reuleaux, dated 10 December 1873, he tells Langen that, following successful tests, the New Atmospheric Kraftmaschine has been recommended for a patent. This is then followed with a suggestion from Reuleaux, that to improve the running, steam should be admitted to the cylinder

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*The vertical design used a slide to control the admission of the heated air 'at the latter end of the stroke'. (The object, presumably, was to assist in the formation of a vacuum during expansion, thus allowing a more effective force to be exerted by the atmosphere.) The presence of the two small holes referred to earlier may well indicate that Otto had attempted to do this.

The case for supposing that there is a connection between Otto's work c.1873 and the four-stroke experimental engine is not overwhelming. It is, however, quite substantial and of all the investigations carried out by the author in this direction, provides the most tangible evidence. It would seem clear, from reading Otto's ideas in his patent for the hot air engine, that he made provision for both a vertical and horizontal version. Having encountered limitations with the vertical model, using a slide valve, it would then have been a simple matter to switch to a horizontal version and it is this latter work which may well have led him into the work concerned with the four-stroke engine.

The combustion chamber section of the experimental engine matches only approximately in external diameter to that of the cylinder and is quite obviously a 'bolt on' arrangement. It contains the exhaust valve with its associated operating mechanism, the slide valve, slide valve cover and gas admission valve, the whole being held onto the cylinder by only four of the eight available bolts, as previously mentioned. Now, when giving evidence of his work associated with the four-stroke engine, Otto claimed that around 1876, he carried out experiments with various arrangements of slide valve; for example, one was mounted at the side (as shown in his patent of that year). No example of this has survived, but a 'bolt-on' end arrangement such as this would enable such a modification to be carried out with a minimum of trouble. By this means he would need to concentrate his efforts only on the combustion end, attaching his ideas as it were to the main body of the engine. In subsequent patent trials which are later discussed, Otto was unable to produce either documentary or practical evidence of such experimental work, but with this arrangement it would certainly have been quite feasible for him to do what he claimed he had and would go some way to explain how he managed to achieve his objectives.

6.1.2 Otto's theories on combustion - stratification

Having produced the four-stroke engine, Otto, after carrying out several tests, then appears to have set about attempting to explain how it worked. The essence of his claim, which led him to his theory of combustion, is a particular mode of admission of the air and gas. He was convinced that the smooth running of his engine was due entirely to this. The fact that his engine compressed the mixture in the working cylinder he chooses almost to ignore. Indeed, in the patent deposition referred to earlier, he states that engines working according to his system will run well enough, with or without the use of compression, but as a rider adds that he prefers the one with compression. His theory was plausible, even convincing, certainly many distinguished men of science and engineering supported him; Dr. A. Slaby of Berlin; Sir Frederick Bramwell, FRS; Mr. John Imray, a prominent

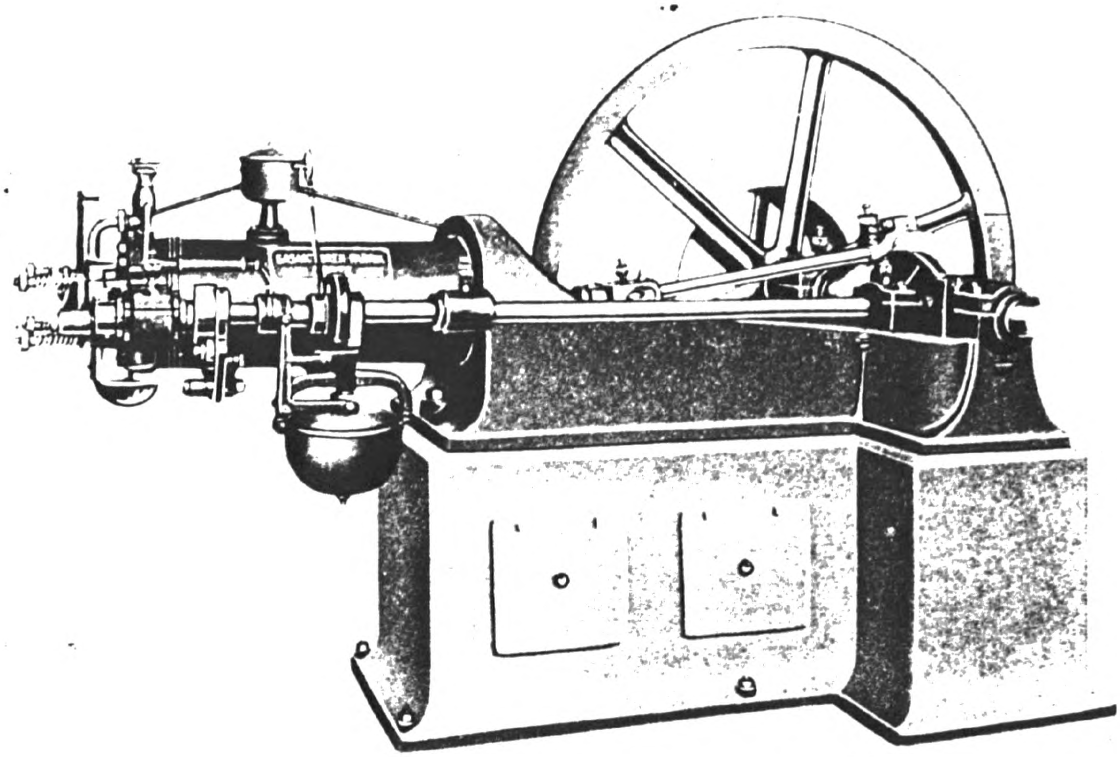

Fig 6.2 Production model of the four-stroke engine, by the Gasmotoren Fabrik, Deutz, Cologne

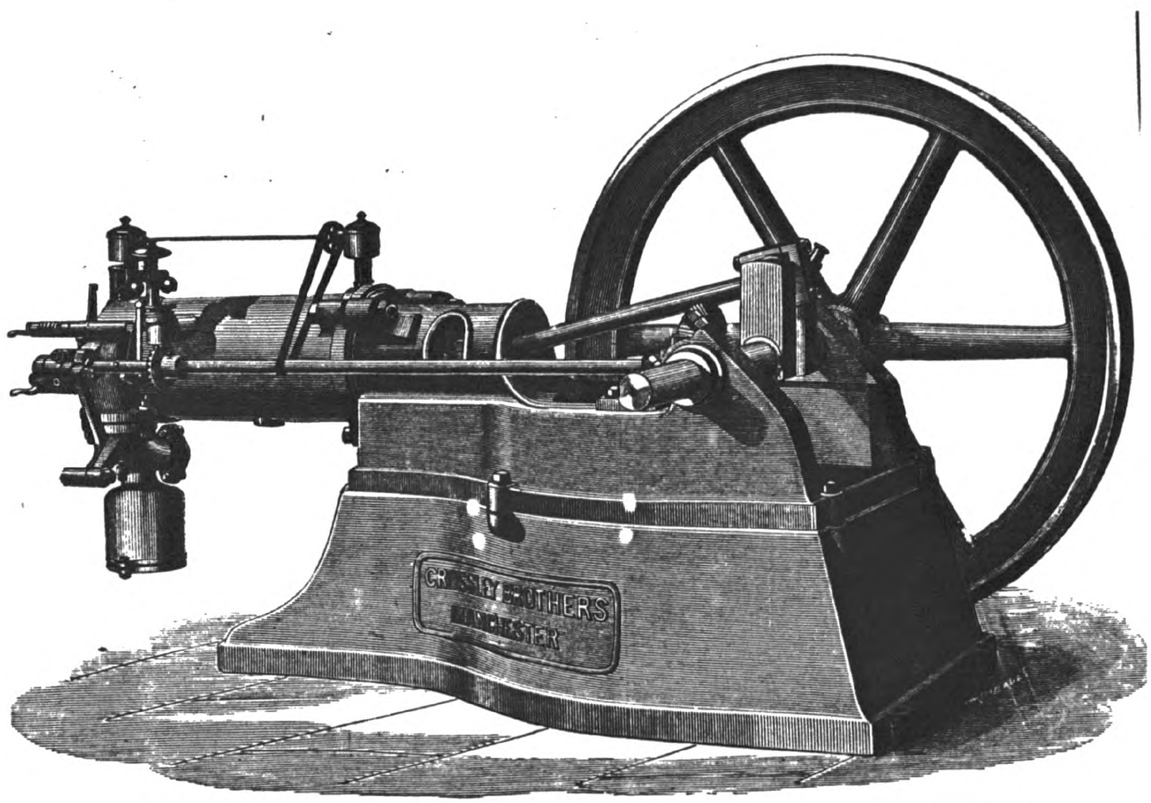

Fig 6.3 Production model of the four-stroke engine by the Crossley Brothers, Manchester, England

figure in the patent trials; Professor Dewar of the Royal Institution and, of course, the Crossley Bros. of Manchester all put their weight behind Otto. It was not until the mid-1880's that opinion finally turned against him, by which time the ideas held up to then had greatly influenced the further development of gas engines.

According to Otto, it was necessary to introduce into the cylinder first a considerable quantity of air; this would then be followed by a strong combustible mixture of gas and air. He placed great importance on the retention of exhaust gases from the previous cycle (Lenoir in his patent of 1860 was adamant that these should be removed, see Chapter Four, section 4.1). At the completion of the induction stroke, the arrangement of gases within the cylinder would then consist of three layers; one of exhaust gases next to the piston, an intermediate layer of air and then a final layer of gas and air which would be 'weaker' at the end next to the air because it would 'co-mingle'. This would become 'stronger' near the ignition point producing a readily combustible charge, thereby affording certain ignition. This particular arrangement was assumed to remain in that form during the compression stroke. Upon ignition, says Otto, there would be at first a rapid burning because of the suitability of the mixture near the point of ignition, but this would quickly decrease its rate since the air and combustible gas, it was claimed, would absorb the heat of explosion. The purpose was to act as a cushion against shock. By this method, the piston would receive a gradually increasing push as opposed to a violent blow, which had become so evident in previous engines such as the Lenoir and Hugon. This arrangement of gases became known as heterogenous, as distinct and opposite to homogenous and was popularly known as 'stratification'. Precisely how Otto sought to achieve this stratified arrangement in the cylinder has been shown by an examination of the valve action on the experimental engine and also other engines produced about that time that still survive. His method is as follows:

During the induction stroke, the timing of the admission ports* is so arranged that air only was allowed to enter the cylinder.

At some point later in the stroke, the gas valve would be opened allowing gas to mix with the air which continued to enter; the combustible layer was thus provided. The incombustible layer of exhaust gases was that provided by the considerable volume of the combustion space and to ensure a sufficient quantity remained from the previous cycle, the exhaust valve was arranged to open later to about bottom or outer dead centre - and to close early at about 5^o after inner dead centre. The opening period was thus 180^o compared with present day practice of 240^o. The first claim of Otto's English patent describes the action as:

> 'Admitting to the cylinder a mixture of combustible gas or vapour with air separate from a charge of air or incombustible gas so that the development of heat and the expansion or increase of pressure produced by the combustion are rendered gradual.'

The second claim refers to the compression of the charge, the third claim to the method of governing and the fourth claim

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*The operation of the slide valve and associated parts is substantially the same as that described in Appendix Three to the general arrangement of the engine whereby four strokes of the piston are necessary in order to complete the cycle.

When carrying out the investigations on the experimental engine, it was observed by the author, that under certain conditions, the order of admission of gas and air was inconsistent with what Otto believed; the cause of this inconsistency was the method of governing that was used. Speed regulation was effected by sliding a specially-shaped cam, which operated the gas valves along a shaft. The cam in question has a sloping edge of the type frequently used on steam engines, so that when the speed of the engine was, say, increased, the quantity of gas admitted would be reduced simply by varying the point at which the gas valve would be opened, the impoverished charge would then be present in the cylinder resulting in a feeble explosion. The method of ignition used on these engines was a flame system which, at best, was apt to miss ignitions and this form of governing did little to alleviate this problem. With the arrangement just described the charge in the cylinder would, at times, be so weak that several ignitions would be missed; a build up of combustible charge would then take place in the exhaust system with a consequent risk of explosion there. The main criticism of this governor, which Otto chose for his experimental engine, however, was that under load with low engine speeds, the gas valve would be opened early in the stroke, in fact, the point at which the latter opened was found to be only fractionally later than that when the air was admitted. Under these conditions it would be impossible to achieve the stratified arrangements that Otto claimed. This is a significant point to be borne in mind when considering whether or not Otto had some clear conception of what he was trying to do; the action of this governor produced a condition contrary to what he claimed in his patent*. On the production engines, this method of governing was abandoned and replaced by a 'hit and miss' method, that is, when the engine speed had become sufficient, the gas valve would not be opened, the speed then falls due to a missed firing stroke. With this method of governing which became universal on gas engines, the quantity of gas admitted is constant at each firing and irrespective of the speed.

Before discussing the patent trials in which Otto's theories were severely tested and their weaknesses exposed, it is interesting to relate how Otto may have developed his idea of stratification. Did he sincerely believe it was the basic cause of the successful running of his engine? or was it a deliberate attempt to obscure the real cause of its success - namely, the use of compression of which he might well have been aware - for the purpose of obtaining a patent?

A story related by Otto in his later years was that he was inspired in his stratification idea when he saw smoke arising from a factory chimney; he noticed that it was dense at the exit point, becoming more dispersed at it moved upwards. If the mixture in the cylinder could be so arranged, he thought, then it would burn rapidly at first, but more slowly as it consumed the less dense mixture. It is an appealing story but unconvincing.

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*It is significant that in preparations for the patent trials the action of this governor caused the patent agents some considerable anxiety and thought was given to disclaim it. The patent trials are subsequently discussed.

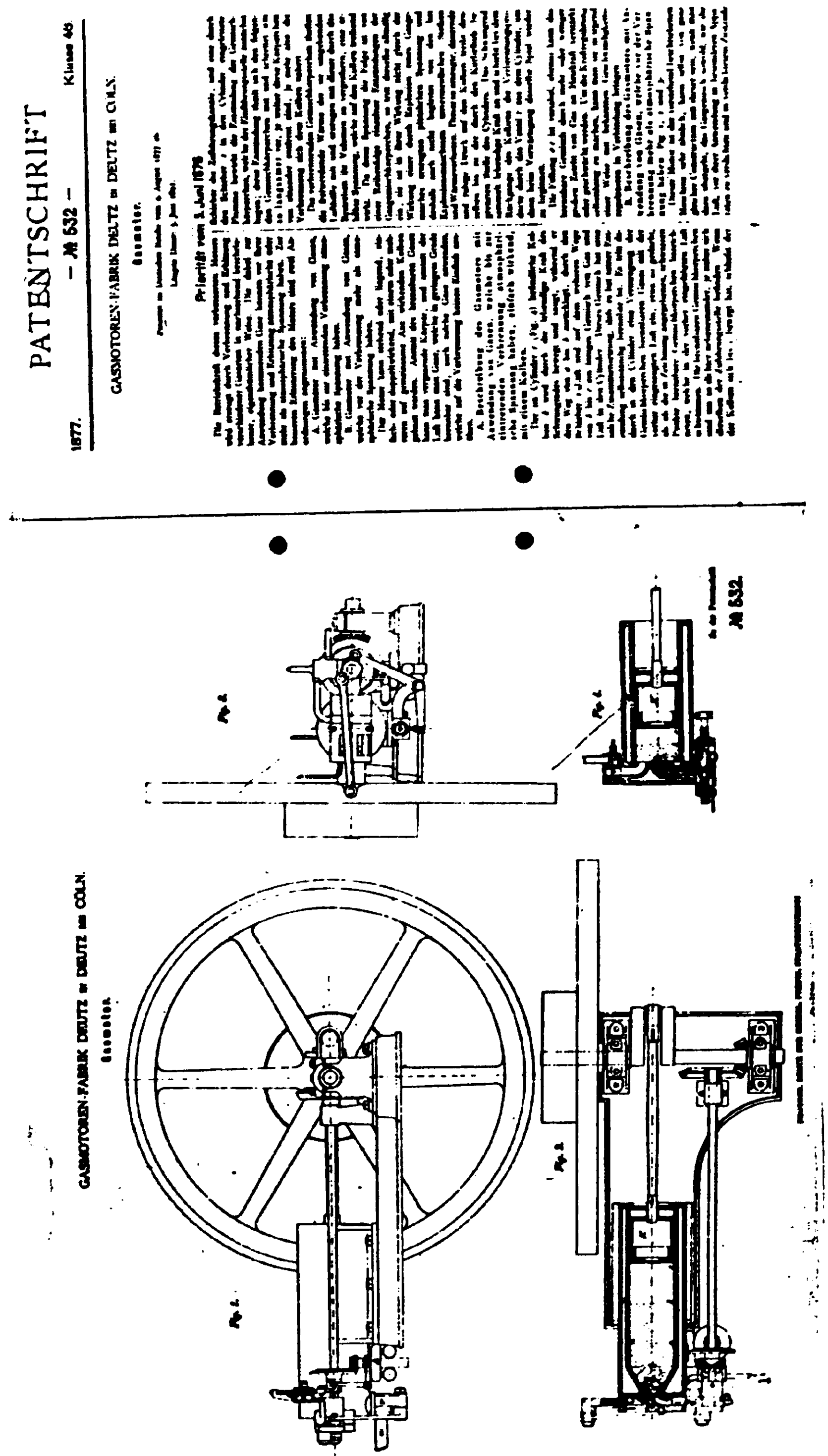

Fig. 6.4
Copy of the German Patent No. 532, for the four stroke engine. Priority was granted from the 5 June 1876.

At some stage, the year is unconfirmed - Otto built a small glass model* of a cylinder containing a tightly fitted piston[5], 1½ inches diameter. A brass cover with a hole ¾ inch diameter was fitted across one end of the tube and a small valve fitted to simulate the gas admission valve. On drawing the piston along the cylinder, the smoke from a lighted cigarette was observed to only partially fill the cylinder. This, it was supposed, proved the idea of stratification.

These two accounts are about the only evidence that exists to shed any light on the question of what Otto thought. Neither of them can be said to carry much weight for even if the date of the glass model is correct, it can hardly be said that such a small model was representative of a full-size engine. There is also the uncertainty of the governor action referred to earlier and, in addition, some confused thinking which is described later, surrounds the working of the English and German patents with regard to the arrangement of gas and air in the cylinder. Otto, it would seem, appears to have been rather uncertain of himself and repeatedly resisted several requests to simplify his ideas. It may be recalled in Chapter Four that Lenoir made some reference to stratification in 1860, but of rather a different nature to that proposed by Otto and Beau de Rochas described in 1862, precisely how a four-stroke cycle of operations using compression could be used. Both of these ideas which were patented contained what Otto, in reality, had used and consequently what he had to do was to describe his own patent in terms which

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* The model was donated by Humboldt-Deutz Motoren to Henry Ford Museum U.S.A. in 1934. It was stated to have been built in 1872 (correspondence - Klöckner-Humboldt Archives)

made it unique.

In making these observations, it has not been the intention to cast doubt on Otto's integrity. Correspondence and reports of a technical nature written by Otto, which the author has been privileged to study, reveal that he possessed a commendable grasp of problems associated with gas engines. There is also the fact, a very significant one, that Otto succeeded in practical terms in producing a successful engine where others before him had not.

6.2 The patent trials

6.2.1 Their cause and effect

It is difficult to imagine expensive High Court patent litigation trials as having any useful purpose, but this is particularly true of that between Otto and Linford in 1881 and Otto and Steel in 1885[6]. Charles Linford of Leicester took out his first patent for a gas engine, No. 2824 in 1876 and up to the time proceedings were taken against him, took out four more incorporating improvements. Robert Steel of Leeds took out his first patent No. 1116 in 1883 and another, No. 560 in 1884. In bringing action against them, it became necessary for Otto and his licensee, Crossley Bros., to substantiate their claims embodied in the 1876 patent, No. 2081, and also to establish that their engines worked in exactly the manner the patent claimed they did. To do this, they embarked upon a series of experiments which were carried out by both the Gasmotoren Fabrik Deutz and by Crossley Bros. An enforced critical examination and scientific study of the events occurring in the cylinder of a gas engine thus resulted The attention of the scientific fraternity was focussed on the Court action that took place and also on the experimental work, as slowly and rather painfully, an understanding of what really happened gradually evolved.

In studying these patent trials, the author discovered a most informative and previously unknown source of information, which reveals a vast amount of detail relating to the preparation and experiments that were carried out prior to the trials*. In this source, ideas on combustion, current at the time, are disclosed in depth and so also is information describing the atate of the gas engine manufacturing industry during the last quarter of the nineteenth century and the reasons which led Crossley Bros. on behalf of the Gasmotoren Fabrik, Deutz, to instigate proceedings against infringers. This aspect will now be discussed since it reveals evidence that there was far greater activity related to the manufacture of gas engines in Great Britain than has been formerly believed. Much of what now follows has been extracted from this newly-acquired source of information.

Having to resort to patent litigation was a measure totally against the nature of F.W. Crossley, a man with strong religious convictions and sense of fair play. The decision to embark upon such a course of action, therefore, could not have been taken lightly. On two occasions, approximately four years apart, he found himself in the High Court and

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* This consists of a book entitled 'Letters to Abel and Imray' which came to the notice of the author whilst carrying out searches. It was reputed to have come into the possession of an employee of Crossley Bros. during the life of Francis in whose writing the letters appear and subsequently handed down through the employee's family

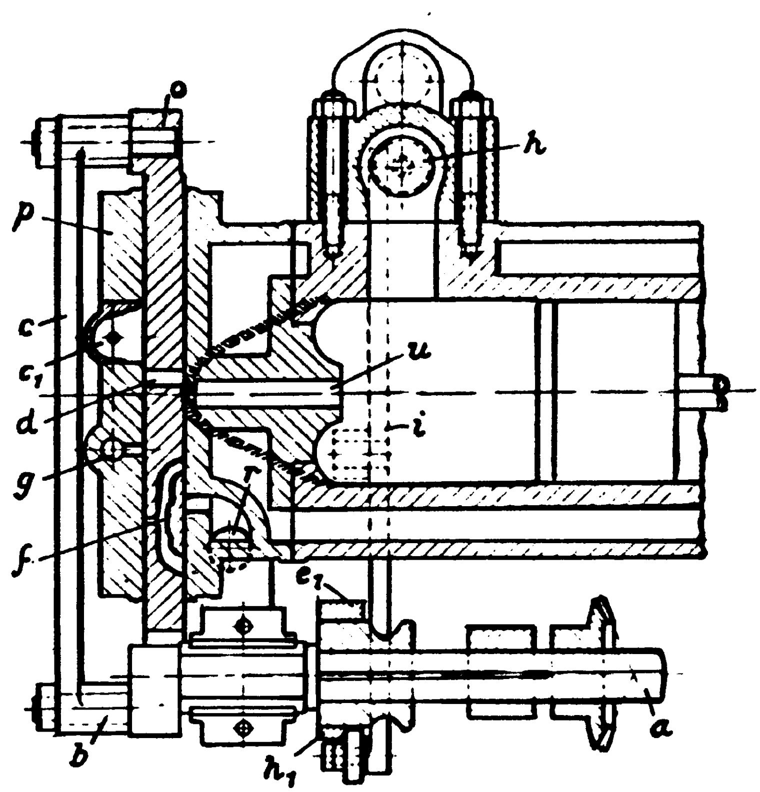

Fig. 6.5
Sectional view of slide valve and cylinder of Otto four-stroke engines using flame ignition and produced up to the year 1888. A conical shaped combustion chamber is shown.

a, drive shaft for slide valve, governor and exhaust valve; b, slide valve eccentric; c, link rod; d, flame communication port; e_1, exhaust valve cam; f, air and gas communication channel; g, gas inlet port; h, exhaust valve; i, exhaust valve lever; p, slide valve cover; r, air admission port; u, explosion canal.

For a detailed description of operation, see Report of Work Carried Out on Three Gas Engines .... (Technical Appendix, Volume Two of this Thesis) during the interim period, was engaged almost continually in issuing warnings to infringers and discussing terms when they retreated under threats of legal proceedings. The technical grounds on which Otto and Crossleys chose to do battle are highly debatable and are discussed later, but at the time, were evidently sincere and understandable since, having overcome numerous teething troubles connected with the four-stroke engine, Crossleys were anxious to preserve the excellent reputation they had built up for themselves and maintain their interests. Their engines were proving reliable and highly acceptable to industry and because of their wide experience in general machinery products, they were able to offer sound practical advice on how best to instal and put their engines to work - an advisory service which was totally absent with other manufacturers. When Crossleys sales began to drop alarmingly (Section 7.12 of Chapter Seven) therefore, some action had to be taken.

The trouble began when various gas engine manufacturers, eager to break into what obviously was likely to be a rewarding market became frustrated by the comprehensive terms of the Otto patent. Its encircling claims had such a stranglehold on the ideas of potential makers of engines, that it was virtually impossible to circumvent them. A monopoly, akin to that of Boulton and Watt with their steam engine, existed. These other manufacturers were not rich; they had not the fruits of seven years of successful manufacturing experience with the Otto-Langen atmospheric engine behind them, and accordingly formed themselves into a 'Gas Engine League'*.

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*A term used by F.W. Crossley. Letters to Abel and Imray p. 140

This was a consortium of gas engine makers, who subscribed to a fund; the idea was that they should all infringe the Otto patent and should action be taken against any one of them, the cost would be met by the fund and the various makers would combine to present a stronger case. The league, however, appears never to have fulfilled its purpose. One reason for this is that the two manufacturers, Linford and Steel, whom Crossleys singled out, appeared not to have been members of the league. The manufacturers named made only a few engines each, but the total number of engines they made was significant. Principal of these was Messrs Fawcett Preston and Co. of Liverpool, whose patents were registered under the name of Beechey; eight patents being taken out between 1880 and 1890. Other names mentioned are Ashbury; Summers, Clayton, Whittaker and Bickerton*. The last-named, Henry Bickerton, founded the National Gas Engine Co. in 1889 (see Chapter Seven, section 7.5.7) and registered six patents for gas engines between 1880 and 1890.

A name not mentioned as a member of the league in 'Letters to Abel and Imray' is that of Dugald Clerk. Clerk's two-cycle engine had quite an effect upon the Crossley Bros.' sales during the early part of the 1880's. This is fully described in Chapter Eight, section 8.3, where Clerk's entanglement with Crossleys is related.

*The patent numbers and year of all these are given in 'The Gas and Oil Engine' by Dugald Clerk, 6th ed. 1896

6.2.2 Experiments to prove stratification

The chief attraction of these engines offered by other makers was that they offered one firing stroke per revolution. They were not necessarily two-stroke engines in the now generally accepted sense of the term, but they managed to produce a similar effect by such means as external pumps or two piston arrangements, which were either in the same cylinder or in separate cylinders. Their mechanical complication was great and their performance from all accounts was inferior to that of the Otto. To the uninformed public, however, who believed that 'two firing strokes gave twice the power' such engines were appealing. All of them used compression in one form or another, but as will be seen later this was not the issue to which Crossleys took exception, but that of stratification. Before issuing written warnings to individual firms, Crossleys would first obtain the relevant engine and carry out tests. If the engine concerned was fitted with an external pump to compress the mixture - a popular device at the time - it would be removed and the engine run without it. (In some cases, F.W. Crossley reports that the engines actually ran better.) The fitting of this pump was then held as merely an attempt to mislead and that the true principle of its working was that used by Otto. Indicator diagrams would be taken from the engines on which the position of the ignition point was varied; the object here was to show that the cylinder contents consisted of separate layers of combustible and incombustible gases as was the supposed case in the Otto engine. Indicator diagrams taken when the ignition was made to occur in a region assumed to contain incombustible gases, were stated to be inferior to

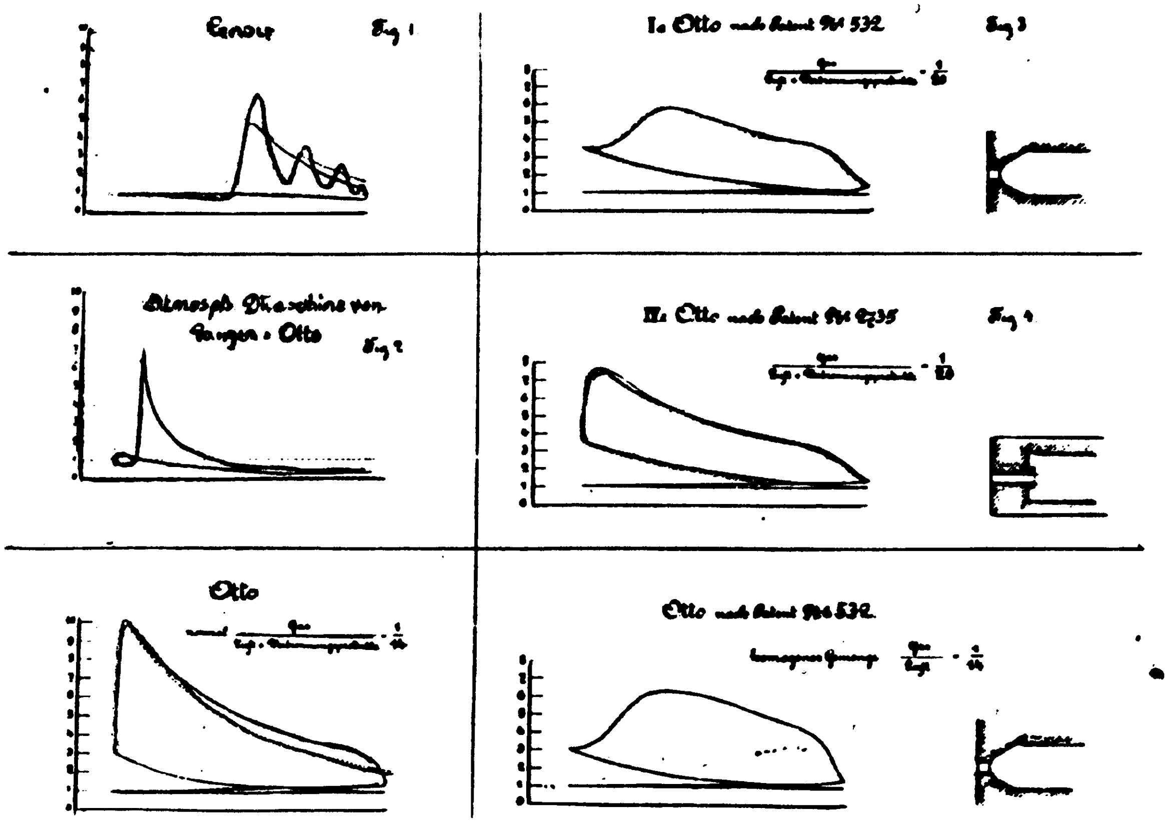

Fig. 6.6
Comparative indicator diagrams of the Lenoir, Otto and Langen and Otto four-stroke engines. Also shown are the indicator diagrams obtained as a result of tests to determine the optimum length of explosion canal with various gas and air ratios. The ratio is calculated as $\frac{\text{Gas}}{\text{air + exhaust residuals}}$ and the tests are intended to show the value of stratification.

Lower left: normal diagram with stratification; mixture ratio 1/14

Top right: short explosion canal; very weak mixture 1/20

Centre right: longer explosion canal; very weak stratified mixtures of 1/20 (this engine was a later patent intended to give a more 'rapid combustion')

Lower right: short explosion canal; a homogenous mixture of 1/14. The inferior diagram obtained from this homogenous mixture was intended to show the advantages of stratification. It was obtained by allowing the engine to 'miss' two or three consecutive firing strokes, thereby expelling all the exhaust profucts. By so doing however, the cylinder would be substantially cooled, hence the poor indicator diagram when compared with the stratified diagram, lower left.

those taken when the point of ignition was in a more 'favourable' place*.

In November 1880, Crossley Bros. obtained a Linford engine from a Mr. Bridgewater, who had found its working totally unsatisfactory[7]; it was sent to Deutz where Otto carried out the tests just described. Another test carried out was to 'invert' the stratification, that is, to cause gas to enter the cylinder first, followed by air. Again, indicator diagrams would be taken and compared with those taken with 'normal' stratification. Mr. F. W. Crossley's written comment accompanying copies of these diagrams is as follows:

> 'In looking at the diagrams enclosed, it is to be borne in mind that stratification is to render ignition and combustion certain and regular. The extra diluent renders its gradual and slow or lasting in its effect on the piston, not the stratification.'

Great importance was at first attached to the electrical proofs of stratification. Otto appears to have carried them out on the Linford engine, since in March 1881 a letter suggests that either he or his engineer should be brought over for the trial**. Another test, to which great importance was attached, was that to show how essential it was for the Otto engine to retain a large portion of exhaust gases from the previous cycle. After allowing the engine to miss se-

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* The means of ignition used was electrical. F.W. Crossley was dubious of presenting evidence of these tests in Court since 'not much is known of the effects of electricity on gases'. p.12 Letters to Abel and Imray

** There is evidence that similar electrical tests were carried out on Otto's experimental engine. In 1883 it was sent to Crossleys from Cologne in preparation for the Otto/Steel trial. (Letters to Abel and Imray p.215). Supporting evidence to this is given by the author's discovery of a number of holes drilled into the combustion space of the test engine through which igniting points could be inserted.

veral consecutive firing strokes, it would then be caused to fire and a diagram taken of that particular cycle. The inferior diagram that then resulted (the cylinder walls having cooled considerably during the scavenging process) was mistakenly held to prove the necessity for retaining exhaust products in the cylinder.

In choosing to do battle in the English Courts on the issue of stratification, Crossley Bros. were on reasonably safe ground. It was difficult for them to establish their case, but it was virtually impossible to counter it, such was the state of knowledge of engine technology at that time. A competent engineer would refrain from making a categorical statement on the issue, least of all, that a High Court Judge should be called upon to pronounce judgement. Amidst such complex issues the Counsel for Linford fought and won the first round, on the grounds that the idea of stratification had been anticipated, namely by Lenoir in 1860. This decision was reversed on appeal.

In the later trial of Otto v Steel, infringement was not denied. The defence once again questioned the validity of the patent and in the light of its having been previously established, would seem to have been a rather foolish course. Not surprisingly, Steel lost.

6.3 An increasing scientific interest

These initial experiments and cursory treatment of the indicator diagrams obtained from engines produced more uncertainties and problems than they solved. In order to produce a greater understanding, therefore, a much closer look was taken of indicator diagrams, particularly of the expansion line and explanations were sought which would account for the slow rate of pressure decline which they showed. Dr. Slaby of Berlin, one highly respected in scientific circles and who later carried out many worthwhile experiments in connection with engines, revealed his views in favour of stratification[8]. He later reversed them in common with most other authorities, but not before his published works had influenced general opinion. Slaby's ideas were based on his observations that the path of the expansion curve lay above that of the adiabatic line, and from this correctly deduced that the working fluid must have received heat. A comparison with the Lenoir diagram was made, in which a rapidly falling expansion line beneath the adiabatic occurred and from which it was deduced that in the Lenoir engine there must be a loss of heat to the water jacket. Slaby's explanation, that in the Lenoir engine all of the heat evolved at the moment of explosion, whereas in the Otto engine a slow evolution of heat results from the arrangement of gases, was totally wrong, but he did succeed in focussing the attention of many other eminent men of science on the problem. Up to that time, only a minimal amount of work had been done on the explosion and combustion of gases. A start had been made by Bunsen in his only book 'Gasometrische Methoden' in 1857 and this was followed by Schmidt[9] in 1861 and Bunsen[10] again in 1867. Professor Letheby had outlined his experiments on the combustion of gas for economic purposes in 1866[11] and its application to motive power and Rankine, working entirely from pressures and volumes - the general practice with steam engines - attempted a quantitative analysis of the working stroke of the gas engine also in 1866[12]. What would have been helpful at the time of the patent trials was information on flame propagation, but scientific experiments on such work only began in earnest about the mid-1880's after some preliminary work by Mallard and le Chatelier[13] and Berthelot and Vieille[14] and by which time Slaby's views had become known. The later and more notable contributions were by Dixon[15], Clerk[16] and Schottler[17]

In addition to this scientific work, practical experiments involving engines were carried out in an attempt to remedy the deficiencies in knowledge and contrasting opinions that were exposed by the patent trials. Dugald Clerk fitted an ignition device to the piston of a 3½ horse-power Otto engine and proved that an ignitable mixture existed as close as ¼" away from the piston[18]. By a simple comparison of piston area and speed to air admission port area, he deduced that the velocity of mixture on entering must be something like 120 miles per hour, resulting in great commotion within the cylinder and a thorough mixing. Together with Dr. John Hopkinson, he built a full-size glass model of an Otto engine into which he admitted smoke and demonstrated that thorough mixing and a homogenous mixture did, in fact, result. The cumulative effect of all this work was that by about 1885 support to the stratification theory had dwindled to little more than a handful of people. The value and advantages of using a compressed mixture then began to emerge - a fact long advocated by Dugald Clerk[19]. Attention was then directed more closely at the cooling effects of cylinder walls and the realisation that a charge compressed into a small space meant that a much less surface area existed through which heat loss could occur. Investigations into the phenomena of dissociation began and so, also, did experiments to determine the effects of variable specific heats of the gases at high temperatures.

Powerful support for the use of compression came also from two other sources at this time (1883-4). Professor Fleeming Jenkin of the University of Edinburgh delivered a paper[20] in which he says:

> 'If I were to compress gas to 40lbs per square inch, a pressure which is used not infrequently, the theoretical efficiency would be 45%*. We actually get something like 24 or 23%. We know that one-half of the heat is taken away by external cooling, thus we find a very close coincidence between the calculated efficiency and that which we actually obtain. If we compress to 80lbs we have a thermal efficiency of 53%. If we do not compress at all, as Mr. Clerk has told you, we have a theoretical efficiency of only 21% ..... I have no doubt that the great gain in efficiency in the Clerk and Otto engines is really due to the fact of compression.'

The second source of support for compression came from Professor Aimie Witz of Lille who published in Paris the results of his analysis of the theoretical efficiencies of the different types of cycles[21] that had so far been tried. These were the direct-acting without compression (Lenoir and Hugon), direct-acting without compression but with free expansion (Otto and Langen) and direct-acting with compression as in the Otto four-stroke engine. He states:

> 'I find myself again in agreement with Mr. Dugald Clerk when he affirms that the success of the Otto is due to compression alone and not to the extreme dilution of

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*This value was obtained from the expression $= 1 - \frac{1}{r^{n-1}}$ where r is the volume compression ratio and n the index of compression for the gas

> The explosive mixture by the products of combustion of a precedent explosion.'

Perhaps the final death-knell of Otto's theories to which he tenaciously clung, occurred when one of his own countrymen, Professor Schottler, published in 1886 a paper entitled 'Die Verbrennung in der Gasmaschine'[22], strongly refuting the idea of stratification. He criticised the small glass model used by Slaby and states:

> 'Whether stratification exists or does not exist in the Otto engine is irrelevant, and not the cause of the slow falling of the expansion line.'

It was during 1886 that Otto's patent was finally broken in Germany (see Chapter Eight, section 8.4.1) and Schottler's work showed that he had long held the view that the use of compression was the single factor on which the successful Otto engine hinged. A good deal of Schottler's work is quoted as evidence by the opponents of Otto.

Much of what was done between 1880 and 1885 to discover the basic physics and chemistry inherent in the working stroke of the internal combustion engine, would, in the natural course of events, have probably been done anyway. The effect of the patent trials was to create interest not only of a scientific nature but financial also, since the rewards of being able to produce such a successful product were great. It is not difficult to understand, therefore the intense activity and interest that occurred during this short period. The net effect of this work was that greater and greater economy of operation resulted, the ceiling of power output was increased with industry reaping the direct benefit as more uses for such engines were found. A marked improvement in experimental techniques took place as instrumentation improved. Attention was given to desirable shapes of combustion chambers and port sizes and investigations began to devise alternative means of ignition to that of the flame. It marked the beginning of an improvement period as seen by the appearance of a wider range of engines to fulfil every need of industry. Small vertical engines of two man-power appeared at one end of the scale, whilst at the other attempts were being made to increase the power ceiling using twin cylinders. The versatility of the gas engine now gegan to reveal itself and was signalling the beginning of the end of the steam engine era.

6.4 <u>The four-stroke cycle - prior claimants and contenders</u>

The vindication of the Otto patent in the English Courts was largely nullified by its defeat in Germany and France. The primary reason for this appears to be that in these latter countries cases were fought, not principally on the complex, often intangible issue involving stratification, but on those more readily understood and concerned with the cycle of operation. The English patent 2081 of 1876 mentioned the working cycle aspect only briefly and by so doing failed to attract sufficient attention to make it a major issue. In the first German patent 532 and also a subsequent one, No. 2735[23] the wording of the claims had been changed, neither of them being similar to the English patent. In the German patents, more emphasis was placed on the working cycle; but what did little to help Otto was that in the latter patent taken out a year after No. 532 (by which time over a hundred engines had been produced according to his earlier ideas) he claimed a different mode of combustion. Instead of the former idea of 'slow combustion', he replaced it by another more 'rapid combustion' which he said 'emanated from a locally rich source of mixture to a leaner but homogenous one'. Such an apparent turn of mind by Otto only added to the confusion which surrounded his ideas and did little to help his case in the Courts.

The distinct emphasis in Otto's German patent of a cycle of operation requiring four strokes of the piston to be executed, meant that attacks upon it were possible from a totally different standpoint than those used in Britain. Three men, other than Otto, were said to have used such a cycle prior to 1876. The French engineer Beau de Rochas, a Munich watchmaker Christian Reithmann and Siefried Marcus, an inventor from Vienna, who is said to have built automobiles long before anyone else, but received little recognition for his work. Each of these three claimants are briefly mentioned by Sass[24], who raises questions as to the validity of their claims. As a result of these more recent searches, the author is now able to discuss these claims and answer some of the questions posed by Sass.

6.4.1 Beau de Rochas

Alphonse-Eugene Beau de Rochas (1815-93) was an obscure, rather eccentric French engineer, who frequently voiced his opinion on scientific and other matters that happened to take his fancy. Sometime about the middle of the nine-

Fig. 6.7
Alphonse-Eugene Beau de Rochas (1815-93)

teenth century, he is known to have published proposals for a submarine telegraph, a rail tunnel under the English Channel, a new kind of drive for canal boats, the use of steel for high pressure boilers and a way of improving the adhesion of locomotive wheels so that they could travel over the Alps[25]. It was while employed as Ingenieur Attaché on service Central des Chemins de Midi in 1862, that he expressed his thoughts, which were purely theoretical speculation, on how to utilise gas engines with steam engines for the purpose of locomotive propulsion. The ideas he expressed are commendably explicit and remarkable for their foresight, but the article, entitled 'Nouvelles Recherches sur les Condition Pratique de Plus Grande Utilisation de la Chaleur et en Général de la Force Motrice' did not receive wide circulation. It consisted of a pamphlet (printed by a lithographic process that reproduced handwriting) of which three hundred were printed. The British Museum received a single copy, which was filed under the author's name and not by subject. The work was granted a French patent No. 52593 dated 10 March 1862, but it lapsed because the annuity, necessary to keep the patent in force, was not paid.

The section relevant to motive power using explosive means begins in section 6[26], and two general cases are discussed; A, an arrangement without previous compression and, B, an arrangement with previous compression. In the latter, Beau de Rochas outlines the conditions for 'the best employment of the elastic forces of gases' and the following is a direct translation as given by the reference quoted above:

(1) the greatest possible cylinder space with the least possible exterior surface

(2) the greatest possible quickness of action
(3) the greatest possible expansion
(4) the greatest possible pressure at the commencement of the expansion

He continues ' .... for the practical operation we are naturally led to execute the following operations':

(1) suction during an entire stroke of the piston
(2) compression during the following stroke
(3) ignition at dead point and expansion during the third stroke
(4) forcing out the burnt gases from the cylinder on the fourth and last return stroke

Beau de Rochas' remarkable foresight extends even further when he clearly recognises the fact that his proposals would entail only one production stroke in two revolutions, and suggests that by making the engine double-acting, this deficiency could, to some extent, be compensated for. The documents, to all intents and purposes, then lapsed into obscurity for over twenty years. It was resurrected in December 1883 by a German patent lawyer, C. Wigand, who was a friend of one of the frustrated gas engine manufacturers, the Körting Bros. of Hannover. Wigand, obviously on the lookout for anything likely to break the Otto patent, wrote a lengthy letter to the editor of the German Association of Engineers[27] describing, in detail, the Beau de Rochas tract. The fact that the proposals were merely thoughts on paper, that Rochas made no suggestion whatever as to how his ideas could be realised in practice, or that the patent had long since lapsed, seemed to be of no consequence to Wigand; he lost no time in filing a suit against Otto, claiming that the four-stroke claim in his patent was invalid. He was successful in 1885 and the four-stroke claim in Otto's patent was declared in Germany to have been anticipated by Beau de Rochas. Otto was shattered by the decision, but whatever its rights or wrongs, there is no escaping the fact that Otto's defence was weak. He claimed that during 1862, he and his engineer, Michael Zons, had constructed a four-cylinder engine that used compression, but could only produce drawings of it that were made at the time of the trial. No hardware of this engine had survived and neither was there any documentary evidence. Zons, therefore, made a sworn statement that he had in fact built it for Otto in the year Otto had stated. During the Körting v Otto trial, at no time was it inferred that Otto in fact had knowledge of Beau de Rochas when he began work on his four-stroke engine. As far as the Court was concerned, he merely had the same idea at a later date.

Many questions, as yet unanswered, can be raised with regard to Beau de Rochas' work. Why had he not appeared to voice his protest either during the trial or even when Otto's engine appeared on the market? He apparently was still very much interested in such matters, since very shortly after the trial he worked for Mignons et Rouart of Paris, who built the later four-stroke engine for Lenoir[28]. The surprising fact, also, is that Lenoir appears to have ignored Beau de Rochas during the 1860's at the time he was experiencing trouble with his first engine. Lenoir is mentioned in the German patent trial and is said to have become acquainted with Beau de Rochas[29]. Many suggestions have been put forward to account for the seemingly lax attitude of Beau de Rochas, but none have been substantiated with evidence.

Jacques Payen, in his Biographical Studies of Beau de Rochas (ref. 25) suggested that Beau de Rochas was in Africa for some years after 1870 (being a Bonapartist who left France when the Second Empire collapsed); Goldbeck in Gebandigte Kraft, p.186, suggests that perhaps Beau de Rochas was out of touch with the Parisian technical world and Hirsch in a Bulletin de la Société d'Encouragement pour l'Industrie Nationale Vol. 90 of 1891, p.363 claims that Beau de Rochas tried, without success, to interest manufacturers with his idea.

It seems unlikely that, during the years of this technical activity, Beau de Rochas, interested as he undoubtedly was in matters of science, would have missed entirely the discussion that took place during the 1880's. Otto engines were being exported to every country in Europe as well as some to the Near and Far East. In addition, patent suits in defence of the Otto patent were going on in half a dozen countries. Another suggestion has been made that Beau de Rochas was apologetic about his ideas and cared little about them, but this conflicts with what is known of Beau de Rochas and his reputed outspokenness.

In trying to assess just how widespread the ideas of Beau de Rochas on the four-stroke cycle may have become, it is interesting to note that in the English patent trial of Otto v. Steel, an attempt by Counsel for the defence to introduce Beau de Rochas was rejected on the grounds that a single copy received by the British Library did not constitute an accessible document. At the same hearing, however, Mr. Haas, a dealer in foreign books in the Strand, London, stated that a certain well-known catalogue, Lorenz's 'Catalogue Générale de la Libraire Francaise' published in 1867 contained a list of Beau de Rochas' publications[30].

Beau de Rochas, it would seem, conceived the idea of a four-stroke cycle, but, as Samuel Smiles remarks in his 'Lives of the Engineer'

> 'the palm should go not to the man who has visions of a new method or product, but to him who fully executes the idea in fully practical terms.'

In 1891, Beau de Rochas was awarded three thousand Francs for the invention of the four-stroke cycle by the Société d'Encouragement pour l'Industrie Nationale. Many contemporary text-books still refer to the cycle as the Beau de Rochas cycle.

6.4.2 Christian Reithmann

A second claimant, Christian Reithmann (1818-1909) had been making and using his own gas engines to drive light machinery in his Munich workshop for a number of years before 1880[31]. In 1882, Gasmotoren Fabrik took exception to a provisional patent issued to one Gerhard Adam of Munich, a competitor of Deutz, who, for his defence, dragged Reithmann out of obscurity and used him or rather his experiences, to fight the claims of the Otto patent. Statements, subsequently extracted from Reithmann, revealed that he built an engine in 1852 which ran on hydrogen[32]. He converted it to run on illuminating gas in 1858, later patenting it in 1860, when he heard of the Lenoir engine. During the 1860's - no precise year being given - he claimed to have built a two piston engine and from this converted it so that it would run on the four-stroke principle. This occurred, it was claimed, between 1870 and 1881.

The Gasmotoren Fabric began proceedings against Reithmann towards the end of 1883 and the enemies of GFD spared no effort in preparing their case. The services of a distinguished engineer, Moritz Schröter, were used who, after studying Reithmann's engine, submitted drawings of how it would have looked at the time of Otto's patent of 1876[33]. There was a marked similarity between the two engines. Included in Reithmann's was a flame ignition system and a method of admitting the charge which implied stratification; one notable difference was that the cylinder of the Reithmann engine was vertical.

Soon after the Court hearing began, there happened the first of a number of astonishing events; Reithmann was allowed to reconstruct his engine to show how it operated in the early 1870's. When this had been done, it was presented in working form to a panel of experts. But by this time it had been fitted with electric ignition, piston rings and an entirely new form of gearing which controlled the admission of the charge. These were major changes and, in this form, bore little resemblance to earlier ideas regarding its construction. It was an obvious and blatant imitation of Otto's engine. Following a further year of confusing evidence and legal wrangling, the Bavarian Court made yet another startling decision and awarded Reithmann the judgement on 13 December 1884. The Gasmotoren Fabrik immediately appealed, but in the meantime - five days after the Court decision - bought the Reithmann engine and paid 25,000 Marks to Reithmann to secure the claim. This may well be construed as a hasty act and, indeed, it was, since the High Court later reversed the earlier decision[34].

In summarising the Reithmann claim to have used the four-stroke cycle, it need hardly be said that the evidence is pitifully weak; that being so, what possible reasons could there be to explain the extraordinary decisions of the Court. Goldbeck, in 'Gebandigte Kraft', suggests that governmental policy at the time was not in favour of the restrictions to enterprise and industry that patents created. This would seem a credible explanation. At that time, the machine tool industry of Germany was making outstanding progress and the Otto engine extended the limit of power-driven machinery. By how much more would these limits have been extended if everyone made similar engines?

6.4.3 Marcus of Vienna

Siegfried Marcus (1831-98) was an Austrian whose undisputed inventiveness and abilities place him well above the status of the amateur. Consequently, any claim to his having used the four-stroke cycle in the engines he used in his automobiles justifies close examination.

While in his early twenties, Marcus developed an interest in the electric telegraph - a popular activity in the 1850's - and a subsequent interest in electricity. (Lenoir trod a similar path about the same time.) He became knowledgeable on matters of science, is said to have instructed Crown Prince

Rudolph, won a prize in 1864 for converting heat into electricity and in the 1870's designed a parallel electrical circuit in which the lights could be individually controlled[35]. His interests included gas engines, but from a different standpoint from other workers in the field. Marcus was concerned more with problems associated with ignition and carburation, so that his engines could be used where no illuminating gas was available. From his early experiences with electricity he developed an electric ignition device for exploding mines without the use of batteries (Otto is said to have received his inspiration for his electric ignition system after seeing these in action). By the mid-1880's he had a reliable magneto, which could be used on gas engines which was driven by the engine.

Concurrent with his experiments involving electrical devices, Marcus was developing a gasifier that would produce an inflammable vapour from a liquid. About the middle of the 1860's, he sought the help of Franz Reuleaux to obtain a Prussian patent for the device. Reuleaux wrote to Langen, telling him of Marcus and suggested the two should meet and discuss how the device could be applied to the atmospheric engine[36]. It is not known for certain that they actually met, but during the early 1870's attempts were made to run the Otto-Langen on liquid fuel (see Chapter Five, section 5.4).

Marcus himself never made claims to have used the four-stroke cycle before Otto; they were made by his patent lawyer, Viktor Tischler two years after Marcus had died and published in 1904[37]. Support was given to the claim by old friends of Marcus and by a Viennese Professor, Ludwig Caischek-

Christien who, whilst arranging an exhibition of Austrian automobiles in 1898, came across a car that Marcus had built. The question is - when was it built? In the first public showing in 1898, the automobile bore the date 1877; when next shown in Paris in the year 1900, its date now read 1875 (the same as it does today). This earlier date not only gives it precedence over Otto, but also that of Selden's automobile in the United States of America, which has the date 1877. The evidence to support this earlier date is very flimsy indeed, and rests on a newpaper cutting, which is said to describe a ride in the car during 1875. The description is missing, however, and no evidence of it has yet been found in any Viennese newspaper. Another point to which no satisfactory answer has been given is that the engine has fitted to it a carburettor, which Marcus did not patent until 1882. Is it likely that Marcus would use a device for seven years without patenting it?

Other questions may be asked - such as why, with all the patent litigations going on at that time (Gasmotoren Fabrik were engaged in about twenty suits between 1881 and 1886) was not the name of Marcus raised? Some of these cases took place in Vienna. Why, after Otto's four-stroke claim had been finally broken and Marcus produced a four-stroke engine on a commercial basis and widely discussed in the technical press, was there no indication or mention made of any earlier engine that he may have produced?

In mitigation of the lack of documentary evidence to support the claims of Marcus, it has been suggested that it was deliberately suppressed by German intervention in Austria in

1938, suffering the same fate as the work of many other notable Jewish personalities. Another suggestion is that documents, sent to America to be used in the protracted patent case of the Selden automobile, were lost[38]. Marcus left his technical models and documents to Viktor Tischler, who is generally assumed to have sent the documents to America, but doubt exists that he actually did[39].

Marcus undoubtedly made worthy contributions to two difficult problems concerned with engine technology - ignition and carburation - but on the basis of available evidence, it is not possible to state, categorically, that he anticipated Otto in the use of the four-stroke cycle. His efforts are worthy of recognition, but it is important to get the dates right.

6.5 The evidence for Otto

Lastly, what of the claims of Otto himself?

The experimental work done by Otto from the year 1861, when he first became interested in gas engines, has been reviewed earlier in this chapter. Consideration of this will show that the important period is that around 1862-63, when he claims to have built a four cylinder engine and to which his engineer, Michael Zons, gives support in a sworn statement. A drawing of this engine made by Otto from memory is shown in Figure 5.1. No indication of how it was supposed to work was given, no valves or control gear are shown and no means of ignition is mentioned. The only factor connecting this engine with his first engine of 1863 is the two piston arrangement in which the rod of one piston slides into the hollow rod of the second piston. There is no surviving hardware of this engine and no engineer could even begin to suppose how it would have worked.

A second source on which supporters of Otto place great store is a letter, dated 14 January 1862, from Otto to his Fiancée[40], in which he says he spent a few hours with Zons, achieved good results and that he expects everything will soon turn out well. The date of the letter is significant, since it precedes the date of the Beau de Rochas pamphlet. There is nothing in it to suggest that the test referred to by Otto involved the four cylinder engine, but his patent for the first atmospheric engine is not dated until 4 August 1863, thus one can allow the possibility that it might well have been. In speculating about this controversial engine, the issue is not 'did Otto make such a thing', but 'when did he make it'? If January 1862, the date of the letter, is accepted, then it means that Otto's tinkerings with the single cylinder Lenoir model during 1861 had taken a great leap forward in the space of a few months. More credible is the suggestion that Otto did, in fact, carry out some experiments similar to those he described, but at a later date and at the time failed to recognise their significances. Almost certainly they involved higher pressures than had previously been encountered, hence Reuleaux's reference to 'high pressure engines' and Otto's statement that the engine destroyed itself. There is still the fact that Otto thought insufficiently of these particular efforts to patent them, or even to record them. It must be remembered, however, that for Otto this was a period of intense experimental activity.

At such times ideas are tried, discarded and tried again and hardware, which has assumed some kind of practical form, is modified and used repeatedly. The emphasis is on attaining a particular objective, which is perhaps not as clearly defined in one's mind as it could be and, if the results do not live up to expectations, the efforts are promptly discarded and often forgotten as fresh ideas are formed.

Circumstances surrounding the birth of the four-stroke cycle are thus seen to be controversial and in attempting to establish priority to its inventor, national pride has played a significant role. Inevitably, it seems, good products of patents are attacked and journals can be found which are full of correspondence from 'prior claimants'. Historians of technology have written a good deal on this particular issue, but when all discussion about the four-stroke engine is set aside, one fact remains; that it was Otto, with his dogged perseverance in the face of many obstacles, who finally made it work.

References - Chapter Six

1. A miscellaneous collection of letters written by Reuleaux (Deutsches Museum, Munich). The author wishes to acknowledge the assistance given in their translation, by Herr H. Rödl, during his visit.

2. The first patent granted for the four-stroke engine was English No. 2081/1876 dated 5 May. A full German patent was granted 4 August 1877, No. 532 when the German Imperial patent system was established. This latter patent had priority from 5 June 1876 - the date of the original patent granted by Alsace-Lorraine.

3. Otto's original four-stroke engine is exhibited in the Klöckner-Humboldt Werkmuseum, Deutz, Cologne. The firm is a direct descendant of N.A. Otto and Co. founded in 1864.

4. The Engineer Vol. 60 (1885) beginning on p.421 Otto's deposition is given on p.433

5. Dugald Clerk, The Gas and Oil Engine (London 1902) p.250

6. Details of the Linford Trial are given in The Engineer Vol. 51 (1881) p.233. The appeal, however, is not given until Vol. 60 (1885) p.412. The second patent trial between Otto/Steel is described in The Engineer Vol. 60 (1885) p.421 and subsequent issues.

7. Letters to Abel and Imray pp. 2, 13 and 14

8. Slaby's views are discussed by Dugald Clerk 'The Theory of the Gas Engine' Proc. Inst. Civil Engineers Vol. LXIX (1881-82 Part III) pp.220-307. Also in a lecture given by Prof. Fleeming-Jenkin delivered to the Inst. Civil Eng. in Feb. 1884. 'Heat in its Mechanical Applications'. The account of this lecture is not recorded in the proceedings. See Clerk op cit (5) p.244

9. G. Schmidt, 'Zur Theorie der Lenoirschen Gasmaschinen' Polytechnisches Central Blatt (Leipzig 1861)

10. R. Bunsen, 'On the Temperature of the Flames of Carbonic Oxide and Hydrogen' Trans. Phil. Mag. Vol. 34 (1867) p.489

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12. W.J.H. Rankine, 'On the Theory of Explosive Gas Engines' The Engineer Vol. 22 (1866) p.55

13. F.E. Mallard and H.L. le Chatelier, 'Recherches sur la combustion des mélanges explosifs' Comptes Rendus l'Academie des Sciences Vol. 93 (1881) p.962

14. C.L. Berthelot and P. Vieille, Numerous papers between Jan. and July 1882 Comptes Rendus .. See also Annales de Physique et de Chimie Vol. 4 (1885) 6th series pp.13-90

15. H.B. Dixon, 'The Rate of Explosion in Gases' Phil. Trans. Royal Soc. Vol. 175 (1886) pp.617-684

16. D. Clerk, The Gas, Petrol and Oil Engine Vol. 1 (London 1910) p.126 Contributions by Grover, Patavel, Bairstow and Alexander & Hopkinson are also given

17. R. Schottler, 'Combustion in the Gas Engine' Proc. Inst. Civil Engineers Vol. LXXXVII (1886-87) pt. 1 p.527 Also included are the opinions of Witz and Körting and the later views of Slaby. See also 'Die Verbrennung in der Gasmaschine' Zeitschrift des Vereines deutsche Ingenieure Band XXX (1886) p.209

18. 'Marks and Clerk Collection' Science Museum Library, London. Details of many of Clerk's experiments are given. Lord Marks, formerly George Croydon Marks, was a distinguished engineer who, before forming a highly successful partnership with Clerk as patent consultants, was associated with Tangye's of Birmingham

19. D. Clerk, 'The Theory of the Gas Engine' Proc. Inst. Civil Engineers Vol. LXIX (1881-82) Pt. II pp.220-307

20. Jenkin op cit (8)

21. Witz op cit (17) pp. 79-115; 128-132

22. R. Schöttler, 'Die Verbrennung in der Gasmaschine' Zeitschrift des Vereines deutsches Ingenieure Band XXX (1886) p.209

23. The first German patent, 532/1876 of 5 June and the later one 2735/1877 of 1 June were together re-dated as

4 Aug. 1877, when the patents previously granted by individual states were taken over in 1877 by the Imperial German Government (see ref. 2)

24. Friederick Sass, Geschicte des deutschen Verbrennungs-motorenbaues von 1860 bis 1918 (Berlin 1962) pp.56-65 pp.162-166 See also Lynwood Bryant 'The Invention of the Internal Combustion Engine' Technology and Culture Vol. VII No. 2 (1966) and Vol. VIII No. 2 (1967)

25. Information about Beau de Rochas can be found in two groups of articles. Bulletin de la Société d'Encouragement pour l'Industrie Nationale Vol. CXXXVII (1938) pp.209-239 particularly that by C. Walckenaer 'L'invention de Beau de Rochas' pp.212-225. Secondly, Document pour l'historie des techniques' Cahier No. 2 (1962) pp.3-42 particularly that by Jacque Payen, 'Beau de Rochas, Etude biobibliographique' pp.3-24

26. English translations of the relevant sections of the Beau de Rochas Tract can be found in The Engineer Vol. 60 (1885) p.441 and B. Donkin The Gas, Oil and Air Engine (London 1900) p.467

27. Zeitschrift des Vereines .. Band XXVIII (1884) pp.45-47

28. The English patents for Lenoir's four-stroke engine 5315/1883 and 610/1885

29. Sass op cit (24) p.57

30. The Engineer Vol. 60 (1885) p.435

31. Sass op cit (24) pp.58-66 after making a critical appraisal of Reithmann's claim, dismisses it

32. This is extremely unlikely. Engine technology in Germany in 1852 was virtually non-existent. In addition, great difficulties were being experienced with fuels. See 'The Gas Engine - its Formative Years and Relationship with the Gas Industry' by K.A. Barlow, Manchester Association of Engineers No. 4 March 1977

33. Copies of Schröters drawings are given in Zeitschrift des Vereines ... Band XXVIII (1884) p.46

34. A misleading account of the Reithmann case is given by

Hugo Güldner. <u>Das Entwerfen und Berechnen der Verbrennungsmotoren</u> (Berlin 1905) Güldner never mentioned the reversed decision and implies that Schröter's drawings were those of the real engine

35. Constant von Wurzbach, <u>Biographisches Lexicon des Kaiserthums Österreich</u> (Vienna 1867) p.422

36. Langen Archives KHD Werkmuseum, Deutz, Cologne. The letter is dated 21 September 1867

37. U. Tischler, 'Das Erste Marcus Automobil' <u>Allgemeine Automobil-Zeitung Wien</u> Vol. II (Oct. 1909) pp.13-15

38. This particular patent suit was brought by the Electric Vehicle Co. claiming infringement of the Selden Patent by the Winton Co. in 1900

39. Bryant <u>op cit (24)</u> p.193

40. A copy of this letter is given in Gustav Goldbeck <u>Gebandigte Kraft</u> (Munich 1965) facing p.33

CHAPTER SEVEN

THE DEVELOPMENT PERIOD - POST 1876

In the field of internal combustion engines, the invention of the four-stroke engine in 1876 had the biggest single impact of all the events that occurred in the nineteenth century. First reactions to it, however, were not at all as favourable as might well be imagined. Following its introduction, a number of technical problems remained to be solved and, almost immediately attempts were made to replace it with engines that produced more frequent firing strokes. In addition to this, much confused thinking had been shown to exist as to the precise working of the four-stroke engine.

In this chapter, the technological progress that was made from 1876 to 1900 is recorded. The nature of the initial difficulties experienced is given and then followed by an account of the methods that were tried to overcome them. Other ideas, with regard to engine operation and design that were put forward are discussed, and some conflicting situations that reflect a good deal of uncertainty in understanding are related.

Two outstanding features of this period emerge. One is the extensive uses that industry found for the gas engine and the other is the contribution made by numerous other manufacturers of gas engines after 1890. The first point is discussed fully in chapter nine, but it may be mentioned here that, in the late 1870's and during the 1880's a very successful merger between gas engines and electrical generators took place and the circumstances which made this possible and the

THE

"OTTO" SILENT GAS ENGINE.

In this Gas Engine there is no explosion in the usual sense of the term.

A part only of the charge is combustible, instead of the whole or as much as possible.

The proportion of Gas to Air is only as say 1 to 16, instead of as usual, 1 to 7.

The result is less suddenness of pressure, consequently less loss of heat, and vastly greater useful effect.

To burn a compound of Gas and Air in which is so little Gas, it is necessary to raise it to a pressure of say 30 lbs. above the atmosphere before ignition. This is here accomplished in the simplest way by the piston of the Engine itself, without the employment of any pump or the slightest additional complication.

The non-combustible portion of the charge is heated by the combustible portion, and acts as a reservoir of force to be gradually given out during the stroke, as shown by the diagram.

The charge is ignited at the beginning instead of at the middle of the stroke (as in the Lenoir and other Gas Engines), thus *leaving the whole stroke available for expansion*, instead of one half only; and entirely avoiding the jar occasioned by applying the power when the crank is at the middle *position*.

MANUFACTURED BY

CROSSLEY BROTHERS, Great Marlborough-St., Manchester.

LIVERPOOL AGENT:

ALFRED GADSBY, 59, Whitechapel.

Fig 7.1 Leaflet issued at the first public demonstration of the four stroke engine in Liverpool, 1877. The erroneous views held at that time, regarding the theory of the Otto engine, are well illustrated subsequent effects of this merger are described in this chapter. The more prominent of gas engine manufacturers and their contribution is given also and the chapter closes with a report of the Gas Engine Research Committee which was given in 1898.

7.1 The four-stroke engine in Britain - initial reactions and consequences

The first public demonstration of the four-stroke engine in Great Britain took place at the Royal Agricultural Show, held at Newsham Park, Liverpool in July 1877*. In commenting on its performance, The Engineer[1], stated:

> '....... probably the most interesting in the yard is the new 'Otto' gas engine shown at Messrs Gladsby's stand by Messrs Crossley. Nothing can be more simple than the principle and action of this remarkable engine, but as it is not generally understood, we do not apologise for explaining it here ....'

A leaflet, Figure 7.1 issued at the stand, reflects the erroneous thinking with regard to its mode of operation and ratio of gas to air that was used. Compared with the noisy and often violent atmospheric engine, however, it ran smoothly and quietly, this being sufficient for it to earn the name of 'Silent Otto'. The shock problem had clearly been diminished in severity, but other new problems now arose. Critics for instance were quick to point out that this new engine required two complete revolutions of the flywheel to complete its working cycle. It was noted also that the ex-

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* The first four-stroke engine made for public use was numbered 1300 and sold to Henry Rogers, East Harnham, Salisbury where it was used to drive three pumps in a chalk mixing mill

haust gases were emitted at a high temperature and at a pressure similar to that at which steam was admitted in a steam engine. Comparisons with the steam engine were thus made in which the advantages of the latter were pointed out; namely two working strokes per revolution, with little negative work being done. Such comparisons were, perhaps, premature and a little unreasonable, since by that time the reciprocating steam engine had reached its zenith as a piece of operating machinery. The criticism did have a useful function, however, because they focussed attention on the work that was now required on gas engines in order to realise improvements, particularly with regard to economy and performance. Another effect this emphasis had on these shortcomings was that it gave birth to ideas for two-cycle engines and other possible alternatives such as 'compounding'; but more urgent and immediate problems in 1877 were those concerned with ignition and the use of the slide valve which controlled ignition. The use of compression created new problems in these respects.

7.1.1 The slide valve used for ignition; its disadvantages and modifications that followed

In his four-stroke engine, Otto had succeeded in producing an ingenious adaptation of the slide valve he had previously used in the atmospheric engine (see Appendix One), but when used on the four-stroke engine, modifications were found to be necessary to cope with the increased cylinder pressures. These were not unduly high - in the region of 150 lbf/in^2, but this pressure required a force of no less than 500 lbf on the slide to prevent leakage. In addition, the heat generated by combustion and by the transport flame used for ignition made efficient lubrication of the slide surfaces impossible. Wear of the slide surface was thus rapid: they would become scored and leak, often they would seize up completely and no less than twice weekly had to be removed and the ports cleared of carbon deposits. It very soon became obvious that the slide valve was a definite hindrance to engine development, but the main difficulty at this time was that no alternative form of ignition had yet emerged. In the Spring of 1877, Otto had made a tentative approach to Werner Siemens to seek his opinion of electrical methods, but Siemens was against the use of electrical ignition and suggested that flame ignition was the best. Later, however, he did carry out some experiments on ignition devices using electricity, but nothing became of them. At about the same time, the idea of using incandescent means was suggested, but this too failed to materialise[2]. With this rather discouraging situation there was little else that Otto could do but to make the best use of the flame system he had available.

The first modification to the flame method that was used on the four-stroke engine was a joint effort by Otto and Crossley[3]. It consisted simply of a small hole (see Figure 2 in Appendix 1) drilled in the slide which, at the right moment, communicated with the main charge in the cylinder. The purpose of the hole was to equalise the pressure of the compressed charge in the cylinder and the small pocket of burning gas in the slide. A gas feed channel was later incorporated to prevent the transport flame burning itself out during the time the slide was moving[4]. This latter improvement was entirely the work of F.W. Crossley[5]. With these modifications the ignition aspect of the slide valve proved tolerable. The one inconvenience remaining was the maximum engine speed that was attainable. This arose because of the finite time required to purge the igniting port of burnt gas as the slide valve returned to prepare for a new cycle. It was this purging problem that gave rise to 'missed ignitions' frequently referred to in reports of engine trials. To overcome this difficulty, Crossleys patented a device in 1882[6] consisting of a coil of platinum, which was placed in the igniting port of the slide. The transport flame then kept the platinum at incandescence, thus assisting in the ignition of the new charge. It was while communicating details of this idea to his patent agents, Abel and Imray (in a letter to Abel and Imray op cit p.152) that Frank Crossley makes an interesting remark:

> '....... hitherto it has been impossible to light the charge with gasoline gas, we have now a means that enables us to do so even more effectively than by coal gas in the ordinary engine. Thus a large field is opened to our engines where coal gas is unobtainable. Moreover, the coal gas ignition is improved by this plan ....' *

A further ingenious attempt at improving ignition methods was made in 1882[7], again being mentioned in 'Letters to Abel and Imray' p.188 dated 19 September. Each end of a thin tube was attached to the combustion end of the cylinder, a section of the tube being brought to incandescence by an external flame. A specially prepared charge was then compres-

* Whether or not Crossley meant 'gas made from oil' or a liquid fuel,in which case the above is evidence of experiments with such fuels, is not quite clear. Otto's surface carburettor did not appear until 1884) See Figure 7.3

sed by a plunger into the tube, passing over the heated surface and igniting as it did so. The plunger also provided the correct timing by forcing the charge through the tube at a chosen moment. The idea does not appear to have caught on, (quite possibly there would be sealing difficulties of the plunger) and incandescent tube ignition of a different design to that just described, was not used on Crossley engines until 1888.

The use of slide valves also presented other difficulties and the problems of obtaining a seal on the one hand, but keeping the forces on the surfaces at a minimum to reduce wear on the other, were conflicting in the extreme. The slide faces had to be hand-scraped and carefully matched to its neighbouring surface, with port edges being left 'high' to provide a seal. Many devices, aimed at relieving the slide of pressure and friction during the induction stroke were tried. One idea of this kind was to allow a light spring to press on the slide cover during the low pressure strokes, but during compression and ignition, the slide would be tightened by a revolving cam pressing on the slide cover[8]. A later attempt to reduce friction on the slide allowed for the cylinder pressure to act on both sides of the slide - thus placing it in equilibrium with respect to the cylinder pressure[9]. From these numerous attempts involving slide valves, it appears that there was a great sense of frustration, generated by their enforced use, but although no effective solution was found, it did prove possible to make the slide valve and its associated ignition give a tolerable performance.

7.1.2 Compounding

Notable other improvements attempted in the early 1880's were those aimed at obtaining an increased number of firing strokes. Daimler had already tried this in 1879[10], by arranging two high pressure cylinders, one each side of a low pressure cylinder, the cranks for both types of cylinder being offset 180° from each other. The gases, after expansion in the high pressure cylinder, passed into the low pressure cylinder via lift valves, where further expansion took place. A few engines were actually made, but Daimler's design never became popular. Crossleys also made attempts to increase the number of working strokes per cycle and in a patent of 1881[11] suggested that the cylinder be only partially exhausted at the end of the working stroke. A new charge was then admitted in time to be ignited on the return stroke, the exhaust valve being modified to make this possible. Crossleys' enthusiasm for compounding revealed itself three years later[12]. The charge was to be exploded in a single-acting cylinder, which was fitted with a very long piston. As the piston moved along the cylinder a port was uncovered leading to one end of a second cylinder, also fitted with a piston - the burning gases then expanded in the second cylinder. In point of fact, the second cylinder was intended to serve a double purpose; at the opposite end the piston acted as a pump, forcing the new charge into the first cylinder. Later that same year, yet another attempt was made[13] using two cylinders, a high pressure and a low pressure, with more careful regulation of the admission, ignition and exhaust of the charge in the high pressure cylinder. No evidence can be found that any of these ideas were used in practice and it must be concluded, therefore, that they were generally unsuccessful.

A significant figure in these attempts by Crossleys during the years immediately following 1877 is one H.P. Holt, His name appears on a number of patent applications and F. W. Crossley, apparently, thought highly enough of him to seek his advice on a number of technical matters. Examples of these were Frank Crossley's idea to produce a tramcar driven by a gas engine in 1881[14] and an overhead travelling crane, also worked by a gas engine. Holt also appears to have been particularly interested in starting devices for the larger engines that were then being made[15]. There seems no doubt that he was an engineer possessing a good deal of ingenuity; the Directors' Minute Book of Crossley Bros. on 6 July 1881 shows that he became a shareholder on that date, by ..... 'handing in bank notes for 15 fully paid up ordinary shares at £100 each'..... Crossley Bros. became a limited liability company on 17 June 1881. On 26 October 1881, F.W. Crossley on behalf of Crossley Bros. Ltd. wrote to Holt accepting the latter's offer to avail his entire services to Crossley Bros. at a salary of £1,000 per annum[16].

7.2 Some conflicting ideas

7.2.1 in design and operation

For seven or eight years following the first public exhibition of the four-stroke engine at Liverpool, a variety of ideas for improvement emerged. For the most part, they failed to produce any practical result, but what is significant is that they conflicted most strongly with ideas that were current at the time, particularly with regard to combustion and illustrate the frailty with which such concepts were held.

The first of these extraordinary ideas took place in 1878 when Crossley Bros. attempted to make a non-compression vertical atmospheric engine to work on either a four-stroke or two-stroke principle[17]. Why should an atmospheric engine be once more considered at a time that the four-stroke compression had admirably proved itself? Another idea, equally baffling, occurred a year later. An engine was proposed in which the exhaust gases were to be expelled from the cylinder by compressed air, using a pump immediately the exhaust valve opened[18]. This conflicted most severely with the idea of stratification on which the patent claims were based and in which the retention of exhaust gases in the cylinder was regarded as so essential. A good deal of consideration during 1884 was given also to the elimination of valves altogether, the idea being to use the movement of the piston to control the admission, ignition and expulsion of the gases[19].

With the exception of that relating to the atmospheric engine, these were not necessarily bad ideas. Indeed, it may be said that such thoughts were a natural end and genuine attempt to bring about improvements and thus alleviate the criticisms that were being directed against the four-stroke engine. None of them appear to have been successfully applied and in attempting to explain why ideas such as these should be raised at this time, it seems quite probable that the four-stroke engine took longer to become widely accepted than is believed today.

By 1882 in spite of these uncertainties, some worthwhile progress in engine technology had been made, when compared with the Otto-Langen engine as the test data given later illustrate. The Otto-Langen engine was tested in 1884 and the Otto-Crossley engine in 1882[20].

	Otto-Langen	Otto-Crossley
Brake horse-power	2	2
Engine weight (pounds)	4000	1250
Piston displacement (cu.ins)	4900	310
Number of power strokes/min	28	80
Speed (rev/min)	90	160
Mechanical efficiency (%)	68	84
Brake thermal efficiency (%)	11.2	14
Indicated thermal efficiency (%)	16.5	16.7

7.2.2 In power ratings - nominal and indicated

One of the most significant contributions of the four-stroke engine was its increased versatility in terms of power output. It immediately made available a much wider power range. At the lower end of the spectrum, small vertical engines rated in 'man-power' appeared in 1885; at the upper end, engines of 40 indicated horse-power were possible from about 1879 onwards*. By the end of 1879, the range of engine sizes shown in Figure 7.2 were offered [21]. Horse-power became an important factor - it was also responsible for much confusion since engines were sold by 'nominal horse-power, a figure which eventually came to bear little relationship with the power available at the flywheel. Furthermore, no-

* The fuel cost in running these engines, however, appears to be excessive and complaints were made. ('Letters to Abel and Imray' p.234, September 1883)

Nominal hp	Maximum hp	Price less water vessel	Nett wt cwt	qr
½	3/4	£ 60	12	0
1	1½	100	18	0
2	2½	135	26	0
3½	4	170	32	2
6	9	210	52	0
8	12	250	54	2
*12	18	300	74	0
*16	24	350	120	0

Speed of all engines 160 rev/min.

Engine sizes available from Crossley Brothers, 1879 (data extracted from a prospectus of that year)

Nominal hp	Year built	HP rating bhp	ihp	Cyl. bore diam. ins	stroke length ins.
3½	1876	4.5	5.9	6.7	12.0
8	1877	11.5	14.7	9.0	16.0
1	1877	2.25	2.7	4.5	12.0
2	1878	2.75	3.96	5.7	12.0
½	1879	1.25	1.9	4.0	9.0
6	1879	9.05	11.5	8.0	16.0
*12	1879	19.0	24.0	11.5	16.0
*16	1879	32.0	40.0	13.0	18.0

The year of introduction of the various engine sizes and their dimensions. (data extracted from "A historical collection of notes", Crossley Brothers, Manchester) Note the gap between nominal and indicated power.

* These engines do not feature at all in copies of testimonials to 1880.

Fig 7.2

minal power was a variable and inconsistent property largely dependent on whose 'rule' was used.

The term nominal was first used in relation to steam engines, where eventually it came to create similar confusion. It was during the time of Watt and his earlier steam engines that a working cylinder pressure of 7 lbf/ins^2 was assumed, such a figure being then quite representative of actual working conditions. A standardised piston speed, dependent on the length of the stroke, was also used; for example, 160 ft/min with a 2 ft stroke and 256 ft/min with 8 ft stroke. The horse-power calculated by using these figures was fairly well matched to that which the engine could output and 'nominal horse-power' became a commercial standard by which engines were bought and sold. Immediately working pressures were raised, however, the nominal horse-power quoted for a particular engine was always less than that which the engine was capable of putting out. But nominal power still continued to be used. Within a few years, the result was that the comparison between the two powers - nominal and actual - became absurd. To add to the confusion, manufacturers of steam engines would introduce different rules. There was in existence a 'London rule', a 'Leeds rule' and a 'Glasgow rule'. Added to these was the 'Admiralty rule' which squared the diameter of the cylinder, multiplied the result by an assumed piston speed (obtainable from a table) and divided by 6,000[22]. The quoted horse-power of engines, even when they were of the same size, varied widely and this was due almost entirely to the failure to use a representative working pressure.

A similar mistake was used with gas engines and attempts by the author to establish some consistency between the nominal and actual horse-power quoted by manufacturers for engines proved quite fruitless. From these attempts, however, it did prove possible to derive a formula, by which the nominal horse-power was calculated. When applied, it gives values close to those quoted in manuals[23]. The expression obtained was:

$$\frac{D^2 \times \text{stroke} \times \text{rev/min}}{28,000}$$

where D = diameter of piston in inches and stroke is in inches. The expression is seen to take account of the three important variables, cylinder diameter, stroke and speed, but like that used with steam engines, it assumes a nominal pressure, in this case, a value of between 30 and 40 lbf/in^2 - the compression pressure before explosion. In practice, the mean effective pressure was more like 70 lbf/in^2 even in 1879. As compression pressures crept up, different manufacturers would adopt their own interpretation of which nominal pressure to use - thus adding to the already considerable confusion. Inconsistencies became even more widespread and one need look no further as to the reason why nominal power was of no use whatever in describing the capabilities of an engine. The practice was discontinued by Crossley Bros. about 1895[24]. All engines then were quoted by the brake horse-power and classified by a letter.

7.3 Engine power

7.3.1 The growth and availability

In tracing the development of engine sizes and available power that took place from 1876, the prospectuses issued by Crossley Bros. have been studied. During the first half of 1880's, a number of 12 and 16 horse-power nominal versions are displayed, but engines of these sizes do not feature well in copies of testimonials, (see Figure 7.2). A prospectus of 1882 for instance, containing letters from satisfied users of Otto-Crossley engines, shows only one 12 horse-power engine as working and no 16 horse-power engines referred to at all. A likely reason for this was that their gas consumption was high (due possibly to poor combustion chamber design - large surface areas exposed to the burning gases) and this is borne out by correspondence between Robert Wilson (the London agent for Crossleys) and F. W. Crossley dated September 1883[25] which reveals that difficulties were being experienced with these larger engines. A sixteen horse-power engine had apparently been sold to a customer, who was promptly landed with a weekly running cost of 31/6d (an eight horse-power engine would be expected to cost 12/-d per week). The Dowson 'Economic Gas' became available late in 1882 which made running costs much less and The Engineer of October 1883 shows a sixteen horse-power (nominal) Crossley engine operating on Dowson gas. Trials of it were reported as successful and these had led Crossleys to construct a two-cylinder engine to indicate seventy horse-power (55 bhp), which was fitted up at the works. This reference to Dowson gas appears to be the first indication of its use in Great Britain and there is no doubt that the developments in this field proved of enormous benefit to industry (see Chapter Nine). Up to 1884, therefore, (and perhaps as late as 1886, see Figure 9.1(b)) it would seem safe to assume that the maximum engine power that was in general use was only sixteen nominal, approximately twenty five brake horse-power. Towards the end of the decade, significant changes in engine design and construction took place, which had a pronounced effect upon the engine power available. These changes are discussed in the next Chapter.

About the middle of the 1880's, the first vertical four-stroke engines in England were built by Crossleys, the first being a two horse-power nominal, Figure 7.4 No. 7376. The crankshaft was at the top with the working cylinder outside the main frame. The advantage of these engines was in space-saving and they proved highly popular in industry with many uses being found for them. In 1885, the design was changed to make the cylinder central being then offered as a 'five Man-Power-Domestic'. The first engine number of this type was 8630. A one and a half horse-power nominal, first number 9170, was later offered. It was this particular engine that was later matched to a generator and sold as a complete unit, a combination highly appreciated by small traders.

Developments with regard to power output at the Deutz works in Cologne show that Otto was a little more adventurous than his licensees in England. Twin-cylinder engines, of nominal twenty horse power, were being used in 1880, four to five years before similar engines were available in Britain - a rather surprising fact when ordinary illuminating gas was much more expensive in Germany than in Britain. There is the possibility that Otto had succeeded in making these en-

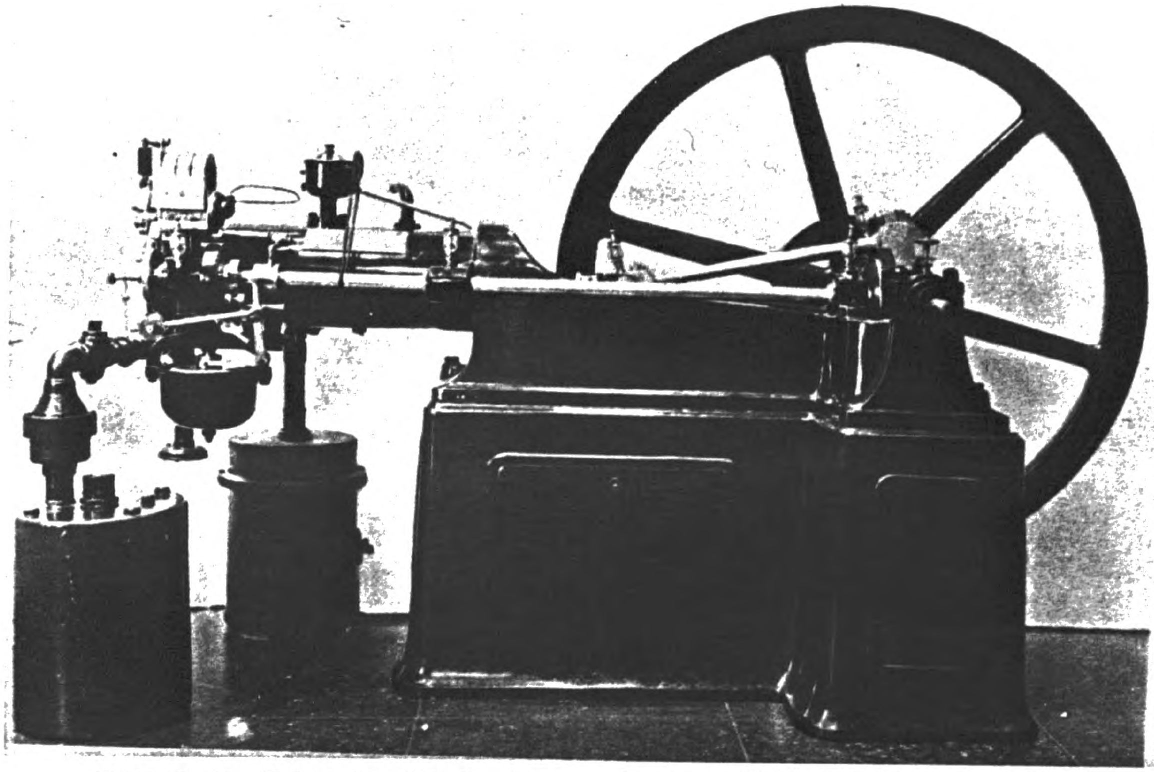

Fig 7.3 Liquid fuel four stroke Otto engine with magneto ignition by Gasmotoren Fabrik, Deutz 1884. Now exhibited in the Klöckner Humboldt Werkmuseum, Deutz.

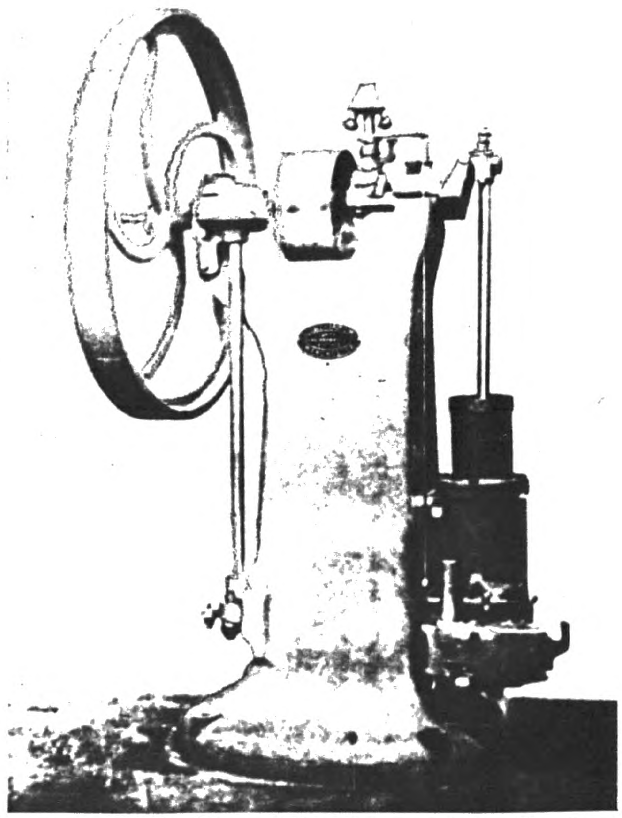

Fig 7.4 Example of the first vertical four stroke engine made by Crossley Brothers 1884. The cylinder is outside the main frame. Horse power is 2 (nominal) and the first engine of this type made was No 7376

gines run with a more acceptable economy; he was particularly successful at solving problems of this kind and after overcoming them, would eventually communicate his findings to Crossleys*. Also being carried out at Deutz was Otto's pre-occupation with ignition problems and by 1884 he had developed a low tension magneto system suitable for production models of both gas and liquid fuel engines. Otto was thus able to dispense with the slide valve, permitting him to raise the engine power with little effect upon economy since he would raise the compression pressure. It is interesting to note that Crossleys did not use the magneto, preferring it seems the heated tube methods. A comment in 'Letters to Abel and Imray' discloses F.W. Crossley's thoughts on electric ignition when, after carrying out tests to establish the stratification theory in preparation for the patent trials during the early 1880's, he states that

> 'not enough is known about the effect of electric ignition upon gases.'

It may, therefore, be construed that Crossley was wary of its use and that two quite distinct schools of thought existed as regards ignition, between Otto and his English licencees.

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* 'Letters to Abel and Imray' op cit. Shows a good deal of correspondence between Otto, Langen and F. W. Crossley discussing technical problems. Ideas flowed in both directions, always in the friendliest of terms.

7.4 Improvements in engine design 1886-96

By the end of the year 1886, a total of 20,000 Otto engines had been sold throughout the World. A year later, the figure was 27,000. The design of these engines had remained basically the same since 1877. There had been minor changes in the design of the governor and their appearance had been made more aesthetically pleasing to the eye, but the main feature of the early engines - flame ignition, slide valve and general design - had been maintained in Great Britain. In the ten year period 1886-96, some quite radical changes took place and a number of events which proved later to have a pronounced effect upon engine technology occurred. The Otto patent, for instance, expired in 1890, which resulted in a wealth of pent-up ideas being unleashed by countless manufacturers, most of whom had spent the best part of a decade in frustration at not being able to circumvent its claims; developments in electrical technology with regard to generating machines and incandescent lamps, created a need for a suitably small prime mover; the slide valve was abandoned in 1888[26] and a number of ingenious engine starting devices were introduced for very large engines. The power ceiling of engines went up in leaps and bounds and by the end of the period, the gas engine industry was transformed as individual firms such as Andrews, Barkers, Tangye, Dick, Kerr & Co., Robey and Fielding and Platt to name just a few, made their contribution. Countless other smaller firms also began making gas engines and some of these, together with those given above, will eventually be discussed. First, the changes in design will be described.

7.4.1 Improvements in construction details - slide valves, gear drives, tube ignition, valve ports and combustion chambers

In order to assess the technological progress in engine design that took place during this period, drawings and performance data of two engines, a six horse-power nominal, built about 1881 and a nine horse-power nominal, Figure 7.5, built about 1892, have been studied and compared[27]. The most immediate and apparent difference is the replacement of the slide valve by the heated tube method of ignition (the first engine ever fitted with a heated tube was a 14 horse-power nominal No. 11284). The beneficial effect of this improvement cannot be overstated. Almost immediately, increased compression ratios became possible with a consequent increase in thermal efficiency and economy. It also became possible to exercise greater control over ignition timing by placing a valve at the entrance to the tube. Without the troublesome slide, lubrication was greatly simplified and mechanical efficiency increased. Another difference was that in earlier engines, the cross-head slide and cylinder were in two distinct parts and great care had to be taken to bolt them together in accurate alignment. On the later engine, the cross-head slide is dispensed with; the piston being made much longer to serve the double purpose of guide and seal.

Still on construction details, the bevel gear wheels used on the older engines to drive the side shaft were replaced with worm gears, having a greater efficiency and providing a reduction in size. There would seem, also, towards the end of the period, to have been a realisation of the need to keep at a minimum the surface area of combustion chamber exposed

	6 NHP No. 4683	9 NHP No. 19772
Cyl. bore (ins)	8	9
Length of strokes (in)	16	18
Compression ratio	2.5 : 1	3.5 : 1
Compression pressure lbs/ins^2 (G)	31	48
Explosion pressure lb/in^2 (G)	126	200
Mean effective pressure	57	81.5
Revolutions per minute	164	164
I.H.P.	9.0	19.25
B.H.P.	6.75	15.75
Gas consumption cu. ft. (per IHP./hr)	25.5	21.2
Indicated thermal efficiency (%)	15.9	17.5
Mechanical efficiency(%)	75.0	82.0
Area of inlet port(ins^2)	Slide valve 1.5	2.3/8s" dia 7/8 inch lift = 4.43
Inlet port setting	¼" open with piston on 'in' centre: closes when piston is 1/8" on outer centre	Opens on 'in' centre. Closes when piston is 1½ inch on outer centre
Exhaust valve	2½" diam 3/8" lift. 2.65"^{2}	3" diam 1¼" lift 7.06"
Exhaust valve setting	Opens when piston 1" before outer dead centre. Closes when piston ½" after 'in' centre	Opens when piston 2½" before outer dead centre. Closes on inner centre
Ignition timing	Ignition port is 1/8" open when piston on 'in' centre (slide)	Tube with timed valve. Opens when piston is 1½" before inner centre
Charge velocity (ft/s)	244	128
Exhaust velocity (ft/s)	137	81
Piston speed (ft/min)	437	480

Figure 7.5 Comparison of engine performance and other data of two Crossley-Otto engines 1882 and 1892

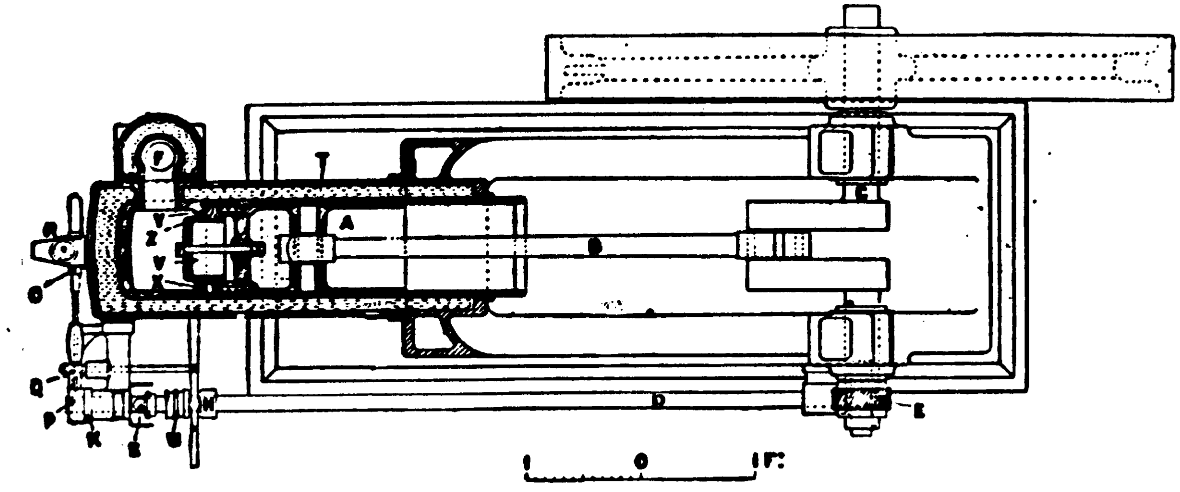

Fig 7.6 Sectioned drawing of a 9hp (nominal) Crossley gas engine, No. 19772, built in 1892 and put to work at the Clifton Rocks Railway, Bristol.

A - piston

V - metal block attached to piston to increase the compression ratio

Y - annulus formed by the attached block and outer end of cylinder, x.

R - ignition tube

E - worm gears for sideshaft

F - exhaust valve

to the combustion gases, although the latter was not pursued as extensively as it might have been.

Consistent with these structural changes which did much to improve the general running and appearance of engines, were improvements in valve design and porting. Older engines, particularly those up to 1885, possessed lengthy exhaust ports, with the valve being situated quite some distance from the cylinders, greatly increasing the heat loss and thus potential work obtainable from the gases. The port area and lift of the poppet-type valve were clearly inadequate - a feature which reflects the thinking at the time, that it was essential to maintain some burnt gases in the cylinder. Severe throttling of both exhaust and inlet gases, therefore, would take place. In these older engines, because of this throttling effect, the exhaust gases would exit at something like 137 ft/second and the inlet gases would admit at speeds exceeding 240 ft/second*. By comparison, the velocity of the exhaust and inlet gases in later engines was 48 ft/second and 87 ft/second respectively, giving a much better 'filling' and 'clearing' action.

Notwithstanding these improvements, however, a detailed examination of a drawing of the later engine, Figure 7.6 reveals some details which shows that the level of understanding of engine technology was by no means as far advanced as it might have been. There is, for instance, the fact that the compression ratio had been increased by attaching a piece of

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*These figures were calculated from the ratio

$$\frac{\text{gas velocity}}{\text{piston speed}} = \frac{\text{cylinder area}}{\text{port area}}$$

metal to the piston crown, thus providing an even greater cooling area and what appears to have been entirely unappreciated, was that the added metal, which was of smaller diameter than the piston, created an annular space into which the flame would be dragged and exposed to a large condensing surface. Placing material on pistons in this manner is particularly bad practice and it is surprising to find such measures were resorted to at that stage. A further mystifying situation arises in that the reduction of the surface area of the combustion chamber is not carried out as fully as it could have been. The design shown, apart from its large surface area, has ports and passages with masses of metal placed here and there. They apparently serve no useful purpose, their presence is unnecessary and they serve only to receive heat that could otherwise have been usefully used. A possible explanation is that this particular engine may well have been an earlier one on which ideas were being tested and evaluated - hence the crude attempt at increasing the compression ratio. Apart from these shortcomings, there can be little denying that progress had been made, particularly with respect to fuel economy. The comparison of engine data shown in Figure 7.5 illustrates this quite effectively.

These improvements in economy led to a consequent increase in power output. A prospectus of the 1890's put out by Crossleys, shows new designs of horizontal engines, incorporating tube ignition and worm gearing for the drive shaft. Single cylinder engines of 25 horse-power nominal (85 indicated) being available. A number of twin cylinder engines, Figure 7.7 of varying powers are also featured, the most ambitious being a sixty horse-power nominal, indicating about

170 - all it is claimed, able to run off ordinary illuminating gas. In the same prospectus is shown a five man-power nominal to 1½ horse-power nominal vertical engine surprisingly still fitted with a slide valve and flame ignition and driving a small dynamo. In 1893, a double-cylinder engine (vis-a-vis) of 80 horse-power nominal, Figure 7.8, indicating 250 horse-power was produced; again to run off common coal gas if required. By 1899 a 400 horse-power two-cylinder horizontal engine was available.

7.4.2 Scavenging engines

Before passing on to a discussion of the Otto gas engines produced by other manufacturers, mention will be made of the 'Crossley-Otto Scavenge Engine' first produced in 1894, since this particular engine represents a substantial technological achievement. It had been known for some time prior to 1894 that the pressure of the exhaust gases discharging in the pipe was superseded by a partial vacuum, to be followed again by a high pressure; in other words, the pulsations or oscillations of pressure that occur in the exhaust pipes of internal combustion engines were appreciated by that time. It was also realised that,if the period of pressure could be made to coincide with the opening of the exhaust valve, there would be a beneficial effect in clearing out the exhaust gases from the cylinder. This is the basis of a 'tuned' exhaust system. It was F.W. Crossley and James Atkinson who made this idea practical, producing enormous advantages to engine economy and performance. What they did was to fit a long exhaust pipe, 65 feet in length (the length and diameter was obtained after much experiment). The effect of this was to create exact timing between the occurrence of reduced pressure and the approach of the piston to the end of its exhaust stroke. The exhaust valve would then be kept open at the same time that the air inlet valve was kept open; a rush of air would then enter the combustion space, clearing out the exhaust gases and filling the cylinder with a new supply. To assist the flow of air and gases into the cylinder, passageways were shaped so as to offer little restriction; the piston crown was also shaped concave spherical.

Performance details[28] for a four horse-power nominal scavenge engine are remarkable when compared with normal engines. A single-cylinder engine of bore 7 inches and stroke 15 inches gave 12 brake horse-power, with a gas consumption of only 17 cubic feet per brake horse-power per hour (a normal 4 horse-power nominal would give about 7 horse-power on the brake and consume about 24 cubic feet of gas). With the scavenge engine in mind, the following shows what had been achieved since 1881.

Type of Engine	Gas consumption cu.ft/bhp/hr.	Compression pressure lbf/in^2
Slide valve 1881	34	30
Lift valve 1894	25.9	46
Lift valve 1894 Scavenging engine	17.0	87.5

Tests made on a larger scavenging engine of cylinder 11½ inches diameter and stroke 21 inches show even greater economy. The indicated power was 46.8 horse-power (approximately 38 bhp) with a gas consumption of 16.5 cu.ft/bhp/hr

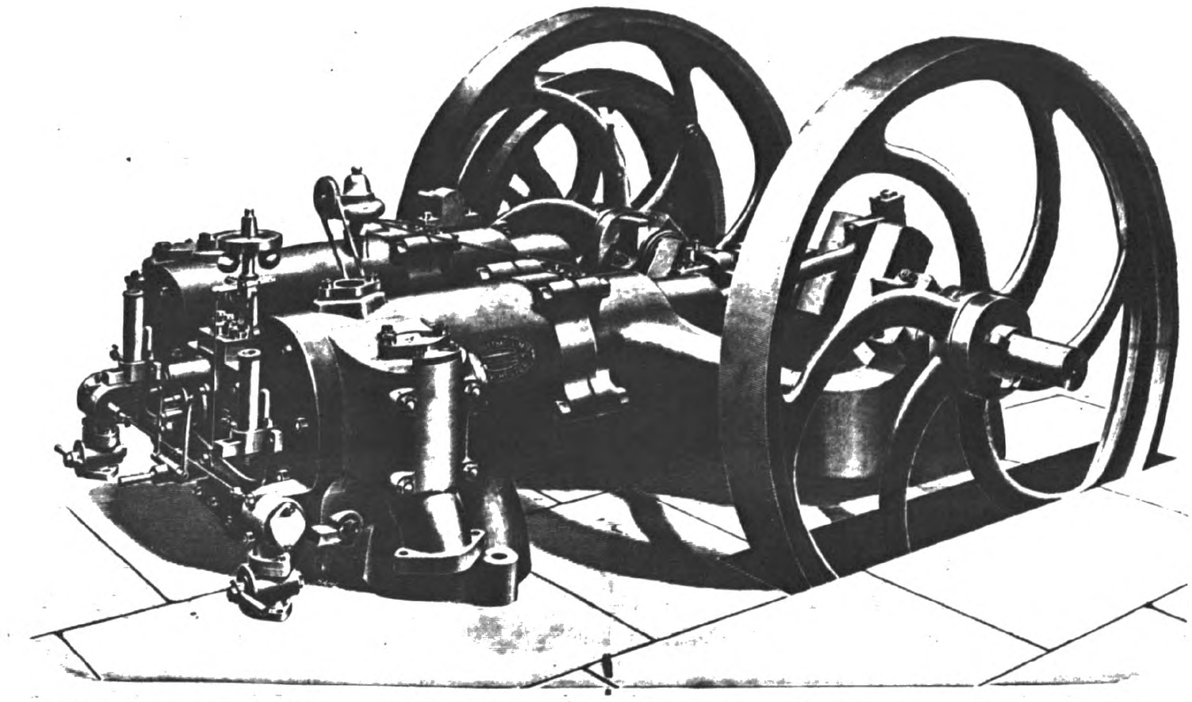

Fig 7.7 A Crossley 'twin' cylinder, C.1892, of 30 nominal, indicating 80 horse power.
Dimensions: length 17ft; width 7ft 2ins; flywheel 7ft 3ins; speed 160rev/min.

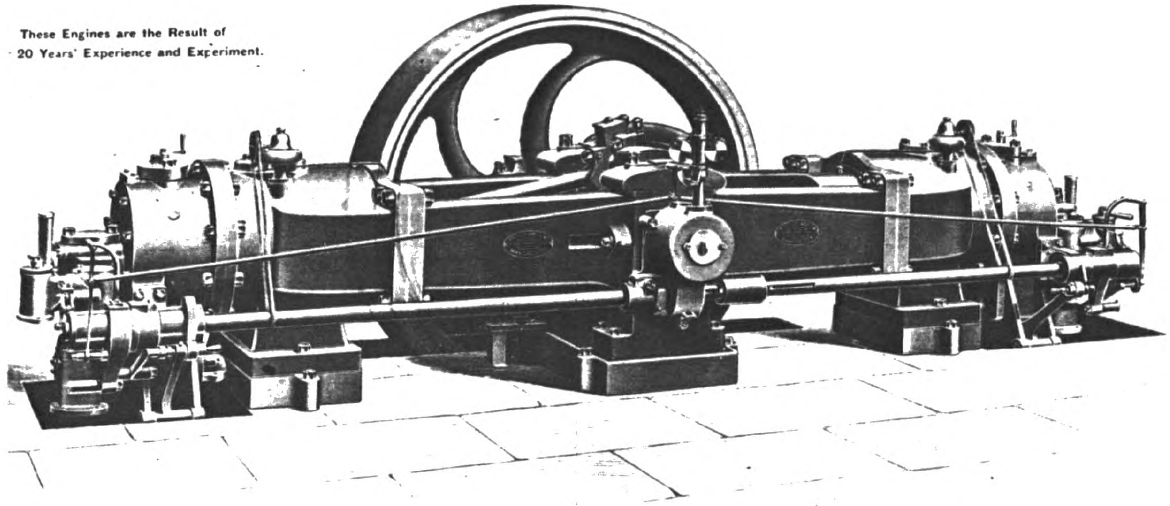

Fig 7.8 A Crossley 'Vis-a-Vis' tandem gas engine, 1895 of 80 nominal indicating 220 horse power.
Dimensions: length 21ft 6ins; width 10ft; flywheel 7ft 6ins; speed 160rev/min.

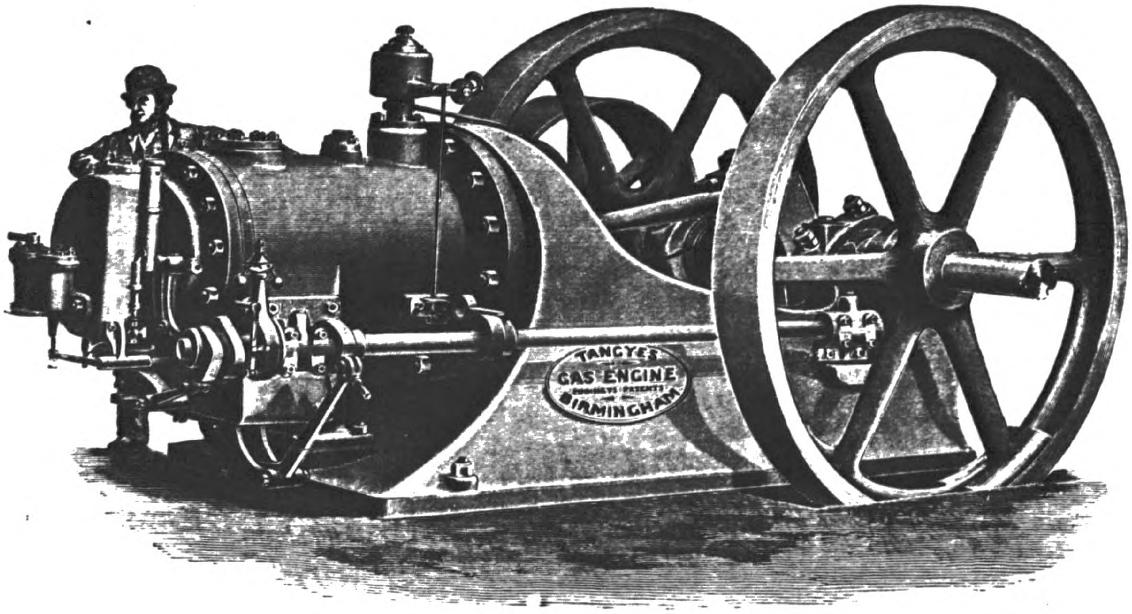

Fig 7.9 A 40 nominal horse power engine by Tangyes of Birmingham. C.1895.

Nom. h.p.	B.h.p. (Maximum)	I.h.p. (Maximum)	Speed (Revs. per Minute)	Size of Fly-wheels		Driving Pulley		Diam. of Cylinder	Length of Stroke	Diameter of Crank Shaft
				Diam. in.	Width in.	Diam. in.	Width in.	in.	in.	in.
Vertical										
½	2	2¾	230	36	3½	10	5	—	—	—
½	2¼	3	230	36	3½	10	5	—	—	—
1	2¾	3½	200	44	4	12	6	5	10	1⅞
1½	3½	4½	200	44	4	12	6	—	—	—
Horizontal										
½	2	2¾	230	36	3½	10	5	—	—	—
¾	2¼	3	230	36	3½	10	5	—	—	—
1	2¾	3½	225	39	4	12	6	5	10	1⅞
1½	3½	4½	200	44	4	12	6	—	—	—
2	4¼	5½	200	44	4½	16	7	—	—	—
3	6	7½	200	54	5	16	7	6	12	2½
4	7	9	200	54	5	16	7	—	—	—
5	9	11	200	60	6	20	8	—	—	—
6	11½	13½	200	60	6	20	8	—	—	—
7	13½	16	180	60	6	24	10	8½	16	3¼
8	15	17½	180	60	6	24	10	—	—	—
9	17	20	180	60	8	27	12	—	—	—
10	19	22	180	60	8	27	12	10	18	4
12	23	27	180	60	8	30	13	—	—	—
14	31	36	170	66	8	36	15	11	18	—
16	36	42	170	66	8	42	17	13	21	5
20	43	50	160	72	9	48	19	13½	22	5½
25	55	65	160	72	9	48	19	15	22	—
30	73	85	160	81	10	54	21	17	24	—
35	85	100	160	90	10	54	23	18	24	—
40	98	115	160	90	11	54	23	19	24	—
		Producer Gas 196	150					24	30	

Fig 7.10 Range of engines manufactured by Tangyes up to 1895.

and a thermal efficiency of 24%. Within thirty years, therefore, the progress with gas engines was such that gas consumption had been halved and compression pressures trebled. Atkinson, in a paper he read before the Manchester Association of Engineers[29], wrongly attributes the economy of these scavenge engines wholly to the scavenging action and neglects to mention the use of increased compression pressure. Scavenge engines ceased to be made in 1904 at which time engines were being made as standard with performance and economy comparable to the scavenge engines.

7.5 Other manufacturers of Otto gas engines

Prior to the expiration of the Otto patent in 1890, a number of gas engines were being made by various manufacturers who, in order to avoid infringement, were forced to resort to various design alternatives. Most of the ideas they tried were of doubtful utility; many came close to infringement and their makers received warnings from Crossleys which, in view of their previous successes in the High Court patent cases, had to be taken seriously. This particular time was a very frustrating one for these other manufacturers and their attempts to combat it produced engines of ingenious designs. The most popular theme involved attempts to produce engines that would work on the two-stroke cycle principle*. Other attempts revived the double-acting idea used by Lenoir. The performances of engines that were actually made, however, were never able to match up to that of the

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* These are discussed separately in Chapter Eight

Otto engine, but a sufficient number were made to cause the Crossley Brothers some concern. The greatest frustration felt by those involved, arose from the generally uncertain concepts that existed with regard to the theories of how the Otto cycle worked. Such was the state of knowledge and level of understanding related to such matters that whatever design or method of working any individual felt disposed to try, sooner or later he would receive a warning from Crossleys (see Chapter Six). In spite of this, several of these engines found a market for a limited time, but ceased to be made when attention could freely be given to the production of the four-stroke engine after 1890. When this occurred, there were immediate benefits to industry; engine prices tumbled - Crossleys were forced to reduce their prices by about a third - an overwhelming variety of engine sizes and types were made available to industry and the quality, which can be attributed to their former experiences, was commendably high. The foremost of these manufacturers and a description of their engines will now be given. The information, unless otherwise indicated, has been collated from assorted descriptions given in the various engineering journals, mainly The Engineer, Engineering, The Practical Engineer and Practical Mechanics Journal.

7.5.1 The Tangye Brothers of Birmingham[30]

Amongst the foremost manufacturers of gas engines who, next to Crossley Bros, built some of the largest in England, was the firm of Tangye. By 1900 they were able to offer single-cylinder engines ranging from a half to two hundred brake horse-power and two-cylinder engines from 86 to 292 brake horse-power, operating with town gas. The principle features of Tangye engines were the conical shaped combustion chambers and a very sensitive governor which provided steady running. Their speciality was undoubtedly large engines (Figures 7.9 and 7.10) and towards the end of the century, they produced an engine with a bore 24 inches and stroke 30 inches, running on Dowson gas. The coal consumption was 0.8 lb of Welsh anthracite per indicated horse-power, per hour. In 1895, Tangyes developed their own gas producing plant. The firm was also one of the first to introduce a gas-operated forging hammer. The smallest one of ¾ cwt. was capable of 120 blows per minute or 2,500 blows for one pennyworth of gas, at 2/6d per 1,000 cubic feet.

Originating from Cornwall, the Tangye brothers, Richard, James, Joseph, George and Edward, after spending some time going their separate ways, came once more together and formed their first company under the name of James Tangye and Brothers in 1857 with premises in Mount Street, Birmingham. The main line of business at that time - and for some years to come - was hydraulic jacks and lifting gear. A few steam engines, entirely hand made, were constructed for a special order in 1858. Until their interest in gas engines, the manufacture of industrial lifting equipment continued to be the main interest.

The success of the Otto engine apparently caught the imagination of Tangyes during 1879 or 1880, who then began searching for an engine which would be worth building. After rejecting a number of 'paper engines', that of Horace Robinson of Manchester was accepted. Robinson, however, was none too prompt in forwarding his drawings* and Tangyes, after negotiating with James Robson of Newcastle, began to make his engine, a two-cycle version which was patented in 1879. About three hundred were actually made. The firm of Tangye was also notable for its association with Dugald Clerk (later Sir Dugald) who became one of the most distinguished authorities on gas engines. Like Robson, Clerk was a pioneer of two-cycle engines, and Tangyes built Clerk engines for about a year between 1886-7. It was during this time that Clerk, who by now had become a highly respected and acknowledged expert on internal combustion engines, formed a lifelong partnership with George Croydon Marks (later Lord Marks); in 1888 the firm of Marks and Clerk, Chartered Patent Agents was established.

7.5.2 Andrews of Reddish and the Stockport engines

One of the strongest competitors to the Crossley-Otto engines was the Stockport, made by the firm of J.E.H. Andrews, Reddish. Founded in 1878, its principal interest at that time was in the manufacture of tobacco and textile machinery, but a visit to the Paris Exhibition of that year by J.E.H. Andrews put a new emphasis on the firm's activities; Mr. Andrews was apparently impressed by the Bisschop engine patented in 1872[31]. Shortly after his visit to Paris, he entered into an arrangement to build and sell them in Great

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* Evidence that Robinson's engine, a two-cycle type, was built by Tangyes is given in Section 7.7. A detailed discussion of Robson's patents is given in Chapter 8, Sec.8.1

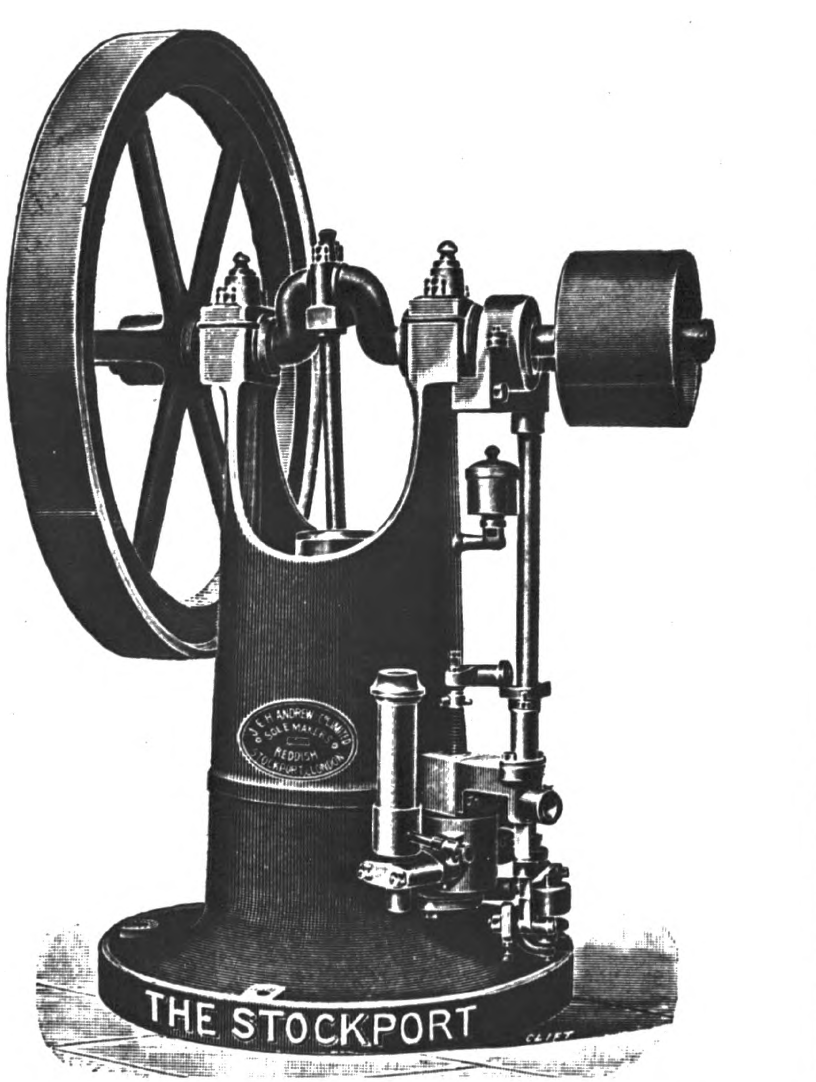
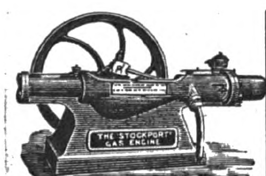


Fig 7.11 A 5 brake horse power Stockport Vertical



These Engines are used for driving

Air Propellers and Ventilating Fans.
Band Saws.
Boot Cleaning Machines.
Boot and Shoe Machinery.
Bottle Washing Machines
Carpet Beating Machines.
Chaff Cutters, Corn Crushers, Churns, etc.
Cloth Cutting Machines.
Coffee Mills, Sugar Chopping, etc.
Cutlers' Tools.
Dentists' Tools.
The Electric Light.
Driving Saws.
Fruit Cleaning Machines.
Lathes (Wood and Iron Turning).
Lathes (Amateur).

June, 1887.

PRICE LIST.

(DELIVERED IN REDDISH.)

NOMINAL POWER.	APPROX. INDI. H.P.	PRICES.	EXTRA FOR WATER TANKS.	Dimensions of Engines.	Approx. net weight of Engines.	Standard size of Pulley.	Diam. of Fly Wheel.
"BISSCHOP"				ft. in. ft. in.	cwts qrs.	Dia. Wid. in. in.	ft. in.
¼ H. P.		£33	No Water Tanks required for these sizes of Engines.	2 9 x 2 0	5 1	10 x 5	2 8
½ ,,		40		4 0 x 2 9	11 0	16 x 5	3 9
"STOCKPORT."							
¾ H.P.	2	60	£1 10	5 4 x 3 3	11 3	10 x 6	3 4
1 ,,	2¾	85	2 10	5 9 x 3 6	18 0	14 x 6	3 10
2 ,,	4	125	3 0	6 9 x 3 8	24 2	16 x 7	4 3
3 ,,	6	143	3 10	7 4 x 3 10	26 3	18 x 7	4 5
4 ,,	8	160	4 0	7 4 x 4 0	31 1	21 x 8	5 0
6 ,,	12	190	4 10	8 0 x 4 6	39 1	23 x 9	5 3
8 ,,	15	230	5 0	8 6 x 4 9	47 2	26 x 10	6 0

All these Engines impart an impulse **every** revolution when working to their full power, and consequently run **steadier** than Gas Engines only imparting an impulse to every **alternate** revolution.

Notwithstanding statements to the contrary, these Engines **consume no more gas** than any other Gas Engine when working under precisely similar conditions, and consume from 10 to 20 % less oil.

They occupy less area floor space than any other Gas Engine of similar power.

The Engines can be seen working in most of the important towns in Great Britain.

Engines and Pumps Combined. Prices on Application.

Engines can be purchased on the Deferred Payment System. Terms on Application.

OVER 1,500 TESTIMONIALS RECEIVED.

These Engines are used for driving

(Continued.)

Laundry Machinery.
Looms (Lace, Hosiery, Silk Winding, etc.)
Mineral Water Machines.
Printing and Lithographic Machinery.
Pumps in Deep Wells.
Organ Blowing.
Pumps for Ammonia and other Liquors.
Roller Ending Machines
Rotary Hair Brushes.
Sausage Machines.
Sewing Machines.
Stamping Machines.
Tailors' Machinery.
Wood Working Machinery.

Previous Lists hereby Cancelled.

Fig 7.12 Range of two stroke engines manufactured by the Stockport Gas Engine Co. prior to the expiration of the Otto Patent in 1890

Britain. About 1880 J.E.H. Andrews died, and control of the firm was taken over by his brother, C.H. Andrews. It was around this time that C.H. Andrews became associated with a Mr. Hugh Williams, a civil engineer of Wigan who was then experimenting with his own version of a two-cycle engine. It was Andrews and Williams' combined efforts which brought about the original Stockport gas engine, the first being sent out from the works in 1882. It had two cylinders, one pumping and one motor, a commonly-used design at that time, but on this engine, were placed end to end. The compressed charge was conveyed from one end to the other. The crankshaft was situated between the two cylinders, (Figure 7.12) and, unlike the Otto engines, had two slide valves, a vertical one for admitting the charge and a horizontal one with a cavity for carrying the ignition flame. This engine also incorporated an ingenious idea, first introduced during 1883[32], for relieving the slide valve pressure. The device consisted of a check valve placed in the passage between the combustion chamber and the slide valve. On compression of the charge, the check valve was closed, leaving a small portion of charge at atmospheric pressure in the passage. When the ignition flame was introduced, this small charge ignited and expanded, raising the check valve and allowed communication with the main charge in the cylinder. The check valve then closed, isolating the pressure rise in the cylinder to prevent its acting on the slide.

The engine was eventually made in sizes of 2 to 10 nominal horse-power; it was later made in a vis-a-vis version, developing 40 indicated horse-power. Its operation was perfectly satisfactory but fuel consumption was generally thought

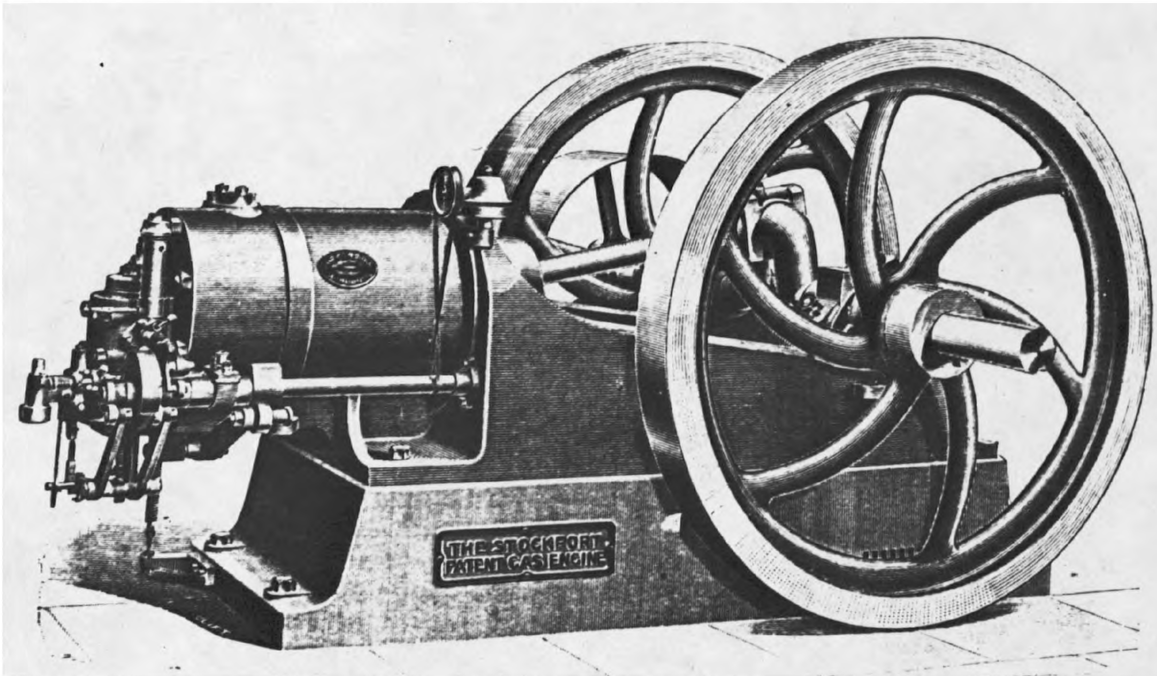


Fig 7.13 A Stockport engine, 21 brake horse power. C 1895.

Brake or Effective h.p.	Speed (Revs. per Minute)	Dimensions of Engines				Approx. Weight of Engines		Size of Fly-wheels			Driving Pulley		Diameter of Cylinder	Length of Stroke	Diameter of Crank Shaft
		Length		Breadth				Diam.		Width of rim	Diam.	Width			
		ft.	in.	ft.	in.	cwts.	qrs.	ft.	in.	in.	in.	in.	in.	in.	in.
Vertical															
1½	200	3	4	3	0	13	2	3	4	3½	10	6	—	—	—
5	200	3	6	3	3	22	2	4	3	4	18	7	—	—	—
Horizontal															
1	From	4	9	2	6	9	2	2	9	2	9	5	—	—	—
2	190	5	3	3	0	13	2	3	0	2½	10	6	—	—	—
3	to	5	9	3	9	18	0	3	3	3	14	6	—	—	—
4	220	6	9	4	0	27	3	3	10	4	16	7	—	—	—
7	From	7	0	4	3	32	0	3	11	4	18	7	—	—	—
9	190	8	0	4	6	38	0	4	3	4¾	21	8	—	—	—
10½	to	8	3	5	0	45	2	4	4	5	21	8	—	—	—
12	210	8	6	5	3	53	0	4	8	5	23	9	—	—	—
15	From	8	9	5	6	60	1	4	9	5½	23	10	—	—	—
17½	175	9	0	6	0	66	0	5	2	6	27	12	—	—	—
21	to	9	3	6	3	74	3	5	3	6	32	12	—	—	—
26	190	9	9	6	6	90	0	5	3	6	36	12	—	—	—
30	From 160	10	0	6	9	100	0	5	4	6	44	14	—	—	—
35	to 175	10	6	7	0	112	2	5	5	6	46	15	—	—	—
44	160	11	10	8	3	148	0	6	2	9	54	19	—	—	—
54	160	12	0	8	3	190	0	6	3	9	54	23	—	—	—
70	155	13	0	8	6	210	0	6	10	10	—	—	—	—	—
85	150	15	3	8	9	245	0	7	0	10	—	—	18	24	—
100	150	17	3	10	0	360	0	7	2	10	—	—	—	—	—
135	140	—		—		—		—		—	—	—	22	30	—
200	120	—		—		—		—		—	—	—	25½	30	—
Tandem															
400	120	—		—		—		—		—	—	—	25½	30	—

Fig 7.14 Range of four stroke engines manufactured by the Stockport Gas Engine Co. to 1896.

to be about 20% greater than that of the Otto engine*. About 3,500 engines had been made and sold by the Stockport Company up to 1890, at which time the Otto cycle was adopted. The site at Reddish, near Stockport, was opened in 1886, the company having become limited in 1885. Herbert Andrews (of no relation) of the Toleda Steel Works, Sheffield became Chairman and Mr. Williams the Managing Director. Williams resigned, however, shortly afterwards, the post being taken by A.R. Bellamy. By 1900, the new works at Reddish covered 5½ acres containing the foundry, pattern shops, smithy, stores, machine shops, assembly shops, engine testing section and packing and painting sections. The whole of the power for driving machines and lighting the works was supplied by four Stockport engines. One of these was capable of developing 190 brake horse-power; the remaining three, each of 100 horse-power. All were working with producer gas. In 1896 the firm of Richard Hornsby and Sons Ltd. of Grantham took over the factory and in the period to 1908, the capacity of the works had doubled. About 550 people were then employed.

The contribution to engine technology and to industry that was made by the firms 'Stockport' and 'Stockport-Hornsby' engines was considerable. Like many other manufacturers prior to 1890, their design was restricted by the Otto patent and their main contribution came late in the day. Even so, they became a formidable rival of the Crossley Bros. Not-

*This increased fuel consumption over that of the Otto was strongly denied by 'Stockport' but for the cycle employed, gas consumption was rarely less than 30 cu/ft bhp/hr. The Otto cycle was averaging 21 cu.ft.

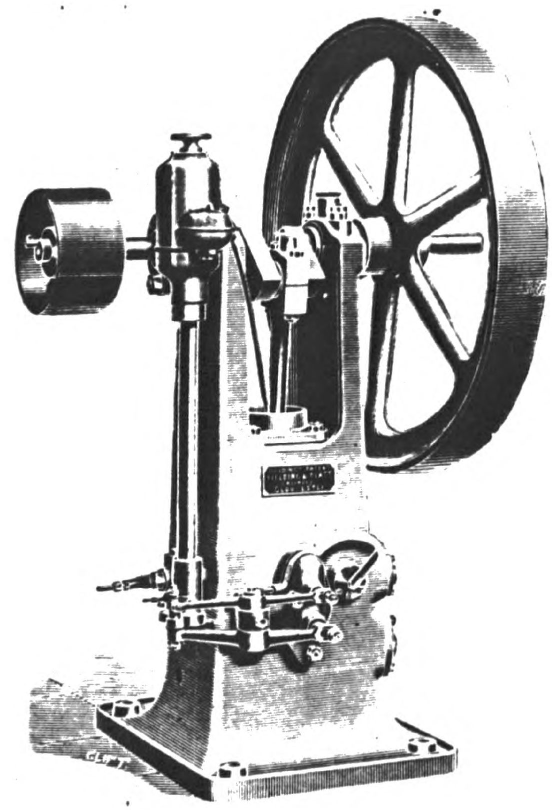


Fig 7.15 A 1½ nominal vertical four stroke engine by Fielding and Platt of Gloucester.

THE FIELDING GAS ENGINE

HORIZONTAL PATTERN

Single Cylinder

Nom. H.P.	I.H.P.	B.H.P.	Speed (Revs. per Minute)	Approximate Outside Dimensions		Approximate Weight		Flywheels		Driving Pulley		Gas Pipe	Water Pipe	Exhaust Pipe	Meter	Diameter of Cylinder	Length of Stroke
				Length ft. in.	Width ft. in.	Nett ton cwt.	Packed ton cwt.	Diam.	Width	Diam.	Width						
1	2¾	1·9	200	5 8	3 6	0 16	0 19	3 6	4½	12	6	¾	1¼	1½	10	—	—
2	5	·3·75	200	6 6	4 1	1 5	1 9	4 0	4½	16	6	¾	1¼	1½	10	—	--
3	8	5·5	200	6 6	4 1	1 6	1 10	4 0	4½	16	6	¾	1¼	1½	15	—	—
4	10	8·0	200	8 3	5 1	1 16	2 0	5 0	5	20	8	1	1½	1½	20	—	—
6	13	10·3	180	9 0	5 2	2 18	3 4	5 6	6	24	10	1¼	2	2	30	—	—
8	18	14·4	180	9 0	5 2	3 17	4 4	5 6	6	27	12	1¼	2	2	50	—	—
10	22	17·6	180	10 0	6 6	4 13	5 0	5 9	7	30	12	1½	2½	2½	60	—	—
12	27	21·6	180	10 0	6 6	4 15	5 2	5 6	6	36	12	1½	2½	3	80	11½	18
14	34	27·2	170	10 0	6 6	5 0	5 6	5 6	7	48	14	1½	3	3½	120	—	—
16	42	35·7	160	12 0	7 10	6 18	7 6	5 9	7	54	18	2½	3	4½	150	—	—
20	50	42·5	160	12 0	9 8	7 19	8 8	5 9	9	54	18	3	4	5	150	14½	22
30	--	--	160	—	—	—	—	—	—	—	—	—	—	—	—	17	27
35	100	80·0	160	13 6	10 0	12 16	13 7	7 3	10	54	18	4	5	6	250	—	—

VERTICAL PATTERN

Nom. H.P.	I.H.P.	B.H.P.	Speed (Revs. per Minute)	Length ft. in.	Width ft. in.	Nett cwt. qrs.	Packed cwt. qrs.	Flywheel Diam.	Flywheel Width	Pulley Diam.	Pulley Width	Gas Pipe	Water Pipe	Exhaust Pipe	Meter	Diameter of Cylinder	Length of Stroke
½	2	1·3	200	3 0	2 11	10 0	12 0	3 0	4	9	5	½	1	1¼	5	—	—
1	2¾	1·9	200	4 0	3 4	14 2	1 62	3 6	4½	12	6	¾	1¼	1½	10	—	—
1½	3½	2·45	200	4 0	3 4	14 3	16 3	3 6	4½	16	6	¾	1¼	1½	10	—	—

Fig 7.16 Range of engines manufactured by Fielding and Platt to 1895.

able features of the Stockport-Hornsby engines were the specially constructed cylinder liner and water jacket and the water-cooled exhaust valve, which was used on large engines. The first feature allowed differential expansion to avoid fracture by freezing, and the second consisted of a hollow valve head and steam with flow and return pipes to convey the cooling water. The power range of Stockport engines was about as comprehensive and wide-ranging as it could be. Horizontal, single-cylinder engines, from 1 bhp to 200 bhp were made and then tandem engines of 400 bhp (Figure 7.14). Small vertical, single-cylinder engines (Figure 7.11) of 1½ and 5 bhp were made during the 1890's.

7.5.3 Fielding and Platt, Gloucester

The Royal Agricultural Show at Doncaster in 1891 was when another engine, the Fielding and Platt of Gloucester, first came to the notice of the public. Their horizontal engines bore a resemblance to the Crossley-Otto engines and had the usual features of heated tube fitted with a timing valve. The side shaft was driven by a worm gear and lift valves were used for inlet as well as for the exhaust. Single-cylinder engines from 1 to 35 nominal were made and 200 horsepower nominal, two-cylinder engines were also made towards the end of the century. Vertical engines of ½ to 1½ nominal were made, being capable of speeds of 200 revs/min (see Figure 71.5). In 1898, the Research Committee of the Institution of Mechanical Engineers carried out a series of experiments to determine the effect on the economy of a gas engine by varying the speed, degree of compression, gas/air ratio and heat loss to the cooling water jacket. The engine used for the test was a Fielding and Platt of 4 bhp.

7.5.4 The forward or Barker engine

The heated tube method of ignition was used almost universally by engine manufacturers in Great Britain in 1890. When fitted without a timing valve, however, engines possessed a particularly troublesome feature in that upon starting up, there was a possibility of engine reversal caused by premature ignitions. With large engines this was extremely dangerous and often fatal to the workman whose misfortune it was to be allotted the task. The danger arose because of the method of starting that was used, which was by standing on the flywheel spokes; any sudden engine reversal would either fling a man several feet or carry him round to pin him beneath it. Timing valves of the poppet type were used by Crossleys which virtually eliminated this danger, but the Forward Gas Engine (Figure 7.17) by Messrs T.B. Barker of Schofield Street, Birmingham used a rotating disc with radial slots. The slots were made to coincide with mating slots on a fixed portion of the port leading to the tube (some Continental engines used a similar device). The rotary motion of the disc, which admitted a small quantity of charge into the tube, was controlled by a governor. The Barker engine, as it was sometimes called, was notable for another important feature and one that reflects the technological progress in engine design that was taking place about the mid-1890's. On many other engines such as the

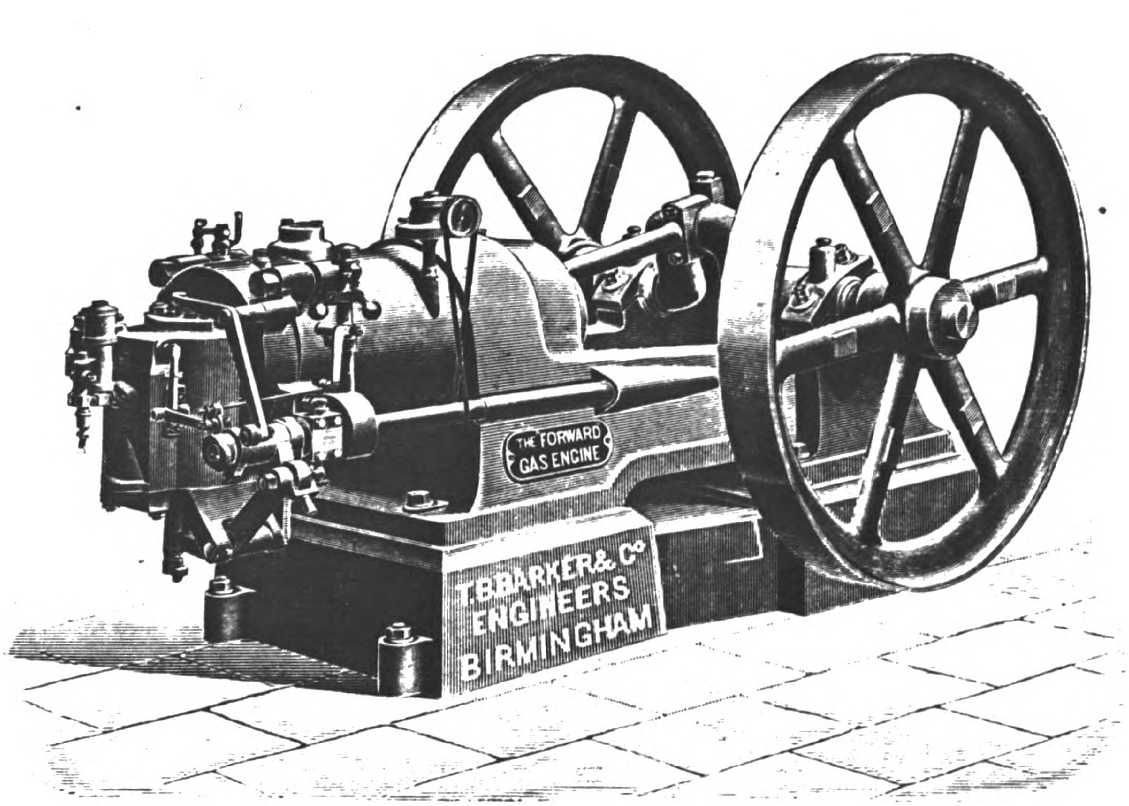


Fig 7.17 A 16 nominal power engine by The Forward Gas Engine Co. of Birmingham.

Nom. H.P.	Maximum B.H.P.	Approximate I.H.P.	Over all Dimensions of Engines		Approximate Weight of Engines	Driving Pulley		Normal Revs. per Minute	Diameter of Cylinder	Length of Stroke	Diameter of Shaft
			ft. in.	ft. in.	cwts.	Diam. in.	Width in.				
1	2¾	3½	5 8	3 4	15	12	5	200	—	—	—
2	4	5	6 10	3 7	20	18	6	200	—	—	—
3	5½	7	7 0	3 9	24	20	7	200	—	—	—
4	8	10	7 3	4 0	30	21	8	200	—	—	—
6	11	13	8 9	4 9	36	24	9	180	—	—	—
7	12	15	9 0	5 0	40	24	9	180	—	—	—
9	16	20	10 4	5 11	56	28	12	180	—	—	—
12	21	27	10 6	6 0	64	30	12	180	—	—	—
14	29	35	10 6	6 6	85	33	14	170	—	—	—
16	34	40	10 8	6 8	92	36	14	170	12	20	4⅝
20	43	50	12 4	7 8	110	48	16	160	—	—	—
25	53	65	12 6	8 0	125	54	18	160	—	—	—

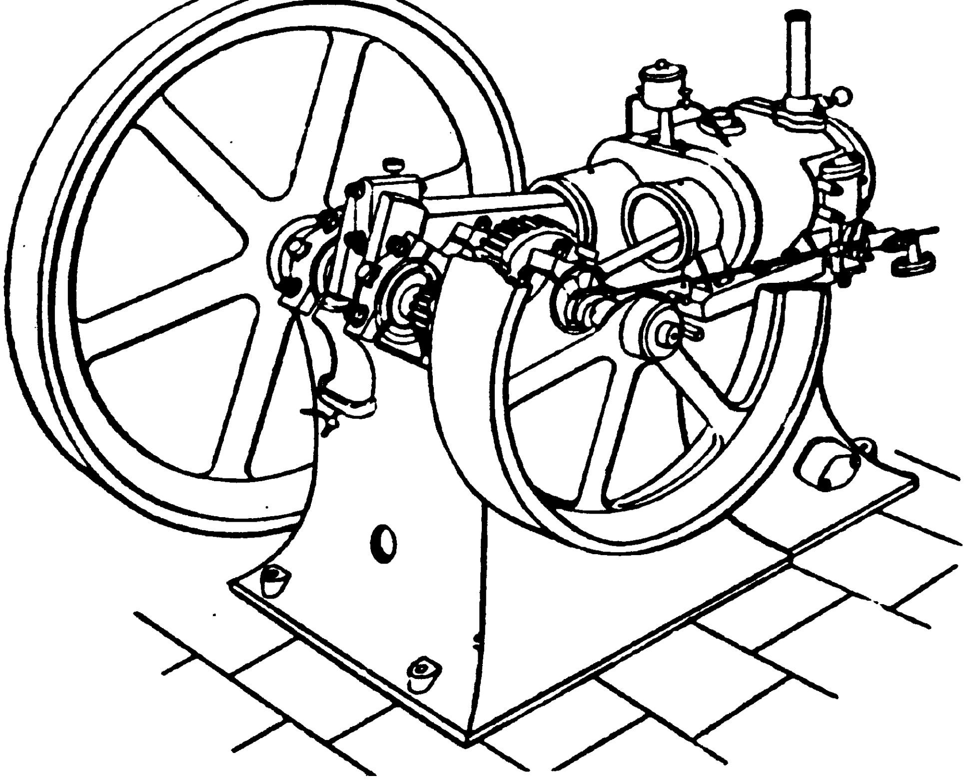
Fig 7.18 Range of engines manufactured by the Forward Gas Engine Co, to 1895

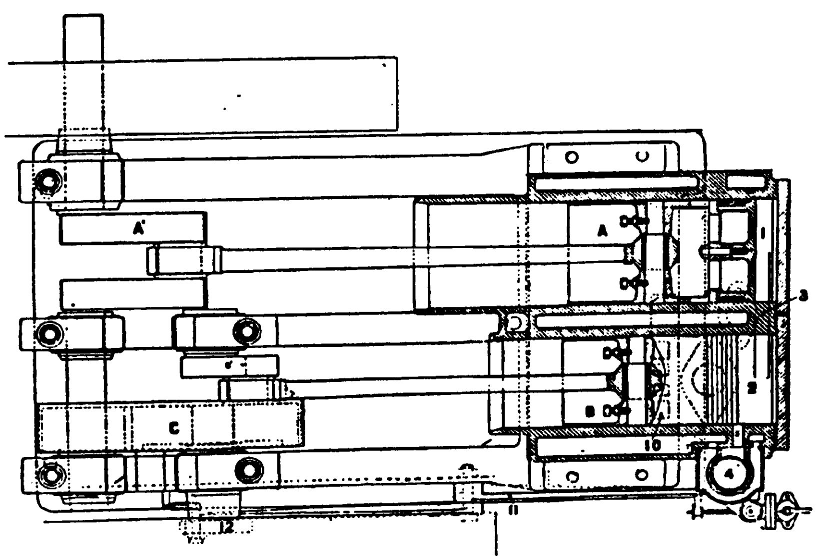
Stockport-Otto and Crossley-Otto, the communicating ports from the valves to the cylinder were unnecessarily large, presenting a large surface area, which as mentioned previously had a detrimental cooling effect upon the gases. One reason for doing this was to provide accessibility to the valves by placing them in a 'box' which was easily removed. The forward engine dispensed with these passages and arranged the valves to open directly into the cylinder. Means were still provided for access, however, by their patent design, much of which was due to F.W. Lanchester, who in 1898 became works manager. His influence in design matters, particularly with respect to governing, ignition and starting devices between 1889 and 1896 is striking. Twenty patents were registered in his name between these two dates. A forward gas engine was installed in the Saltley gas works in 1893 and tests carried out on it in 1894 not surprisingly showed a very low gas consumption at that time of 21 cubic feet per brake horse-power per hour with a compression pressure of 50 lbf/ins^2.

7.5.5 The Burt Acme expansion engine of Glasgow

This was a cleverly designed engine which used an increased expansion to that existing before compression; Figure 7.19 shows a simple line diagram and a sectional view which will be used to describe its working. As can be seen, two cylinders are used with a gearing arrangement which enabled the pistons to move with variable degrees of travel. It was by this means that the increased expansion was obtained.

The two cylinders were in constant communication with each





LEADING DIMENSIONS.—Short stroke cylinder, 10″ diam. × 11″ stroke; long stroke cylinder, 11½″ diam. × 20″ stroke; both crank shafts, 4″ diam.; feed valve, 3′ diam.; exhaust port area, 10 sq. ins.; gas valve diam. 1¼″; exhaust pipe diam. 3″; air pipe diam. 2″.

LIST OF PARTS.—Long stroke cylinder, 1; long stroke piston, A; long stroke crank, A′; short stroke cylinder, 2; short stroke piston, B; short stroke crank, B′; crank shaft gearing, C; port connecting cylinders, 3; feed valve, 4; port from feed valve to cylinder, 5; gas valve, 6; inertia governor, 7; governor blade hit or miss, 8; igniter, 9; exhaust ports, 10; governor motion lever, 11; governor cam, 12.

Fig 7.19 The Burt-Acme 'expansion' engine, by McGhee and Burt, 1887.

other via the port, 3 and consequently both pistons received the same pressure after ignition. The lower diagram of Figure 7.19 shows the positions of the pistons when ignition had just occurred, the tube igniter being situated in the smaller cylinder on the right (No. 2). In this position the larger piston is on its dead point and the smaller piston has moved outwards about 1/7th of its stroke. During the expansion stroke, the larger piston makes a complete stroke, but at this point the small piston has travelled only about 5/7th of its stroke, and at that point uncovers the exhaust ports, 10, cut into the cylinder wall. Piston A then returns to push out the exhaust gases. When the piston A completes its exhaust stroke, Piston B has then just covered the exhaust ports.

The next outstroke of A draws in the new charge filling both cylinders. Compression of the charge takes place by both pistons and the cycle is then repeated.

The gear ratio used on the Burt engine was 2 : 1 and by proportioning the stroke and diameter of the cylinder A to that of cylinder B, any desired expansion of the charge could be obtained. Patents for this engine were registered under the name of McGhee and Burt, the first being No. 11678 of 1887. In 1892, one was tested while working in a corn merchants, Messrs Herbert Bros., Kennedy Street, Glasgow*. It had the distinction of recording the lowest gas consumption (17.3 cu.ft/bhp/hr) of any Otto engine of that power at the time and in 1894 the Burt engine was awarded a Gold Medal

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* Details of the engine and test are given in Clerk, The Gas and Oil Engine, p.338

at the Antwerp Exhibition.

Like many other engines whose working principle was in any way different from the established and simple four-stroke cycle, the Burt engine lost favour. Had it appeared ten years earlier, the story might well have been a different one. Its chief disadvantages were the large bulk and weight in comparison to the power developed and the use of gears in the drive train.

7.5.6 The Robey of Lincoln

An engine with the most pleasing appearance and high quality of finish was the Robey Engine of Lincoln, Figure 7.20. It was made according to the patents of Richardson and Norris, No. 11755 of 1890 and became known as the 'girder' engine. It possessed no novel features, except that it was fitted with a very heavy flywheel and an excellently designed governor, which made it eminently suitable for driving electric generators. The power range was up to 120 brake horse-power and the engines used tube ignition with the exhaust valve opening directly into the cylinder and not in a lengthy passage as with many other engines. The governor was provided with adjustment, enabling the speed to be varied from 140 to 300 revolutions per minute.

7.5.7 The National Gas Engine

National Gas Engines were manufactured in Ashton-under-Lyne and conformed to the general pattern and design of most other manufacturers using the Otto cycle. The firm became

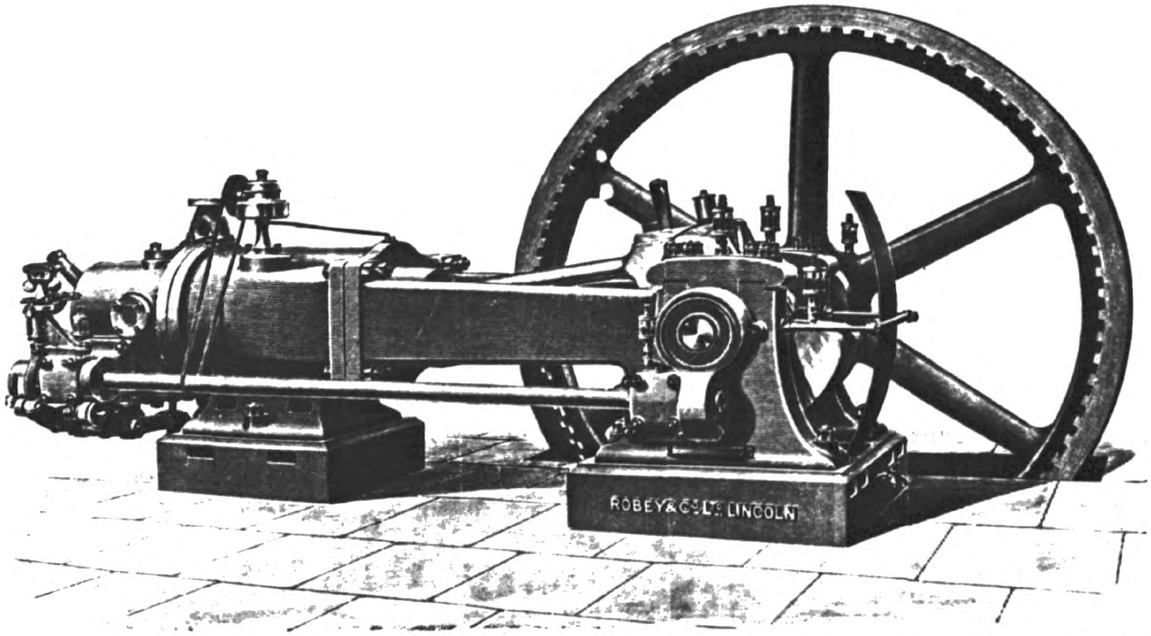

Fig 7.20 The Robey 'Girder' engine of Lincoln.
100 brake horse power.

Maximum b.h.p.	Speed (Revs. per Minute)	Over all Dimensions: Length ft.	Length in.	Width ft.	Width in.	Approximate Weight of Engine: cwts.	qrs.	Size of Fly-wheels: Diam. ft.	Diam. in.	Width in.	Driving Pulley: Diam. in.	Width in.	Cooling Water cub. ft.
½	400	3	3	1	9	5	0	2	0	3	11	2½	8
1¼	350	3	9	2	1	7	2	2	6	3	11	3	10
2	300	4	6	2	8	9	2	3	0	3½	12	5	10
2½	230	5	0	2	5	14	0	3	0	3½	12	5	10
3¼	230	5	6	3	0	17	0	3	6	4½	12	6	28
3¾	220	5	9	3	3	19	2	3	6	4½	17	6	28
5	220	7	0	3	6	27	0	4	0	4½	20	7	28
6	220	7	0	3	6	27	2	4	0	4½	20	7	28
8	220	7	3	3	9	34	0	4	6	5	22	8	56
9	200	7	6	4	3	38	0	5	0	5	24	9	56
11½	200	8	9	4	6	56	2	5	0	6	24	9	56
13½	180	9	9	4	9	60	0	5	0	7	24	10	56
16	180	10	0	5	0	69	0	5	0	7	27	12	84
18	180	10	0	5	0	70	0	5	6	6	30	12	84
24	180	10	6	5	6	90	0	5	6	7	36	12	84
31	170	12	0	6	0	107	0	5	6	9	48	14	112
36	170	14	0	7	9	160	0	5	9	10	54	16	130
42	160	14	3	7	9	180	0	6	6	10	54	18	150
55	160	14	6	8	0	220	0	7	3	12	—	—	—
76	150	14	9	8	3	280	0	10	0	12	—	—	—
100	140	15	3	8	6	355	0	10	0	15	—	—	—
120	140	15	6	8	6	375	0	10	0	18	—	—	—

Fig 7.21 Range of engines manufactured by
Robey of Lincoln.

renowned for their 'electric light engines' which were engines having two flywheels and stiffened crankshafts capable of giving a very steady output speed. The National Gas Engine Company was the result of an enterprising and gifted engineer, Henry Nield Bickerton, who was born in Oldham on 6 October 1856, and educated at Tattenhall College, near Wolverhampton. In 1880 he started his own engineering business at Ashton-under-Lyne and designed a small two-cycle gas engine, which was made by someone named Ogden*.

The engines were successful enough to cause Crossleys some concern. On 4 April 1882, F.W. Crossley wrote to Bickerton pointing out that this two-cycle engine was, in their opinion, an infringement of the Otto four-stroke patent. After some discussion with the Gas Motoren Fabrik, Deutz and consultation with Bickerton, an agreement was drawn up in July 1883 in which Bickerton and Ogden surrendered and Crossleys bought the patent for £1000. Clearly Crossleys were concerned - this is stated quite clearly in the letters to Deutz - that the Bickerton engines were likely to find a market. Up to that time, thirty-six engines had been made and Crossleys asked for royalty payments of 15% of the selling price, which was £90; Bickerton was then to cease their manufacture.

Sometime between 1880 and 1890, Bickerton moved to another works at Wellington Street, Ashton-under-Lyme which had formerly been occupied by one Isaac Boulton. It was here, in

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* F.W. Crossley states this in a warning letter sent to Bickerton pointing out that his engine was considered to infringe the Otto patent (letters to Abel and Imray p.161) Kelly's Trade Directory of Manchester 1880/81 shows no-one by that name who could possibly have made this engine.

1889, that he began work on his four-stroke engine, forming the National Gas Engine Company in 1890. Work on the smaller four-stroke engines continued up to the 1930's and about 1910 large vertical gas engines of 1,000 brake horse-power were produced. Two such engines were made during that year for the Empire Festival at the Crystal Palace, London to work on town gas. Oil engines and gas producers were also made, the latter enabling them to build engines of 2,000 bhp for power generation. An undated prospectus (probably about 1915) shows Henry Nield Bickerton as Chairman and Sir Dugald Clerk as a director of the National Gas Engine Company.

7.5.8 The Premier from Nottingham

A firm whose history did not date beyond 1889, but who very rapidly established themselves as foremost manufacturers, was the Premier Gas Engine Co. of Sandiacre, Nottingham. The proprietors of the firm were the Wells Brothers and the moving force behind the technological developments was brother Alfred and a John Henry Hamilton. It was Hamilton who carried out experimental work which led to a form of 'positive scavenging' (the present day term would be pressure charging). All Premier engines were fitted with an arrangement for introducing a scavenging charge of air which cleaned the cylinder of burnt gases. The charge of air was obtained from a separate pump. Single-cylinder Premier engines (Figure 7.23) were made in sizes from ½ to 40 bhp with one flywheel and from 20 to 350 bhp with two flywheels. A few small vertical engines were made at first, but were soon discontinued. They also made very large tandem engines

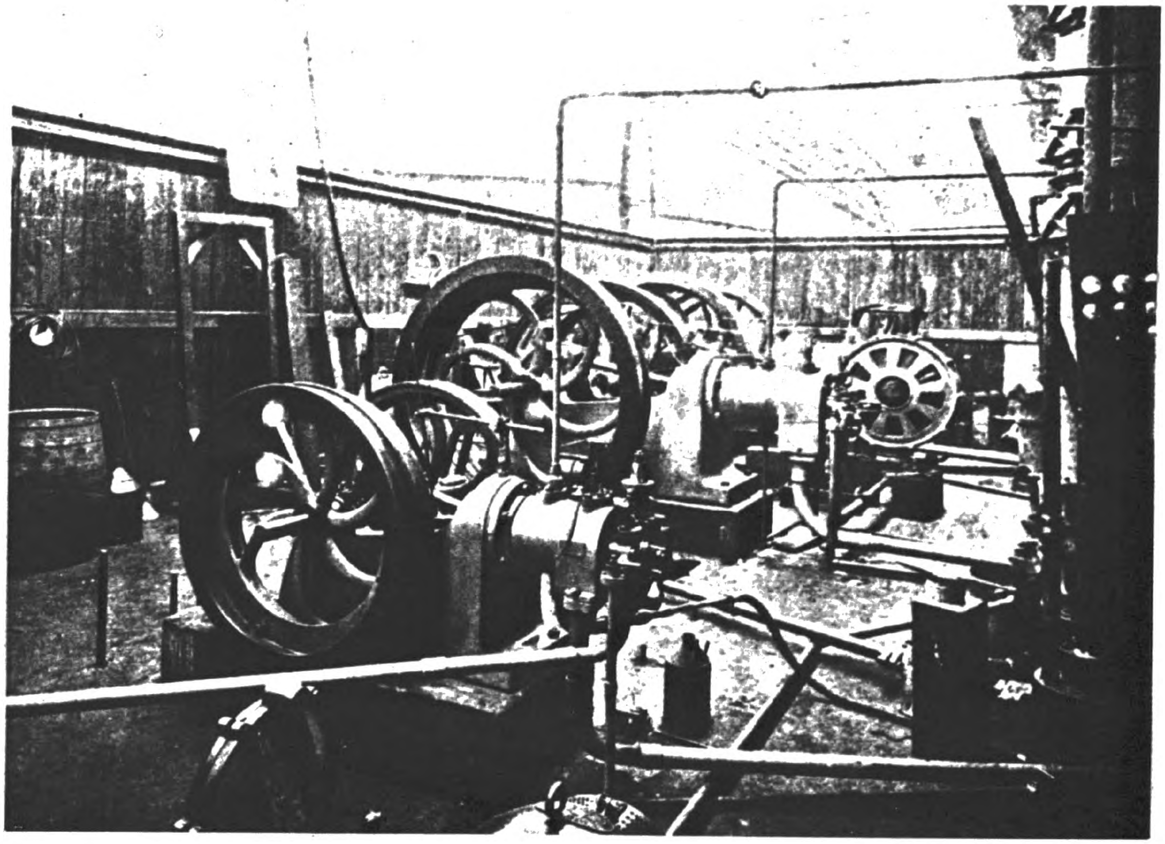

Fig 7.22 Engine testing shop of the National Gas Engine Co. C. 1900.

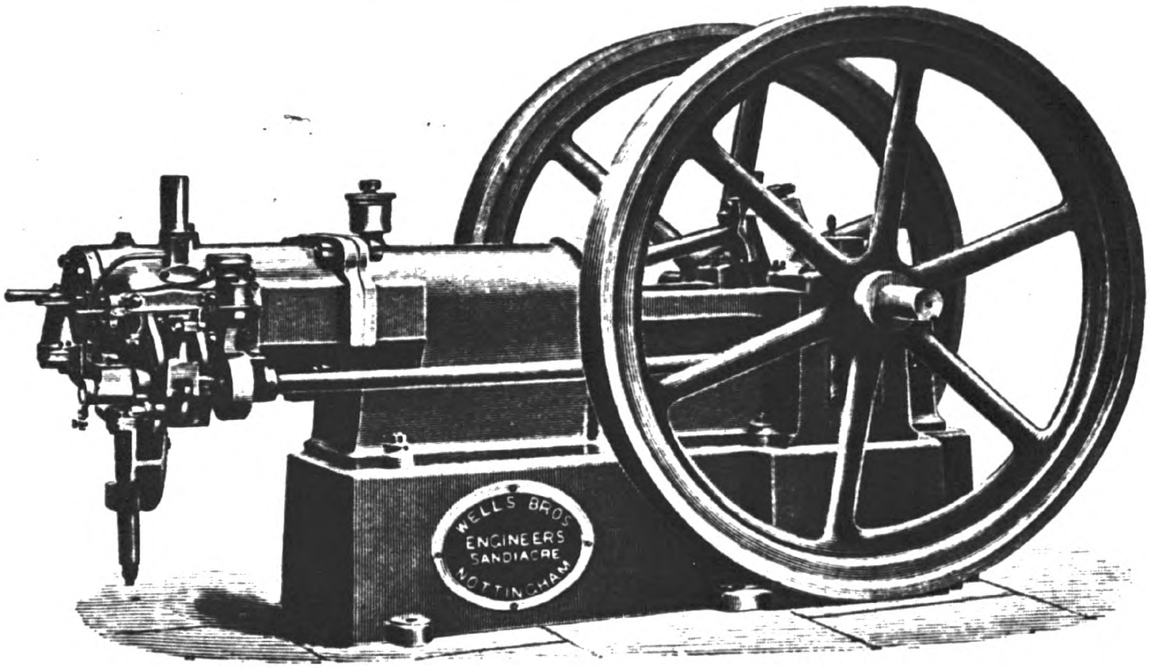

Fig 7.23 The Premier 'scavenge' gas engine. C1895

from 50 to 600 brake horse-power.

The Premier Gas Engine Co. was acquired by Crossleys in 1919 and in 1936 was absorbed into the Crossley organisation, the firm bearing the name Crossley Premier Engines to this day.

7.6 Lesser known manufacturers of gas engines

The list of gas engine manufacturers that has been given so far is representative of the leading ones, most of whom made the largest engines that were available at that time. In addition to these were countless other manufacturers dotted about the country, who made an equally worthwhile contribution to the needs of industry. Prominent names were the Midland Express, Gardner, Trusty, Campbell, Duplex, Clarke-Chapman, Dawson, Birmingham and Robinson. Individually they adopted their own ideas and put their theories, aimed at increasing efficiency and improving economy, into practice. Collectively, their efforts resulted in a greater understanding of engine technology and a brief description of each will now be given.

7.6.1 The Midland

The first 'Midlands' were manufactured by Messrs John Taylor of Nottingham before the Otto patent expired in 1890 in the form commonly used at that time - a motor and a pump piston. The pump was used to assist admission and to compress the charge, transferring it then to the motor cylinder where it was ignited, one explosion every revolution being obtained.

The firm later adopted the four-stroke cycle, producing vertical engines up to 4 bhp and horizontal engines from ½ to 150 bhp. Heated tube ignition was used with no timing valve on engines up to 18 bhp. (Ignition, it was maintained, could be kept regular by adjusting the height and length of the tube.) A Midland engine of 16 inch bore and 21 inch stroke was tested in Nottingham in 1897 running on gas made from coke, and gave 47 bhp at 218 rev/min with coke consumption of 1.53 lb/bhp/hr.

7.6.2 The Express

The town of Reddish, near Stockport, the home of the notable Stockport engine, was also that of the Express gas engine, made by Messrs Furnival and Co. It possesses no unusual features and consisted of a single cylinder, horizontal engine working on the Otto cycle. Four Express engines were shown at the Brussels Exhibition of 1897.

7.6.3 Gardner Gas Engines

On 5 May 1894, Lawrence Gardner, at the works in Hadfield Street, Cornbrook, Manchester, tested his first gas engine[33]. it was a horizontal version, engine No. 81* developing 1 bhp at 350 rev/min. The ignition was by incandescent tube and the engine was used to light a small room at the works (the firm had previously been engaged in making dynamos). A

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* The numbers prior to this are thought to be Hot Air Engines manufactured for A.E. and H. Robinson of Manchester

batch of these engines, Nos. 83 to 88 with increased bore diameter, were produced in July of that year for general sale. An entry in a notebook for engine No. 88 reads, 'was troublesome - had compression reduced by turning off piston - will only do 10 lights at 48V, to Bradford 22nd September'. By the end of the year another 12 had been made. Other entries in diaries show that piston rusting was causing problems and satisfactory running was not possible until the piston rings had bedded in. Gas consumption for these engines was heavier than most - 30 cubic feet per bhp per hour. During 1895, both smaller and larger engines were built, from ½ to 5 bhp and a comment on a larger engine, No. 148 reads 'this engine is not running so nicely as the other sizes - it bucks and thumps'. To rectify the problem, the compression pressure was reduced to 45 lbf/in^2 by turning off the head of the piston and pulling the lathe round by hand. After running in the works for a month, it was much improved and was sold to a customer in London.

Most of the engines made by Gardners were sold in the Lancashire and London areas; their first export being to Barcelona in 1896. A great many also found their way into France. The workmanship displayed on Gardner engines was of the very highest order and no engine would be sold until it had first proved itself in the factory. Sometime during the latter half of 1896 experiments were made with liquid fuels, using paraffin oil, but these were discontinued 'for want of time' until April 1897 when four-stroke 'oil engines' of various sizes were sold.

Gardners seemed always to be on the look out for development.

In 1897 engines that had previously run on gas were converted to run on petroleum spirit by fitting a carburettor and non-return valve in the inlet manifold (to prevent back firing). Electric ignition was tried in 1898 on a spirit engine, No. 1038, which was the tenth petrol engine produced by the firm. The year 1898 also saw the firm move to the present premises at Barton Hall, Patricroft.

Engine production figures - L. Gardner & Sons 1894-98

	Engine type												
Date	0	1	1A	1AV	2	3	4	4A	5	6	6/6	7	Total
1894		20				1							21
1895	7	36	7		12	4	2						68
1896	12	44	24		12	9	2			1	1		105
1897	31	71	36		27	12	13		4	3			197
1898	10	107	61	1	54	16	18	7	13	5	1	2	295

7.6.4 The Trusty

A novel feature of the Trusty gas engine was that it was often shown with two or three cylinders side by side. An eight horse-power Trusty was tested at the Crystal Palace Exhibition in 1892. The manufacturers were Messrs Wyeman of Cheltenham and later became more widely known for their oil engines.

7.6.5 The Campbell

The Campbell Gas Engine Co. of Halifax began making gas engines at the time the Otto patent was in force. In common with many other manufacturers then, they adopted the impulse every revolution type. Four-stroke engines were made in 1891 and these Campbell engines were noted for their easily removable cylinder liner. Horizontal single-cylinder engines in sizes of 1 to 65 bhp were made with smaller power vertical engines being made later.

7.6.6 The Duplex by Griffin

The Griffin 'three-cycle' engine will be described in Chapter Eight (see Figure 8.17 and 8.18) which was made prior to 1890. Samuel Griffin was also responsible for producing a most unusual vertical engine, (Figure 7.24) made by Dick, Kerr and Co. of Kilmarnock. It was unusual in the sense that two cylinders were used, but only one connecting rod. The two pistons operated in parallel, being connected at their lower ends to a cross-head, to which the connecting rod was attached. The four-stroke Otto-cycle was used, with a heated tube for ignition. One firing stroke per revolution was possible by arranging for ignition to take place in each cylinder alternately. Vertical space-saving engines such as this appear to be very popular during the 1890's and the Duplex would appear to have been well received by industry. A later version, shown in Engineering, May 1898 was specially developed for driving electric dynamos, produced 40 bhp at 180 rev/min and had a bore of 10.25 inches and stroke of 15 inches. Gas consumption was 21.5 ft^3/bhp/hr. This later Griffin engine was made by Piercy and Co., Broad Street Engine Works, Birmingham.

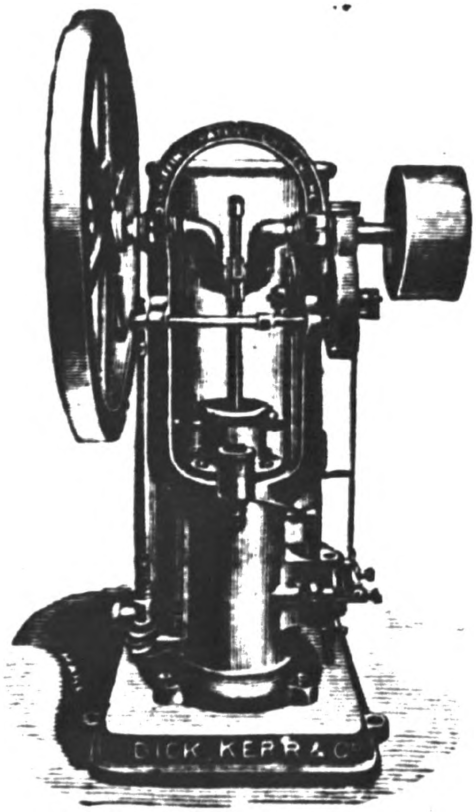

Fig 7.24 A 1 nominal horse power vertical Griffin, or Duplex engine made prior to 1890. Gas consumption was high at 35 cubic feet per brake h.p. per hour.

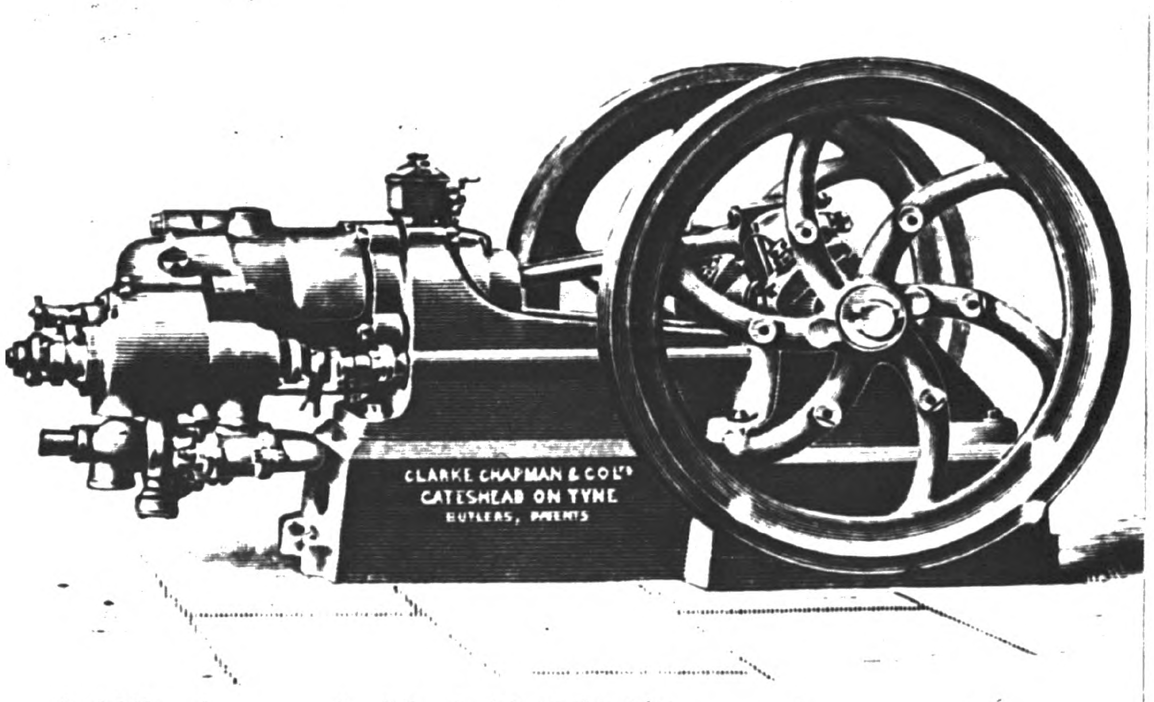

Fig 7.25 The Clarke, Chapman gas engine with rotary valves.

7.6.7 The Clarke-Chapman

An attempt to replace the lift valves used for admitting and expelling the charge, by a rotary valve was a feature of the Clerke-Chapman Gas Engine, made in Gateshead, Figure 7.25. The design followed that of Butler's patent, the first related to this engine being No. 6990 of 1890. The revolving valve had two ports for the supply of gas and air, and two ports for the exhaust. The ports corresponded with passages to the cylinder. A shaft driving the valve, worked at quarter engine speed. The charge of gas and air was first admitted into a mixing chamber called an 'inspirator' passing then to a throttle valve controlled by the governor. After entering the cylinder it was compressed, ignited and expanded in the usual way, exhausting through the ports in the rotary valve. Governing was effected by reducing the quantity of the charge admitted. A choice of ignition was available with the Clarke-Chapman - heated tube or electric. No record of test data for this engine can be found and, although offered in sizes of 2 to 40 bhp, does not appear to have obtained a prominent place for itself in industry.

7.6.8 The high-speed Dawson

The maximum speed attainable by a few of the engines so far described was approximately 350 rev/min. Most manufacturers were quite content with speeds of 100-200 rev/min. When an engine capable of 900 rev/min appeared, not surprisingly, it created quite a stir. The Dawson (Figure 7.26) made by the Paris Singer Co. of ½ to 35 bhp appeared in 1894. Dawsone engines were made as single-cylinder vertical up to 20

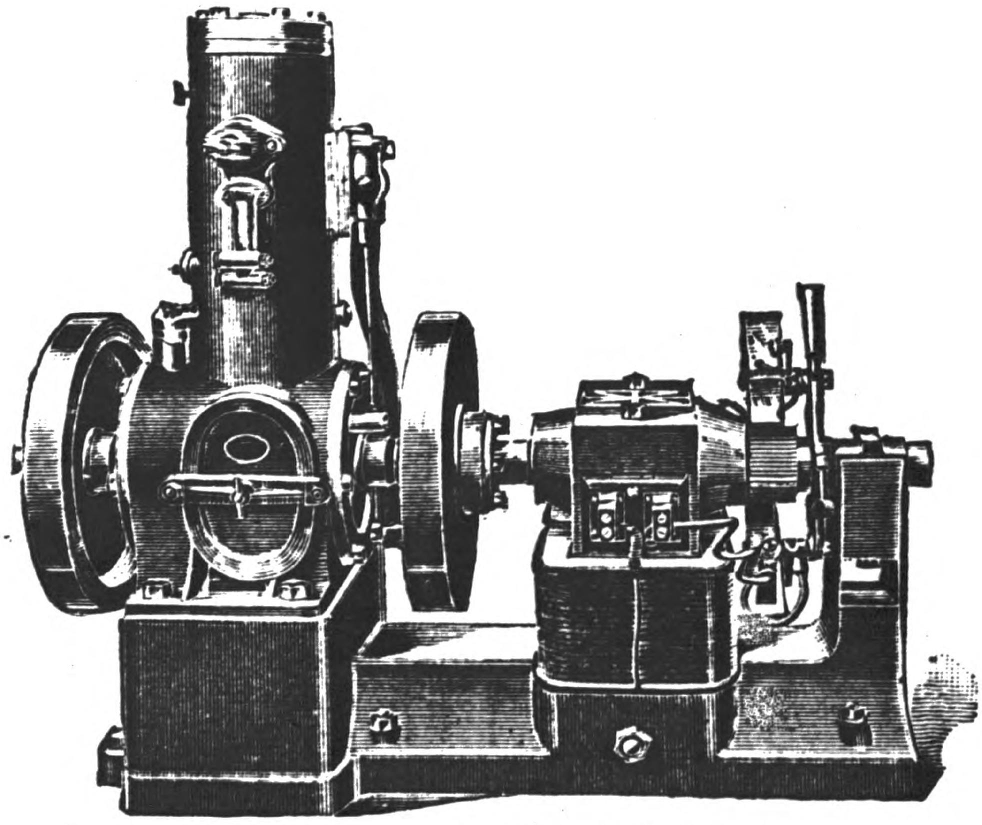

Fig 7.26 The high speed Dawson gas engine and generator.

Made by the Paris Singer Co. 1894
No levers or valves were used;
admission, firing and exhaust were all
controlled by the piston.

bhp and two cylinder vertical above that power. Heated tube ignition was used and in order to achieve the rapid firing necessary, the tube was heated to intense heat by a small air-blast gas burner. No levers, cams or valves were used on this engine, the admission, ignition and exhaust being all controlled by rotating the piston around its vertical axis. Ports were out in its sides and around the cylinder walls. The rotary movement of the piston was made possible by two worm wheels, one on the crank and one on the crank shaft.

The mechanical difficulties involved in producing a reciprocating and rotary piston movement in an engine, operating at what then was an outstandingly high speed, would have been enormous. Credit must be given, therefore, to the designer and manufacturer for such an achievement. Several factors would militate against its general acceptance; it is doubtful, for instance, that the quality of lubricants in use at that time would be sufficient to cope with the speed. The rate of wear, particularly with a rotating piston, would consequently be extremely rapid. The ported piston and cylinder walls would induce a severe throttling effect upon the ingoing charge and the tube used for ignition, particularly if it was of the commonly-used wrought-iron, would last only a matter of hours at such intense heat as was suggested. Porcelain as a material for ignition tubes began to appear from the mid-1890's, which was a considerable improvement on the use of wrought iron and it is possible that tubes of such materials were used on this engine.

7.6.9 The Birmingham

This particular gas engine proved extremely popular with owners of small workshops. It was manufactured by Messrs Grice and Sons of Birmingham, in sizes of 1 to 90 bhp operating at speeds of 150 to 250 rev/min. The design, which reduced the number of moving parts to a minimum, was based on patents by Rollason (the names of Rollason and Hamilton - of former Premier Gas Engine Co. - frequently occur in the patent abridgement lists).

7.6.10 Miscellaneous

Probably no other district was more prolific in its contribution to gas engine manufacture than that of Manchester. Two major firms of world renown were firmly established and yet there was still room for anyone enterprising enough to fill in the gaps either left, or created, by the giants. Notable of these were the Lawton and the Sturgeon.

The Lawton (or Lawson) gas engine was made by Messrs Lawton of Openshaw and was a very simple engine, having much appeal to small traders. No ignition or timing valve was used and no starting gear was thought necessary. It did, however, have an inertia governor, which acted directly on the gas valve. Vertical engines from 3 to 6 bhp were made and horizontal engines of a respectable 2 to 20 bhp were offered, having two flywheels.

The Sturgeon was made by Henry Wallwork and Co. of Manchester, Union Bridge Works from about 1888. The working cylinder was vertical and contained two pistons which connected through a complicated linkage to a revolving disc. A charging cylinder containing a piston was placed horizontally in the middle of the working cylinder, again worked by a complex linkage. Flame ignition was used and the power range was one-quarter horse-power (nominal) as 220 rev/min to twelve horse-power at 160 rev/min. Sturgeon patents began in 1885 with No. 8897 with four more in 1887.

7.7 A.E. & H. Robinson

The firm of Arnold Edward and Horace Robinson will long be remembered in Manchester as a manufacturer of gas engines. Many of their engines now owned by enthusiasts are still in working order and are frequently displayed at various machinery exhibitions.

Founded in 1871, the firm occupied premises in what was then called Church Street, Openshaw. The present name of the street is Parcel Street, but the firm stands on its original site. Up to 1880 the work carried out by Robinsons would come under the heading of 'light engineering' but it was during 1880 that the first patent, No. 117 for a gas engine was issued to Horace Robinson. The proposed working of this engine is similar to that used in present-day two-stroke engines. A charge of gas and air was drawn in beneath the piston as the latter moved to its outer, or top dead centre, and as it completed its return stroke would push the mixture through a transfer port into a space above it. The exhaust valve was a port cut into the cylinder wall and uncovered by the piston at the appropriate time. Ignition, it was suggested, could be either by flame or by a cavity containing a piece of porcelain, heated to incandescence by an external flame.

Patents of improvement to this engine numbered 2344/1880 and 4260/1880, taken out by Robinson would indicate that he was serious-minded about this engine and suggests that he may have had a working form of it. This suggestion was later found to have some substance. On 24 March 1882, F.W. Crossley wrote to the Tangyes of Birmingham* pointing out that:

> '....... an engine lately made and exhibited by you in Birmingham under Robinson patents was an infringement of Otto's patent 2081 of 1876 as it produced the same condition or arrangement of the charge therein set forth and specially claimed. We have, therefore, to request that you remove from the Gas Engines which you are now making and showing (whether Robinson, Robson or others) such parts as cause to be delivered to the cylinder, a charge of combustible mixture separate f from a charge of incombustible gas and air ....'

During 1881, Robinsons turned their attention to hot air engines. A number of these were made by a firm, Messrs E. pearce and Co. of Manchester**, according to a patent No. 5056. In 1886 a much larger hot air engine was made according to a patent, No. 12346 and up to 1896 about 80 of them had been made by L. Gardners, now of Patricroft, Manchester, who have one exhibited in the entrance hall to their works. The first version of a gas engine which was to make the name of Robinson a household word appeared in 1892[34]. The patents leading up to this engine began with No. 14787 of 1890. It was

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* Letters to Abel and Imray, p.143

** This is stated in Donkin Gas, Oil and Air Engines (1900) p.439 but no trace of such a firm can be found in Kelly's Trade Directory. A working engine of this patent is to be found in the Birmingham Museum of Science and Industry.

a four-stroke engine, made in sizes X, Y and V from $\frac{3}{4}$ bhp to 4 bhp. A full description of the X model is given in Volume two, . Appendix One. Robinson gas engines were remarkably simple in construction and proved tremendously popular to countless small traders for driving machinery such as that used in shoemaking, sausage-making, potato-peeling, coffee-grinding and in workshops for driving small lathes. The short and uncomplicated construction allow high speeds of 500-600 rev/min to be achieved. No records of sales figures for Robinson engines are available, but engine numbers which are still in existence indicate that about 4000 must have been made. A.E. & H. Robinson is now a subsidiary of the Northern Sheet Metal Company.

7.8 Gas engines and dynamos - a merging of technologies

By the early 1880's the developments in three technologies - those of gas engines, electrical machinery and the electric light - had reached a technically acceptable level. The four-stroke Otto engine was establishing itself, electric dynamos had featured in Great Britain since the late 1870's, and arc lighting had already been used in a variety of places. What was now needed was a convenient and economical prime mover to drive the small dynamos that were being produced. The gas engine answered this need and the merger began, but, in doing so, deficiencies in each appliance, which had previously been tolerated, at once became unacceptable. Engines being produced at that time, for instance, whilst having a speed steady enough for the general work they performed in driving such things as hoists and pumps, proved unsuitable when used to drive dynamos* and defects such as unsteady lighting and overheating in the dynamo appeared. The merger, however, possessed enormous potential and great stimulus was given to attempts to solve the problems just mentioned. Improvements in governing methods applied to engines were implemented, the design of dynamos improved and, within a short space of time, gas engine manufacturers were able to offer matched units of engine and dynamos which could easily be detached if required.

The combination of gas engine and electric generator and, later, the incandescent electric light was one which provided general benefit to the social and economic life of the community. By the early 1890's such was the progress in engine and generator combinations that serious consideration was being given to the use of large gas engines for public electrical supply systems. These particular applications are discussed in section 7.8.2, but first the relevant developments in electrical machines which led up to their being used with gas engines will be given.

7.8.1 Magneto electric to dynamo electric Dynamos by Siemens and Gramme

Within months of Faraday's discovery in 1831 that electricity could be produced from magnetism, various forms of magneto - electric generators were being produced[35]. These were primitive devices which, either by rotating permanent magnets in close proximity to coils formed round a soft iron core or,

*The contributing causes for this are subsequently discussed vice-versa, would produce an electric current. In 1849, Professor Floris Nollet of Brussels attempted to make a large unit that would be suitable for illumination in light-houses which was later taken up by an Englishman, Frederick Hale Homes who returned to England from France in 1856 after working on Nollet's ideas.

The chief disadvantage of these so-called magneto-electric machines was their physical size and weight in comparison to their power output. One of Home's machines designed in 1867 for Scouter Point Lighthouse, Sunderland consisted of 56 compound magnets arranged in seven rings of eight, between which were six rotating discs. Each disc carried 16 coils. The physical dimensions were 6 feet long, 4 feet 4 inches wide, 5 feet 6 inches high and eight 3 tons. Two Allen condensing steam engines, each of 5 horse-power nominal (made by Sir Joseph Whitworth) were required to drive it[36]. There was no doubt that the equipment worked; at the Paris Exhibition of 1867 similar arc lamps designed by Homes were placed in towers, 120 feet high and used to floodlight the area. In 1871, the generators were installed in Scouter Point Lighthouse and remained in service until 1900.

The objectionable size and weight of these early machines spurred on the work that was concurrently being done with other types. These were self-excited machines suitable for producing direct current (earlier efforts had used separately excited field systems). The second type of machine had wound field systems and by common consent, to distinguish them from those in which large permanent magnets were used, became known as dynamo-electric machines or dynamos for short. The two most popular dynamos used with gas engines were those originated by Werner Von Siemens and Zenobie Theophile Gramme. Both types had the advantage of being small and compact and, eventually, good magnetic performance. Siemens patented his well-known 'H' or shuttle-wound armature in 1856, which he used in small generators. Gramme was a Belgian and his machine became widely used throughout Europe. A principal difficulty of both types was their inability to provide a steady, undeviating intensity of light. Gramme appears to have had the first success in overcoming this problem when he incorporated a ring-wound armature, first suggested in 1860 by an Italian Dr. Antonio Pacinotti[37]. The first Gramme dynamo was demonstrated in 1870. An English patent 917/1870 shows the feature of this dynamo. Gramme dynamos were manufactured under licence in England by the British Telegraphy Manufactury , c.1872 and from about 1873, many other versions of it appeared. Notable of these was the Burgin, the Brush and the Farmer.

7.8.2 Electric lighting and the first uses of a gas engine for generation

Pioneering work with arc lamps began in the 1850's, In England, F.H. Homes and W.E. Straits became involved and in France J.B.L. Foucault, J. Duboscq and V.L.M. Serrin made contributions[38]. It was Serrin's lamps that were used with the Gramme dynamo when the latter appeared in 1870-71 and this combination appears to have been more extensively used on the Continent than in Great Britain, where little development work had taken place. Consequently, the supply of lamps and dynamos required in Great Britain had to come from other European countries. About 1878, however, the situation changed when Col. Rookes Evelyn Bell Crompton began to import Gramme dynamos and arc lamps into Britain. He installed them at the new pipe foundry at the Stanton Ironworks in Derbyshire; the Gaiety Theatre, London was lit by six Lontin arc lamps in August 1878 and during 1877, the Jablochoff 'electric candle' had reached England from Paris[39].

The earliest public reference to the use of gas engines for electric lighting can be found in a Crossley prospectus of 1878[40]. An eight horse-power engine is described as being used by Messrs Van der Weyde Light Studios, London for work in photography. Another, in the same year, was Messrs Parker and Bury, Market Street, Manchester, who were the sole agents for Gramme machines for Lancashire and Yorkshire. The latter was full of praise for the 'steadiness of the engine'. Both of these applications in all probability used arc lights.

This potentially promising combination of gas engine, dynamo and electric light received a further stimulus during 1880, when Swan's incandescent lamps appeared[41]. Some installations using these had already been carried out in Scotland and the North of England, such as, the Main Post Office and Railway Goods Yard, Glasgow in 1880; Sir W.G. Armstrong's house at Cragside, Rothbury and Swan's own house at Gateshead in 1881. Quite possibly, steam engines were used in these cases, but since the four-stroke engines were gaining in popularity (nearly 3,000 had been sold in Britain from July 1877 to December 1881) see section 7.12, it was inevitable that it should be considered as an alternative. In 1886, horizontal engines from ½ hp to 16 hp feature several times in prospectuses by Crossleys (Figure 9.1(b)) and from 1885 the small vertical engines of 5 man-power were fitted with Crompton dynamos. These were capable, it was claimed of filling

> 'six 20-candle power, or ten
> 10-candle power Swan lamps'

These engines were made specifically for shops and small traders. By day, they would be used to drive machinery and at night to drive the dynamo to produce electric light.

The references in these prospectuses to 'steadiness of speed' and 'consistency of light' is interesting and indicates that problems in this respect had been encountered and to all accounts, virtually overcome. Sophisticated governing methods are in evidence on the engines and heavy discs can be seen on the dynamos. The problem of uneven speed is a characteristic of all engines of the type under discussion, that is, those in which the burning of a gas vapour is propagated by a localised ignition source such as a spark, flame or incandescent material. It is a phenomenon known as cyclic variation and occurs largely as a result of variations in the rate of flame propagation after the mixture has once been ignited. Modern high speed spark engines are prone to it and in recent years the topic has been the subject of much intensive research by many workers, the author included[42].

With the slow speed single-cylinder engines of the type being manufactured at that time, the variations in light intensity would have been exaggerated and measures to alleviate the problem would immediately have become necessary. Another interesting situation arises here in that, whilst the problem was acknowledged, its causes were not understood, indeed, no attempts to explain it can be found, yet the remedies proposed to rectify it - more firing strokes per revolution, higher speeds, more sensitive governors and shorter working stroke - were in the right direction. In largely overcoming these difficulties, therefore, there is little doubt that both engine technology and electrical machine technology derived great benefit. By 1890, engines fitted with sensitive governors and two carefully balanced flywheels were capable of maintaining a tolerable variation in speed. To further improve the steadiness, dynamos would be fitted with leather pulleys and placed in direct contact with either the engine flywheel or driving pulley, thus avoiding variations due to belt slack if leather driving belts were used. The dynamo itself would also be fitted with a heavy flywheel.

Encouragement for the use of small prime movers for electric generators was given by the Society of Arts when, in the Autumn of 1886, a competition open to prime movers of every class, steam, gas, hydraulic was announced[43]. Three gas engines were accepted; a Crossley, a Griffin and an Atkinson Cycle engine and one steam engine by Paxman[44]. The trials took place in September 1888 and tests included those to determine the thermal efficiency, fuel consumption, power output and regularity of running and governing. Each engine had its virtues but since the tests were primarily concerned with the production of electric light, emphasis was placed on steady running consistent with acceptable economy. The Atkinson Cycle engine returned the lowest fuel consumption and produced the lowest percentage variations in speed - it was awarded first prize. (For sections 7.9 - 7.12, see end of chapter.)

7.13 The automobile engine - a development of the gas engine

The desire to produce a motive power unit which could be used for propulsion appears to be as strong throughout the whole of the period being considered as that to drive machinery. It may be recalled from chapter one that John Barber suggested his idea be used in a ship; Rivaz actually succeeded on land in 1807 and so also did Samuel Brown in 1826. In 1843, the American, Dr. Alfred Drake was keen to put his engine 'below decks where it would be out of the way of shot'. The most notable later achievement in this direction was undoubtedly that by Gottlieb Daimler and his ever-faithful protegé, Wilhelm Maybach, who between them developed a small high speed liquid fuel engine. The circumstances which enabled them to do this were a direct consequence of their experiences with gas engines and, in the case of Daimler, his being dismissed from Deutz.

The successful enterprise that became known as 'Die Gasmotoren Fabrik' Deutz, owed much to the creative ability of Otto, the masterful management of Langen and the clear sense of the objective by Daimler. Collectively, talents like these are ingredients destined for success, but in the case of GFD, their blending together was not easily achieved. Personality clashes between Otto and Daimler (mentioned in Chapters Five and Six), strained Langen's patience to the utmost and a tense situation existed at Deutz until 1880. In December of that year, Gustav Langen - brother of Eugen - suggested to Daimler that he (Daimler) should leave his position at Deutz to found a foreign subsidiary of GFD. The following Summer Daimler agreed and left for Russia to study the possibilities there[47]. On his return, Daimler submitted a report which showed that conditions were favourable for starting up a factory in St. Petersburg. He was offered the job of seeing this was done but declined. GFD then responded by terminating his contract with six months' notice, Shortly after this, Daimler left and Maybach joined him in October 1882 and a contract between them was signed on 1 January 1883.

At the time Daimler left Deutz, it employed three hundred men, was manufacturing six hundred engines a year and, largely as a result of his efforts, had become a highly organised production unit. In contrast, the new environment at Caanstaat, near Stuttgart, consisted of a converted toolshed as an office and a greenhouse as a workshop. By the end of 1883, in these meagre surroundings, Daimler and Maybach had produced a liquid fuelled engine using incandescent ignition and a surface carburettor in which heated air from the exhaust was bubbled through the fuel. A German patent No. 28243 incorporated the general features of this engine and from it there evolved a series of engines leading eventually to one that was put in a motor cycle in 1885. The following year, a larger one was put into a carriage which was originally intended to be horse-drawn. This particular engine, which was later made with a water-cooled jacket, developed 1.1 horse-power at 650 rev/min. from cylinders which were 70 mm diameter and 120 mm stroke. Its first trials were in September 1886 in the garden of Daimler's house. As Daimler and Maybach worked to improve this engine, it became lighter and more mobile and eminently suitable for use in boats, industrial locomotives and for operating pumps. Vee engines followed in 1889 which were so successful that they were accepted and used by the French automobile builders in 1891. On 22 July 1884 Peugeot cars, fitted with Daimler engines, came second, third and fifth in what was probably the first automobile test run for endurance[48]. It began at 8 am (to avoid undue altercations with spectators) in Paris and consisted of a 78 mile run to Rouen. Dion-Bouton's twenty horse-power steam engine vehicle was the first to finish.

Their experiences gained at Deutz were obviously a great factor in the success of Daimler and Maybach in their ventures with high speed engines. In addition, income from shares plus savings and monetary payments by the Deutz firm had provided Daimler with essential capital to begin with but, by 1890, when he had produced a successful four-cylinder, ten horse-power engine, money was not as plentiful. As a result of this financial situation, a company was formed in November 1890, Daimler Motoren Geselleschaft in which Daimler, Maybach and two businessmen, M. Duttenhofer and W. Lorenz were the shareholders. By this time, Daimler was in a very weak financial state and Duttenhofer and Lorenz controlled the majority of the shares. Almost immediately discord within the company arose - Daimler found his freedom to embark upon technical and business developments curtailed and Maybach left to begin work on his own, eventually followed by Daimlet in 1892 who, by remaining on the Board, maintained a tenuous link with the former company. Such must have been an impossible situation for Duttenhofer and Lorenz, but it existed until 1895 at which time they were forced to accept the return of Daimler and Maybach, this time on the latter's terms. Daimler had control over management and manufacture, Maybach became the technical director. This new situation was one which allowed Maybach to display his potential to the full. From then on, all patents became registered in his name and many engines became known as 'Maybach' engines. After Daimler's death in 1900, Maybach assumed technical leadership of the company and played an overwhelming part in the development of both the engine and chassis of the thirty-five horse-power Mercedes racing cars*.

7.14 The Gas Engine Research Committee - first report

The first authoritative research programme involving gas engines began in 1897[49] when the Institution of Mechanical Engineers formed a Committee of eminent engineers consisting of:

Prof. Alexander B.W. Kennedy, LL.D, F.R.S. Chairman
Mr. Henry J. Burstall
Prof. Frederick W. Burstall, Reporter
Mr. Bryan Donkin
Mr. John Fielding
Mr. William H. Maw
Mr. James Platt
Prof. W.C. Roberts-Austen C.B., F.R.S.
Mr. Charles J. Wilson, F.I.C.

The purpose of the investigation was to determine the effect on the economy of gas engines of varying one or more of the parameters associated with its working.

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* Emil Jellink, a businessman was a wealthy promoter of Daimler cars. On Daimler's death he had his daughter's name Mercedes bestowed on cars fitted with Daimler engines.

Prior to this investigation, no serious experimental work on engines had taken place in Great Britain. A small amount had been done by individual firms, but no attempt to publish their findings had ever been made. Professor William Robinson after hearing the presentation of the report, notes this fact[50], and remarks upon the wasted efforts and unnecessary duplication of tests that had taken place as a result of such work not being generally available.

The report is particularly useful in providing information about the state of the art of making engines both at that particular time and since 1876. It is very clear, for instance, that considerable problems existed with instrumentation during the twenty-five year period from 1875; problems still remained to be solved with the use of electric ignition; combustion chamber design used on British engines came in for some criticisms and so also did the experimental technique used by those involved in the tests.

On the first point regarding instrumentation, Professor Kennedy remarked that eleven years previously, when he had been engaged in a series of tests involving gas engines* no thermometric instruments suitable for the accurate measurement of temperature in gas engines existed[51]. Another disclosure was the fact that no attempt had ever been made in Great Britain to measure the quantity of air entering the cylinder of a gas engine. This, apparently, had always been arrived at by deductions and calculations[52] - a fact which explains the grossly inaccurate claims for air/gas

* The Society of Arts Trials of 1888

ratios that accompanied the Otto-Langen and the four-stroke engines. Yet another remarkable statement was that after trying out a great many indicators, only one, the Wayne Rotary Indicator, was found to give accurate results.

Dugald Clerk who, by that time, was probably the most distinguished authority on internal combustion engines in Great Britain, was highly critical of the experimental methods used by the Committee. Clerk possessed a wealth of experience in such matters and his comments require to be taken seriously. There was little evidence, says Clerk, to show that the relevant variables had been altered one at a time as had originally been intended. The result was a confused picture and we still are not sure what specific effects arise from, say, increasing the compression ratio. Mr. James Atkinson of Crossley Bros. and Professor Robinson both supported this criticism. Clerk was also disappointed to see that the design of the combustion chamber used in the test engine was bad; it possessed a large surface area which cooled the expanding gases rapidly, thus a great amount of available energy was lost. He then made some interesting comments with regard to some tests he himself had made on a Crossley engine in 1879.

In attempting to increase the compression ratio, Clerk states that he was surprised to find that the performance and economy were actually reduced. At that time he was quite unable to understand why, since he believed then that the reverse should have happened. The reason was now well understood and was concerned with his earlier remarks regarding the surface area exposed to the burning gases. This is why, continues Clerk, he was indeed surprised to find that the test engines exhibited such shortcomings; if improvements were sought, difficiencies such as these should be remedied immediately*.

Yet another surprising feature of the report is one that describes the unsuccessful efforts, extending over a period of four months, that were made to equip the test engine with a satisfactory electrical method of ignition[53]. It is surprising because a number of commercial gas engines equipped with electrical ignition at that time were in general use, but the problems with the test engine was that a number of varying conditions were used and a reliable means of electric ignition had not been found in spite of exhaustive efforts. Having failed in these attempts, a heated tube method of ignition was used with a timed valve as used on Crossley gas engines.

The reactions to the report by the eminent authorities in Germany and France are also interesting. Professor Aimie Witz of France, having done excellent work on combustion in closed vessels, was in favour of a synthesized theoretical analysis based on his laboratory experiments from which he had been able to formulate certain physical laws. Professor Boulvin felt that more consideration should be given to cylinder wall temperatures and the effect upon performance of increasing their temperatures. M.E. Delamare-Debouteville believed that more work should be done with different com-

* These early experiments by Clerk raise some interesting points. If Crossley Bros. had also tried similar work and obtained the same result this could well have influenced them in their belief that it was stratification and not compression that was responsible for the success of the Otto engine

pression ratios to obtain a value most suitable for a given ratio of gas and air. Professor Slaby of Berlin was critical of the measuring methods used; that the heating value of the gas should have been obtained by a Junkers calorimeter and not by calculations of its analysis; that the ignition method should have been electric, such methods being available on the Continent.

The report, therefore, attracted a good deal of commentary, much of it adverse, but it must be considered as having a general beneficial effect. It focussed attention, for instance, on the immediate problems associated with gas engines, showed up the shortcomings existing in Great Britain with regard to instrumentation and experimentation and probably, most important of all, made its findings available to the many makers of gas engines throughout the country. Also made known was the state of the art in the two other principal countries, France and Germany, which were concerned with such work.

7.9 The year and engine number of significant designs made by Crossley Brothers of Manchester

Year	Engine type	Nominal Power	Engine Number
1876	First Otto gas engine	3 ½	1300
1883	Twin. Two connecting rods on to one crank-shaft bearing	6	6670
1884	Vertical. Overhead crankshaft with cylinder outside main frame	2	7376
1885	Vertical, Crankshaft at top with cylinder central	5 man 1 ½	8630 9170
1888	First tube ignition engine horizontal	14	11284
1889	Twin cylinder vertical	16	13750
1890	Twin cylinder vertical	30	15860
1893	Vis-a-Vis engines	60	-
1904	Twin vertical crank-shaft at bottom	30	44280
1906	Tandem horizontal		50921
1908	Side by side, flywheel in the middle		54905
1909	Horizontal (size 124)		59830

7.10 Commencing numbers of engines with tube ignition[45]

Engine power	Year	Engine number
2	1888	12600
3	1891	17250
4	1888	12760
6	1889	14550
7	1888	13600
9	1888	12700
12	1888	11960
*14	1888	11284
16	1888	13472

*First tube ignition engine

7.11 Commencing numbers of the first vertical gas engines by Crossleys[46]

2 man	1887	10200
5 man	1885	8630
½ hp	1886	10630
3	1889	13740
5	1886	10190

7.12 Yearly list of engine sales by Crossley Brothers 1877-1900

Year	No. engines sold	Total nominal HP	Total indicated HP
1877	133	466	798
1878	445	1603	2670
1879	590	2183	3540
1880	781	2972	4692
1881	942	3674	6594
1882	1162	4648	11620
1883	1172	4806	11720
1884	1187	4985	11870
1885	1205	5182	1325
1886	1304	5738	14344
1887	1365	6145	16380
1888	1482	6818	17784
1889	1615	7591	20995
1890	1805	8664	23465
1891	1933	9472	27062
1892	1944	9771	27916
1893	2043	10215	29624
1894	2117	11009	31226
1895	2364	12293	34869
1896	2501	13506	37515
1897	2832	15576	43896
1898	2971	16733	50507
1899	3020	17073	52850
1900	3067	17121	53632
	40031	148242	548824

References - Chapter Seven

1. The Engineer Vol. 44 (1877) p.24 Also Engineering Vol. 24 (1877) p.27
2. Three principal difficulties arose in the use of incandescent ignition systems; premature ignitions during running and when starting up (in the latter case, engine rotation would be reversed, producing a potentially dangerous situation); irregular ignitions and lastly, a very short life (of a few hours) of the material heated to incandescence
3. English Patent 491/1877 dated 5 Feb.
4. English Patent 2177/1877 dated 4 June
5. F.W. Crossley claims that he made this modification during his cross-examination at the Otto/Linford hearing. The Engineer Vol. 51 (1881) p.235
6. English Patent 1754/1882 dated 13 April (To Anderson & Crossley)
7. English Patent 4489/1882 dated 20 September
8. English Patent 1722/1883 dated 5 April
9. English Patent 11578/1884 dated 23 August
10. German Patent 10116/1879 dated 15 August. The equivalant English Patent to this is 3245/1879 dated 12 August
11. English Patent 5469/1881 dated 14 December issued to Crossley and Holt. A follow-up patent attempting to improve upon the former was taken out in July 1882 No. 3449
12. English Patent 4777/1884 dated 12 March
13. English Patent 15311/1884 dated 20 November to Holt and Crossley
14. Letters to Abel and Imray p.62 F.W. Crossley wrote a number of letters to F.P. Holt describing his numerous ideas for the applications of gas engines. The one relating to gas engine tramcars is dated 14 May 1881
15. English Patents 370/1881; 3537/1774; 14248/1888

16. *Letters to Abel and Imray* p.118

17. English Patent 5113/1878 dated 13 December

18. English Patent 4297/1880 dated 21 October

19. English Patent 15312/1884 dated 20 November. F.W. Crossley had previously suggested (Patent 8637/1884 June) that valves could be designed which worked automatically according to variations in cylinder pressure.

20. The test data shown had been collated from various engine tests described by D. Clerk. *The Gas and Oil Engine* (London 1902) 6th Edition p.141 and W. Mcgregor, *Gas Engines* (London 1885) p.82

21. Gas Engine Handbook File No. K32 Crossley-Premier Engines Ltd. Openshaw, Manchester

22. *The Engineer* Vol. II (1861) p.235

23. A somewhat similar expression is given by Parsell and weed *Gas Engine Construction* (London 1900) p.263 Different constants are used but the horse-power figures given by each agree closely

24. A file labelled 'Historic Notes'. Crossley-Premier Engines, Openshaw. A letter dated 21 October 1899 from Crossley Bros. to Messrs Bradford & Co. Crescent Iron Works, Salford. The identification letters began with J for 1½ bhp engine, using every letter to Z a 79 bhp engine and ZB a 100 bhp engine

25. *Letters to Abel and Imray* p.234

26. The first Crossley patent for a heated tube form of ignition which replaced the slide valve, was English No. 15101/1887 dated 3 November, issued to Crossley and Anderson

27. Clerk *op cit (20)* p.297

28. 'Historic Notes' *op cit (24)* The figures quoted agree with those given by Clerk *op cit (20)* p.317 but appear to be original test date.

29. J. Atkinson 'The Modern Development of the Gas Engine' *Trans. Manchester Association of Engineers* (1894) p.153

30. Rachel F. Waterhouse <u>A Hundred Years of Engineering Craftsmanship</u> (Birmingham 1957) The work is a short history of Tangeys Ltd. 1857-1957

31. <u>The Engineer</u> Vol. 105 (1908) p.265

32. English Patent 4291/1883 dated 16 September to Charles Henry Andrew

33. The author is indebted to Mr. D.G. Houghton of Gardners Ltd. for his co-operation and assistance in allowing records and drawings to be examined

34. <u>The Engineer</u> Vol. 74 (1892) p.56

35. C. Mackecknie Jarvis 'Machinery for the New Light' Pt. I <u>Journal of Inst. Electrical Engineers</u> (May 1955) p.280

36. Ibid p.284

37. Jarvis <u>op cit (35)</u> Pt. II (September 1955) pp.566 and 570

38. Jarvis <u>op cit (35)</u> 'The Development of the Electric Load' <u>Journal of Inst. Electrical Engineers</u> (June 1957) p.314

39. Ibid p.315

40. 'Gas Engine Handbook' <u>op cit (21)</u> File K.32 p.9

41. Jarvis <u>op cit (38)</u> p.315-318

42. K.A. Barlow, 'Cyclic Variations in Flame Propagation in Spark Ignition Engines' <u>M.Sc. Thesis 1974 Univ. of Salford</u>

43. <u>Journal of the Society of Arts</u> Vol. 36 (No. 1891) p.213

44. 'Historic Notes' <u>op cit (24)</u>

45. Ibid

46. Ibid

47. Friederick Schildberger, <u>Gottlieb Daimler, Wilhelm Maybach and Karl Benz</u> (Daimler-Benz Atkiengeselle-schaft, Stuttgart) For much of the background work quoted, the author is pleased to acknowledge the assi-

stance during his visit by the various members of staff of the Daimler-Benz Museum, Stuttgart

48. Ibid p.39

49. Frederick W. Burstall 'First Report to the Gas Engine Research Committee' Proc. Inst. Mech. Engineers (April 1898) pp.209-267

50. Ibid p.244

51. Ibid p.230

52. Prof. Slaby of Berlin had used a metering method in 1890. B. Donkin Gas, Oil and Air Engines (London 1900) p.469 (Appendix C) But Slaby's work in this respect appears not to have been generally recognised in Great Britain

53. 'First Report ...' op cit (49) p.218

CHAPTER EIGHT

ENGINE CYCLES OTHER THAN THE FOUR STROKE

The main criticisms of the four-stroke cycle engine when it appeared before the public in 1877 was that two revolutions of the driving shaft were needed in order to produce only one working stroke. Its smooth running and silent operation compared with any previous engine was acknowledged, but by no means did this assure its unqualified acceptance. It was inevitable, therefore, that attempts should soon be made to experiment with alternatives. The primary aim in these attempts was to produce an engine that would give one firing stroke per revolution using a cycle which was distinctly different from that used by Otto. No attempts to copy directly the Otto cycle were made*. Indeed, as shown in Chapter Six, the true significance of the four-stroke in the sense that it could not be bettered appears to have been unappreciated.

This chapter describes the work and achievements of the pioneers who embarked upon work in this field and who strived to overcome the associated technical problems. Their efforts were not crowned with the success that was accorded to the four-stroke, but they eventually succeeded in producing working engines of exceptional technical merit, thus paving the way for much later advances.

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*Accusations of infringement came from Otto and Crossleys and originated from an erroneous concept of combustion. See Chapter Six, section 6.1.2.

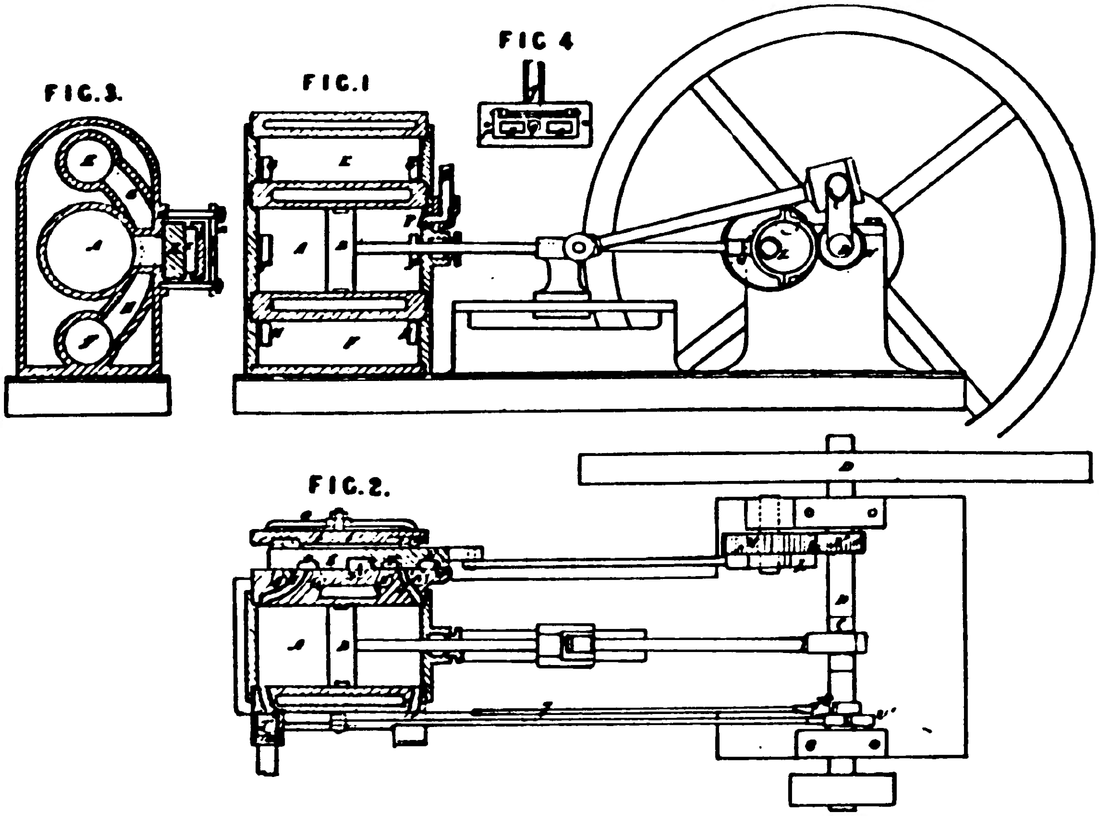


Fig. 8.1
Design of two-stroke cycle gas engine by James Robson 1877 from his patent of that year

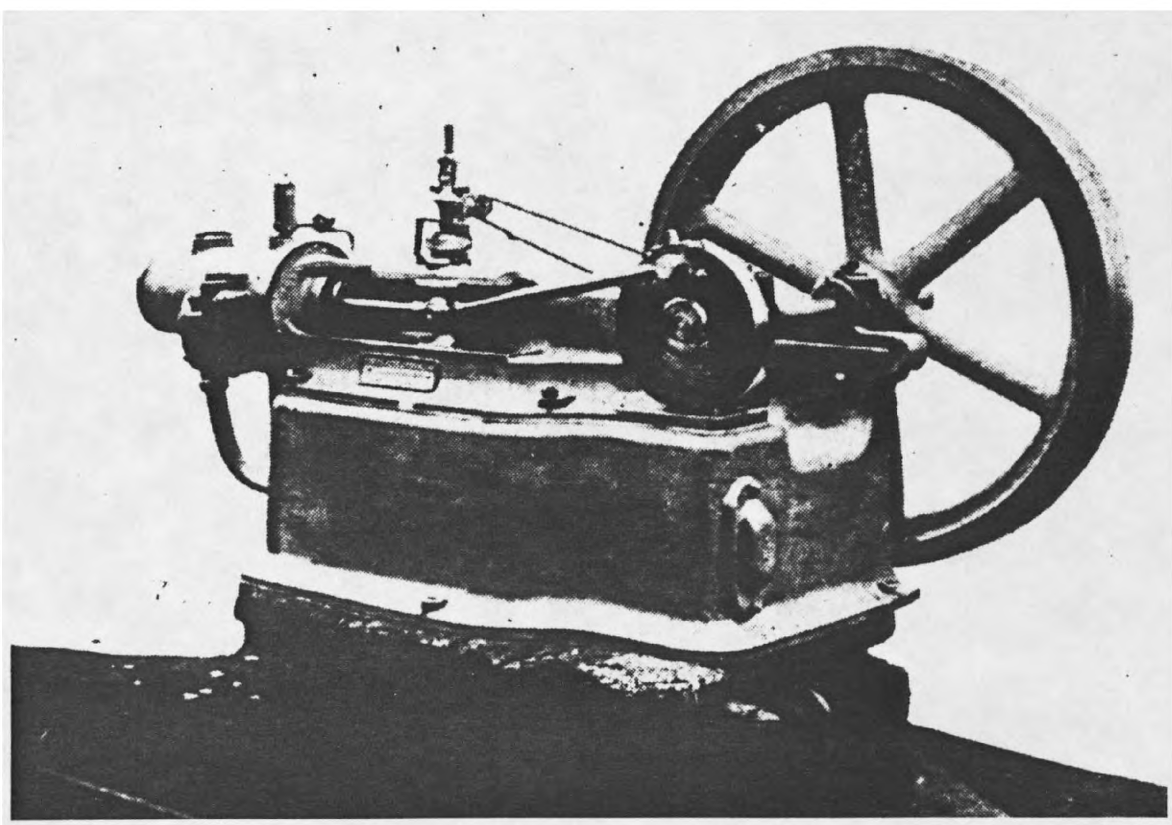


Fig. 8.2
A production version of Robson's engine made by Tangye's of Birmingham c.1881

8.1 The Robson two-stroke

The earliest work of James Robson (1833-1913) in connection with gas engines is mentioned in Chapter Two, section 2.7 where it may be recalled that his fame and achievements were of a localised nature, no patents for the engines which he made, c.1858 ever being taken out. The first patent granted to Robson, No. 2334 of 1877 describes a two-stroke cycle gas engine, Figure 8.1, but prior to this he appears to have been working on another idea for an engine described as a 'spring type' atmospheric engine[1]. This was a small gas engine called 'The Patent London Gas Engine', one being shown at the Agricultural Hall, Islington in December, 1880[2]. The idea, it was claimed, had lain dormant for many years and was eventually protected by a patent No. 4050 of 1880. In appearance, it resembled the Bisschop engine (Chapter Five, section 5.8.3), but Robson's had two vertical cylinders, a smaller one, containing a piston which was used to draw in a charge of gas and air and a larger cylinder also containing a piston to which was attached a toothed rack and geared with a 'free-wheel' device of a type similar to the Otto-Langen atmospheric engines. An explosion beneath this larger piston would thrust it upwards to encounter the resistance of springs placed in the upper part of the cylinder. The energy stored in the springs would then be used to drive the piston downwards. The 'free-wheel' then became a fixed wheel to the driving shaft. It was an attempt to achieve a double-acting engine using only one firing stroke.

This so-called atmospheric engine by Robson appears not to have proved popular, no evidence of usage having been found.

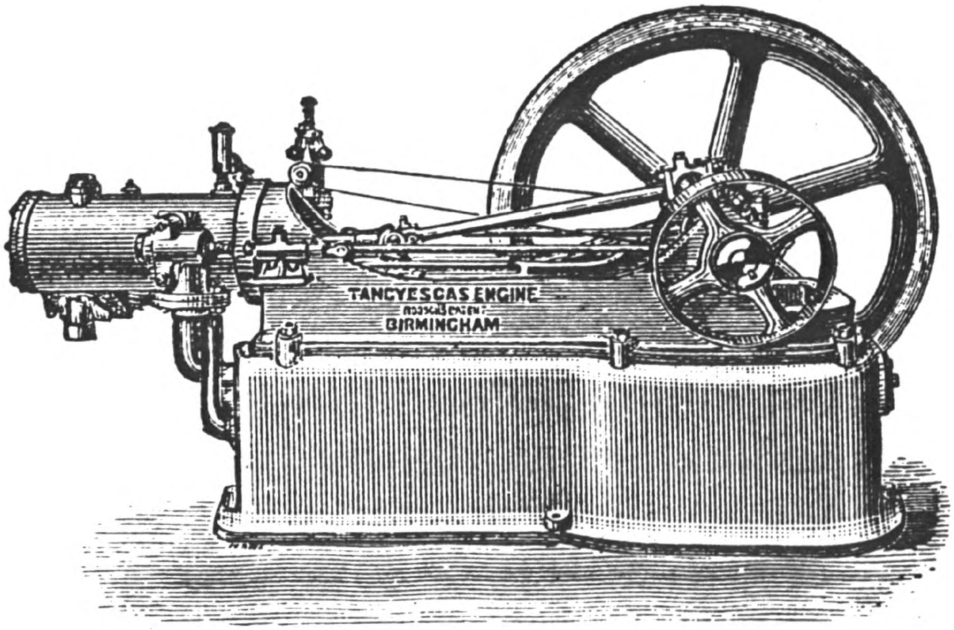
Fig. 8.3
James Robson (1833-1913) aged 27 years.
The booklet seen resting on the plan is
entitled 'The Seam Coals' and could
possibly have been written by him.

THE "TANGYE" GAS ENGINE

(Robson's Patent.)

ROYAL CORNWALL POLYTECHNIC SPECIAL GOLD MEDAL, 1882.

(Also for Gas Producer and Feed Pump.)



The ½, 2½ and 4 H.P. sizes are of the type shewn in illustration.
The 1 H.P. size is of the type of the "Tangye" Steam Engine.

Working Size	½ H.P.	1 H.P.	2½ H.P.	4 H.P.
Test Horse Power	1	1.4	3	6
Revolutions per Minute	180	170	170	160
Price, Engine on Base with Tank ... ... £	60	82	115	140

Note.—The Test Horse Power in the table above is that given off at the Driving Pulley in actual test with Dynamic Brake at our Works.

Fig 8.4 The Tangye two stroke cycle gas engine of 1884 (made according to James Robson's patent)

More promising was his two-stroke cycle engine which was later made by Tangyes from about 1881. Its principle of operation was precisely that used on modern two-stroke engines in which one end of the piston is used as a pump to draw in and compress the charge while the opposite end receives the explosion force. In Robson's engine the charge was transferred from one end of the cylinder to the other, but first into a receiver. Admission from the receiver into the combustion chamber was controlled by a slide valve. Only one of this type was ever made which was used to drive the machine tools in Robson's own workshop at North Shields until it was replaced by his 1879 patent for an engine working on a similar principle[3].

A distinctive feature of Robson's engines was the absence of separate charging pumps so frequently used by other workers in this field who came after Robson. The second patent, No. 4051 of 1879 shows quite clearly that Robson fully appreciated the possibility of carrying out the operation of charging, compressing, igniting and exhausting the mixture in one cylinder and in one revolution of the crankshaft. The specifications in this second patent are much clearer than in the first and are devoted exclusively to the particular cycle. The first claim reads as follows:

> 'The arrangement and general combination of an engine by which a charge of inflammable gas is drawn in and then compressed into a reservoir by one side of a piston working in a cylinder and the expulsion and replacement during the backward stroke on the other side of the piston of the burnt gases of the previous forward stroke, by the compressed gases from such reservoir, and completing the compression of the gases by the continued backward motion of ascent of such piston, and explosion on the forward stroke for obtaining motive power, substantially, as herein before described ....'

The piston rod end of the cylinder was the pumping half which supplied the new charge to the reservoir at a pressure of six pounds per square inch. When entering the opposite end of the cylinder, it helped to expel the burnt gases and when this was done, was compressed by the piston to a pressure of thirty-five pounds per square inch. Ignition was by flame using a slide valve. This particular engine, (Figure 8.2) was made by Tangye c.1881, 'many hundreds', it was claimed, being built[4]. Engines were rated in nominal horse-power, the brake horse-power being about 33% greater. Gas consumption was about 35 cubic feet per brake horse-power. The 'Tangye Gas Engine - Robson's Patent' (Figure 3.4) as it became known, was made in four sizes, ½, 1, 2½ and 4 nom. horse-power. A number were still in use at the turn of the century, their owners apparently being reluctant to replace them.

James D. Roots, in an article on cycles of gas and oil engines[5], pays tribute to the pioneering work of James Robson in the field of two-stroke engines.

8.2 Dugald Clerk and the Clerk Cycle

Dugald Clerk (1854-1932) (Later Sir Dugald) was a second pioneer of the two-stroke engines. He was about twenty-two years of age when he began his career with gas engines and for the next ten years or so experimented and worked out his own ideas related to impulse-every-revolution engines. Clerk was extremely critical of his own work as well as that of others and quite freely published his failures. In his estimation he never succeeded in overcoming, to his own satisfaction, the technical problems associated with two-stroke engines and in describing his work in this field says[6]

> '....... at first blush, it seems a very simple matter to make a compression gas engine to give an impulse for every revolution; this was my opinion when I commenced work for the first time upon gas engines using compression in October 1876. Since then, I have had every occasion to modify this opinion; the difficulties are very great; any engineer who doubts this would speedily be convinced upon making the attempt...'

8.2.1 His early life and involvement with gas engines

Clerk was born in Glasgow and left school aged fourteen to work for his father who was in business as a machinist. In the evenings he studied mechanical drawing at the Mechanics' Institute and in November 1868 became a pupil to the head draughtsman of Messrs H.O. Robinson and Co., Engineers, Glasgow[7]. From 1872 to 1876, he studied at the Andersonian College, Glasgow and at the Yorkshire College of Science, Leeds where he taught chemistry and became assistant to Prof. T.E. Thorpe. On returning to Glasgow, he was appointed senior assistant to Dr. E.J. Mills in the Young Chair of Technical Chemistry, where he remained for about a year.

Clerk's interest in internal combustion engines began in 1876 when, apparently inspired by an Otto and Langen engine working in a joiner's shop in Glasgow, he set about making an engine of his own in his father's works towards the end of 1876. It was while working on this engine that he became acquainted with Mr. Louis Sterne of Thomson (or Thompson) Sterne and Co. After entering into an agreement with them

Fig. 8.5
Dugald Clerk (1854-1932) c. 1890
A Pioneer of Gas Engines

Clerk was made a Fellow of the Royal Society in 1908 and created a Knight in 1917.

at the beginning of 1877, Clerk moved his engine to the Crown Ironworks of Thomson, Sterne and for the next nine years until 1885 devoted his whole time to work on internal combustion engines. As well as the practical aspects of construction and design, he studied and eventually established, the fundamental laws of gaseous explosions and the theory of compression applied to internal combustion engines.

8.2.2 The first two-stroke cycle engine by Clerk

The work which eventually led to Clerk producing his first two-stroke engine really began at the end of 1877, when Messrs Sterne obtained a five horse-power Brayton engine from America. It was handed over to Clerk to be studied. The Brayton engine, it may be recalled, operated on a constant pressure cycle; the mixture, having been previously compressed by an external pump was ignited as it entered the combustion chamber. Clerk made alterations to this engine - the inference is that he caused compression to be carried out in the working cylinder - and, as a result of these experiments, produced his own two-stroke engine, employing compression in 1878. This new engine used a pump to compress the mixture into a receiver at the full pressure required for compression. During the first part of the working stroke, this compressed mixture was admitted to the cylinder and after the supply was cut off, ignited to produce the power stroke. The return stroke expelled the burnt gases and a new charge entered the cylinder. At full power, this engine was capable of four horse-power nominal, at three hundred revolutions per minute (a very high speed for

1878). After testing it for a year, this engine was exhibited at the Royal Agricultural Society's Show at Kilburn, London in July 1879. Clerk claims that this was the first successful engine introducing compression with ignition at every revolution*.

The Kilburn engine was not wholly successful and Clerk was quick to acknowledge the fact[8]. After mentioning minor difficulties with ignition governing and starting gear, he describes two major difficulties, one concerned with back-fire ignitions to the reservoir and the second with shock in the motor cylinder. The difficulty of ignition spreading back to the reservoir was serious and was never completely overcome. It would occur on full load when the burnt gases had not been completely expelled, these being sufficient to ignite the incoming fresh charge. These back-fires occurred only seldom and no danger resulted, but when they did the engine would stop, since the charge was spent. The shock problem, Clerk realised, was due to too rapid ignition and redesigned the combustion chamber to reduce its effect. Clerk continued his experiments and towards the end of 1880 built an improved engine which was shown at the Paris Exhibition of 1881. In this second engine, a separate pump was used as before, but it served only to displace the mixture from the receiver at a pressure of only four pounds per square inch. The motor piston performed the compression. Figure 8.6 shows a sectional plan and elevation of this engine.

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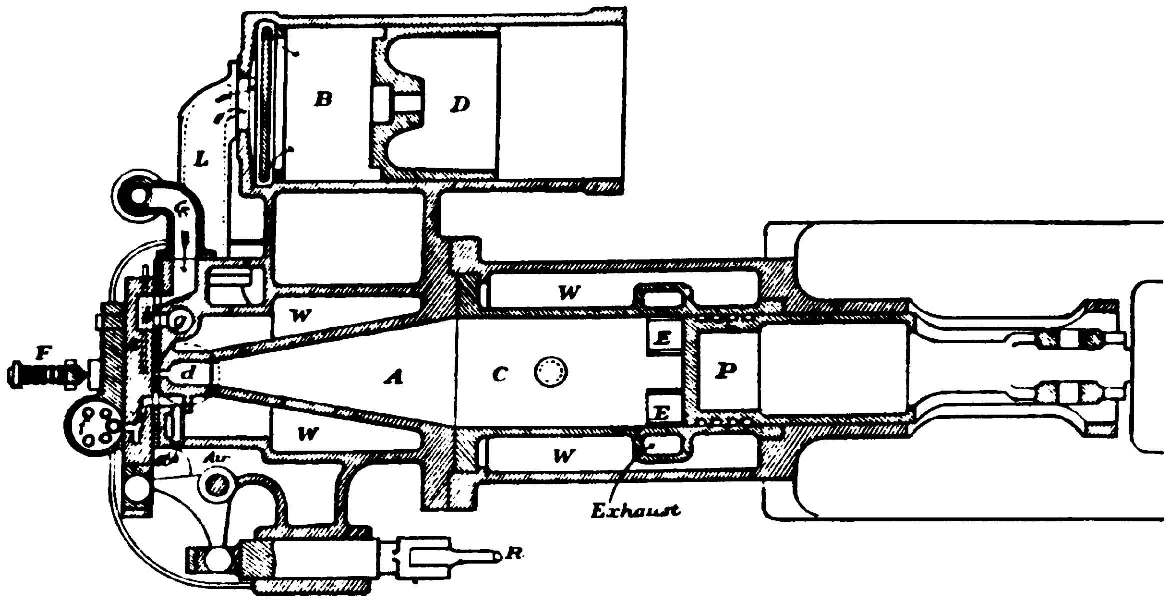
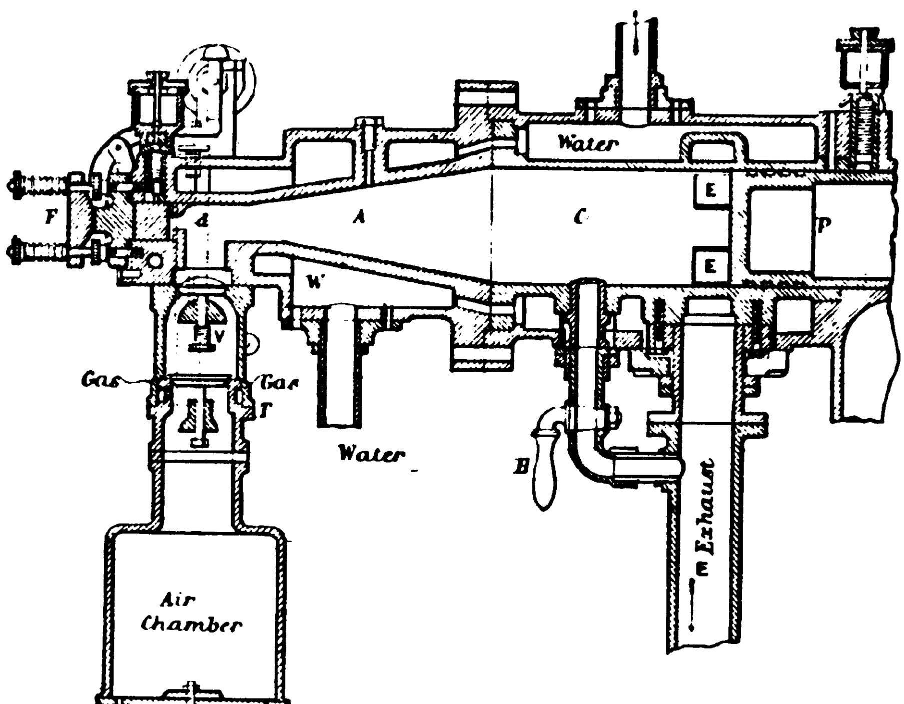
*Although Robson's work is dated earlier than Clerk's, it does appear that Clerk was the first to produce a satisfactory working engine

Dugald Clerk's views on the theory of gas engines are discussed in Chapter Six and it may be remembered that he became a strong opponent of Otto's theory of stratification and a firm believer in the use of compression. His engine designs clearly reflect what Clerk thought was desirable for the efficient and economical operation of a gas engine. The conical shaped combustion chamber, shown in his engine, was an attempt to reduce the surface area in contact with the burning gases; generous inlet and exhaust ports reduced the throttling effect of the gases; the inlet port was short and so positioned that it would not unduly heat up the incoming charge and the exhaust valve was situated close to the cylinder in a further attempt to keep the surface area exposed to burning gases to a minimum. As an understanding of engine technology evolved, Clerk's views proved well founded. He was not afraid to publicise what he considered should be done to produce more efficient engines and was highly critical of manufacturers whose engines were a blatant contradiction of what he believed[9]. It is interesting to reflect upon what would have been the result on engine developments in Great Britain had Clerk's scientific talents combined with Crossley's manufacturing skills. But this never occurred, in point of fact, largely because of Clerk's opposition to Otto's theories and also because Clerk's engine was considered an infringement (see section 8.3), Relationships between Crossleys and Clerk appear to have been none too friendly.



SECTIONAL PLAN.



LONGITUDINAL SECTION.

Fig. 8.6
Sectional views of the two-stroke engine of Dugald Clerk, 1881. Note that the gas and air are mixed (lower view) before entering the main cylinder

The charging cylinder and piston is shown at B and D respectively (upper view)

8.2.3 Clerk's igniting device

Another significant contribution by Clerk was the means of ignition which he used on both the engines previously described. The flame ignition system that was then used on four-stroke engines was found unsuitable for this new engine since the maximum number of ignitions possible was only 125 per minute. When attempts to operate it above this figure were made, mis-firing would occur due to the igniting port which transported the igniting flame, having been insufficiently purged of burnt gases. Instead of a flame, therefore, Clerk used a platinum cage, which was fitted into the slide valve and raised to incandescence by an external flame. Figure 8.7 shows a section of this valve which was capable of 300 ignitions, and thus 300 revolutions per minute, with a two-stroke cycle engine. Ignition difficulties with engines were present for many years and this particular effort by Clerk is worthy of note since it represents a great improvement on other ideas at that time.

The platinum cage (5) was made to fit the port (2) of the slide valve (1). One end of the port (3) communicated with the stationary pilot light (9) and the other end (4) to a passage (10) when it was not in the igniting position. When the cylinder mixture was being ignited, the port (3) was in communication with the explosion port (6). In the position shown, gas mixture flows through the platinum grating into the space (2) immediately becoming lighted by the pilot light. The flame at the grating burns in the cavity, discharging into the atmosphere through the passage (10). As the slide moves to ignite the main charge, communication

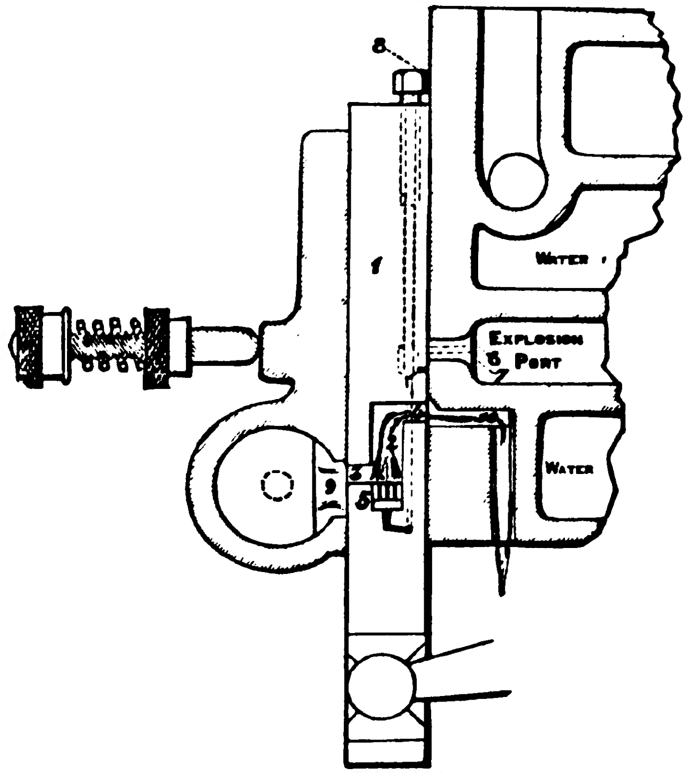


Fig. 8.7
Flame ignition system by Clerk used on his two-stroke engines c. 1879. Ignition is about to occur.

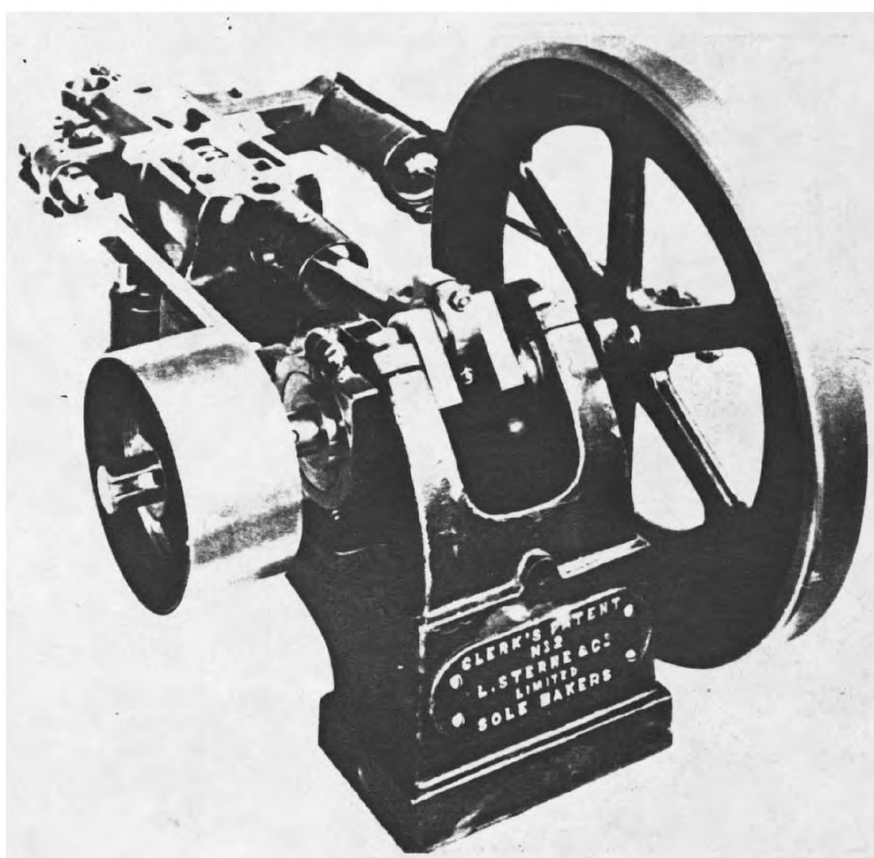


Fig. 8.8
Production model of the Clerk engine c. 1885
(exhibited in the Deutches Museum, Munich)

with the atmosphere ceases and shortly after, the port (4) opens with the port (6). The incandescent platinum cage then ignites the main charge. After ignition, the slide moves back to the original position where the sequence of operations is repeated. No purging is necessary since the platinum cage, once having been brought to incandescence, would remain in that condition. Means of regulating the gas to the slide is provided by the screw (8) so that a correctly proportioned ratio of air/gas could be obtained.

8.2.4 Trials of Clerk's two-stroke engine

Clerk engines were made in nominal horse-power of 2, 4, 6, 8 and 12. During 1884, Mr. G.H. Garrett of the Crown Iron Works, Glasgow carried out tests[10]. The following data is extracted from them:

Nominal horse-power	2	6	12
Motor cylinder bore/stroke (ins)	5 x 8	7 x 12	9 x 20
Displace cylinder bore/stroke (ins)	6 x 9	7½ x 12	10 x 20
Average speed (rev/min)	212	146	132
Brake horse-power	2.7	7.23	23.21
Maximum pressure (lbf/in^2)	155	195	238
Compression pressure (lbf/m^2)	38	48	57
Gas consumption (cu.ft/bhp/hr)	40	30.42	24.12
Mechanical efficiency	75	80	85

Due mainly to pumping losses, the brake horse-power was always slightly less than that which could be obtained from an equivalent sized four-stroke engine; consequently, the brake thermal efficiency of Clerk engines was about 17% compared to four-stroke engines which, at that time, gave about 21%.

8.3 The Clerk engine and its infringements of the Otto patent

Sufficient detail of the Clerk engine has been given to appreciate that neither its design nor operation could, in any way, be considered to coincide with that of the Otto engines. Yet, as explained in Chapter Six, such was the understanding of relevant theories of gas engines at the time, this was precisely what did take place. In common with many other gas engine makers in the early 1880's, Thomson, Sterne received a warning from Crossley Bros. that they considered the Clerk engine to be a 'blatant infringement' of the Otto patent. The first of these warning letters was dated 24 March 1882[11]. Between this date and 1885 a good deal of correspondence took place between the two firms. Sterne refused to take the threat seriously and pointed out to Crossleys the constructional and operational differences of their engine compared to the Otto, but Crossleys were perfectly serious and went so far as to prepare for a possible court action against Sterne. A comprehensive document dated 31 October 1884, entitled 'Otto v Sterne and Clerk', 'Utility of Stratification', leaves one in no doubt as to Crossleys' intentions[12].

The text of this document, which covers six pages of close handwritten explanations of Otto's theory of stratification*, is a brief to prosecuting Counsel in preparation for the possible High Court action. In reality, the matter never quite got so far. A letter dated 23 January 1885, indica-

*The article is exceedingly informative about theories on combustion which were held at that time. These have been discussed in Chapter Six.

THE CLERK GAS ENGINE.

Highest Award, American Institute, New York, 1883. Silver Medal American Institute, N. Y., 1884. Gold Medal, Awarded Crystal Palace Electrical Exhibition, London, 1882. Highest Award for Motive Power British Section International Exhibition of Electricity, Paris, 1881.

Reliable.

No Boiler.

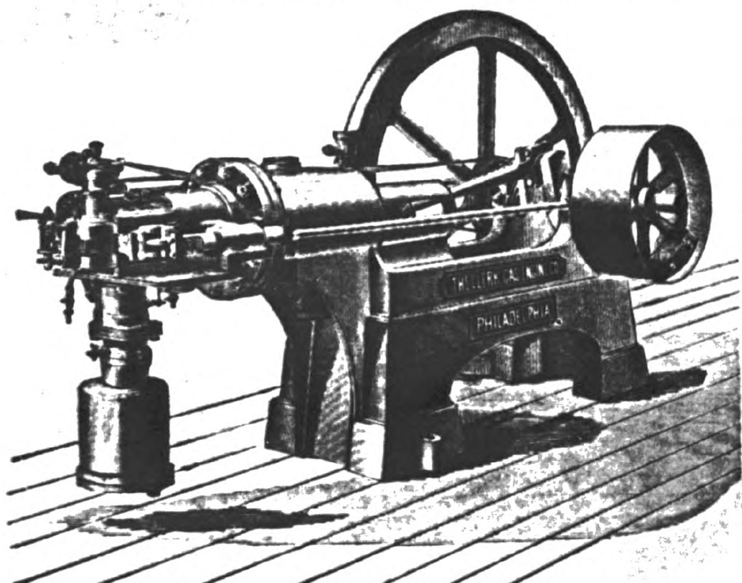
Steady.

No Coal.

Simple.

No Ashes.

Compact.



Economical.

No Engineer.

No Explosion

No Gearing Wheels.

No Danger.

No Parts requiring frequent renewal.

REQUIRING ONLY A MATCH TO START IT--GIVING ITS FULL POWER IMMEDIATELY.

We would inform the public that during the last few months we have improved THE CLERK GAS ENGINE to such an extent that we can now offer an engine vastly superior to our former pattern. These improvements have enabled us to sell our engine at a GREATLY REDUCED FIGURE, partly on account of the decreased weight (our engine weighing about half that of others giving the same Brake H. P). The consumption of gas has been decreased to a considerable extent, and the Brake H. P. has been increased some 25 to 30 per cent. All parts of the old design that were considered defective have been remodeled and new designs added. We now have an engine second to none as regards power, consumption, and ease of working. With our new engine all trouble in starting has been removed, the noise reduced to a minimum, and the regularity of motion is now all that can be desired. We guarantee all we claim for it, and the material and workmanship being of the best, enables us to guarantee the engine for twelve months.

SOLE MAKERS,

THE CLERK GAS ENGINE CO.,

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Fig. 8.9
Clerk Gas Engine Co. Philadelphia. American builders of the Clerk engine from 1882. From a reading, it would appear that difficulties had been encountered earlier.

ted that Sterne was willing to negotiate terms, but would do so only with Otto himself. After much correspondence between Otto, Crossleys and Sterne, plus a visit to England by Otto's engineer, Herman Schumm, an agreement was finally reached in October 1885. Sterne was to withdraw from defending the action and submit to an injunction, each part paying their own costs. A licence was granted to enable Sterne to use the first claim of Otto's patent (which related to the method of admission) at a Royalty of 10% for engines made according to the Dugald Clerk patent, but Sterne could only build and sell engines in the United Kingdom and America. In making these engines, Sterne was not to come any closer to the Otto patent than he had done so already and, as a concession, Otto agreed not to take proceedings against the American firm in Philadelphia - The Clerk Gas Engine Co., - who had been building Clerk engines since 1882.

Something like three hundred Clerk engines had been built in Great Britain up to 1884[13], and although terms had been agreed with Crossleys, Sterne of Glasgow ceased building Clerk engines and Tangyes of Birmingham began making it during 1886-87[14]. The number built by Tangyes, however, is unknown.

It would require several pages to relate the total contribution made by Dugald Clerk to internal combustion engine technology. From 1882 when he delivered his first paper[9] on the theory of the gas engine*, his work, dealing with such topics as the specific heat of gases at high temperature,

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* This paper was awarded the Watt Medal and the Telford premium. (<u>The Engineer</u> Vol. 154 (1932) p.516)

heat flow to cylinder walls, dissociation and explosions, proved of immense value. He became a Fellow of the Royal Society in 1908, was President of the Junior Institution of Engineers in 1905, and President of the Engineering Section of the British Association in 1908. In 1920 he became President of the Institution of Gas Engineers and delivered an address on 'The Future of the Gas Industry'. Four years before his death, he was still actively involved in developments with internal combustion engines when he delivered, in 1928, to the Institution of Civil Engineers, a paper which dealt with Standard of Thermal Efficiency for Internal Combustion Motors.

Dugald Clerk was created a Knight of the Order of the British Empire in 1917, whilst serving as Director of Engineering Research to the Admiralty, an appointment he held from 1916 to 1918. During the war years, 1914-18, he served also on numerous panels and committees, such as the Panel of the Board of Inventions and Research and Advisory Committee for Aeronautics. In 1932, the year of his death, he was elected President of the Institution of Civil Engineers, but his failing health prevented him from taking office.

8.4 Two-stroke Cycle Engines and the German contribution

Although development work in Germany on engines using a different working cycle from the Otto began only a year or two after that in Britain, it appears not to have been pursued there with the same vigour. One reason for this may well have been an unwillingness to risk infringement of the German

Otto patent which laid more emphasis on the actual cycle that was used and less on the arrangement of gases within the cylinder. By this means, virtually any engine that was made, whatever its mode of working, would be considered by Otto to be a transgression of his ideas. Added to this was Otto's generally unforgiving nature which displayed itself whenever he felt his work was likely to be de-valued; he was not as tolerant as his English friends were in such matters and pursued his opponents relentlessly. Despite this, however, the names of three Germans emerge as pioneers in the two-stroke field, whose work subsequently led to large scale acceptance both in Germany and in Britain.

8.4.1 Wilhelm Wittig and Wilhelm Hees

After working together at the Maschinenbauenstalt, Humboldt AG, in Cologne, Wittig and Hees moved to Hanover, c.1878 where they were employed by the Hannover'sche Maschinebau AG[15]. In 1879 while still working for this company, they designed and patented a two-cycle engine[16]. The working cycle was similar to that used by Clerk in that two cylinders, one for pumping and one working a motor cylinder, were used but the cylinders were placed vertically with the crankshaft at the top[17]. No other novel features are shown; a valve used in the transfer port was spring-operated to prevent back-fire, and a slide valve controlled gas and air admission and the flame ignition.

Sometime during 1881 production of the Wittig and Hees engine ceased, the Hanover firm having received the inevitable warning letter from Deutz. Prior to this they had achieved some notable success with the engine by making it operate on liquid fuel, afterwards installing it in a tramcar[18]. This is believed to be the first application in Germany of an internal combustion engine to power a railed vehicle. Wittig and Hees did not succumb to threats from Deutz too easily. Initial warning letters were ignored and they even went so far as to display one of their engines at an Exhibition in Cologne - almost on the doorstep of the Gasmotoren Fabrik. This was too much for the Deutz firm and they managed to have the engine impounded by a Court order. After lengthy legal arguments lasting until 1882, the Hannover firm agreed to pay a ten per cent Royalty on all two-stroke engines that they built. As events transpired, all the legal wrangling proved to be wasted efforts. Orders for the locomotive engine exceeded one hundred by 1881 and Hannover'sche concentrated their efforts in this direction[19], their interest in gas engines having waned.

The Gasmotoren Fabrik had cause to regret the tangle with Wittig and Hees. Shortly after they began proceedings against the Hanover firm, the engineer supervising the work on the engine, Georg Liechfield, left and went to Gebrüder Körting, who were then building steam engines. He apparently persuaded Körting to build gas engines (with a similar engine to the Wittig and Hees) and named it the Körting-Liechfield. It was made in this form until about 1884 when, suddenly, it appeared as a four-stroke[20]. The reaction of Deutz was swift and there began a patent battle which, ultimately, caused Otto's patent to be invalidated in Germany. Körtings went on to become one of the most successful engine builders in Germany, employing many licensees throughout the world[21]. Körting engines of several hundred horse-power each were in common use by 1904[22].

8.4.2 Karl Benz

The use of a separate pump and cylinder stroke on two-stroke cycle engines, to either compress the charge into a receiver or transfer it to the working cylinder was an unwelcome complication. Apart from the mechanical arrangements involved to work the pump, the nett power available at the flywheel was reduced because of the friction and pumping losses that were incurred. The Benz two-stroke cycle engine succeeded in eliminating this extra pump and became one of the most successful of German engines to work on this principle.

Benz was a product of the same engineering school as Eugen Langen and Franz Reuleaux - the Karlsruhe Polytechnikum - which he entered in 1860 and left in 1864[23]. After working in various branches of engineering, he set up in business with a machinist, August Rutter in 1871. The partnership, however, was a brief one; after some disagreement, Benz bought out Rutter's share of the business and continued on his own until 1877, when he began to experiment with engines trying to produce an impulse every revolution. On New Year's Eve, 1879 the first engine made by Benz breathed into life. Benz described the occasion[24]:

> 'After supper my wife said 'let's go over to the shop and try our luck once more' ...... I turned the crank. The engine started to go ... we both listened to it run for a full hour, fascinated, never tiring of the single tone of its song ....'

A German patent for this engine was never taken out and it was not until 1884, when an English patent, 9949, was issued. Prior to this, Benz was pre-occupied in trying to obtain financial aid and so form a company and with improvements to his engine to make it a saleable commodity. Eventually he succeeded in both. On 1 October 1883 with the help of a businessman, Max Rose, and an engineer, Friederich Wilhelm Esslinger, the firm of 'Benz and Co., Rheinische Gasmotoren - Fabrik' in Mannheim was founded[25].

The engine built by Benz[26] was obviously based on the working principle suggested by Clerk; its chief novelty was the introduction of a charge of compressed air to assist the piston to drive out the products of combustion (the contrast here to the Otto theory of stratification is striking). The supply of compressed air was obtained by the crank side of the piston filling a receiver placed beneath the engine. A small gas pump supplied gas separately from the air, both gas and air being admitted by a slide valve. The ignition system used by Benz was electric which consisted of a Ruhmkorff coil, a make and break circuit and a sparking plug with platinum points. Benz was particularly successful in applying his own electrical ignition system to his engine[27].

One of the earliest examples of an engine built by Benz, c.1884, is exhibited in the Werkmuseum of Klöckner-Humboldt-Deutz. Later engines have an improved governor. The firm Benz and Co., built these engines until 1886, at which time the Otto patent ceased to be valid in Germany and most engine makers concentrated on the four-stroke. Benz was one of the few engine builders from whom Deutz never claimed infringement. The most probable reason was the use by Benz of the 'loop scavenge' method involving compressed air, which would have made a stratification claim extremely difficult to prove. It was the use of this scavenge method which also contributed greatly to the outstanding economy of the Benze two-cycle engine. (Dugald Clerk, it may be remembered, was a strong advocate of the efficient cleansing of burnt products from the cylinder). Performance figures obtained from a test in 1886 show a consumption of 25 cubic feet of gas per brake horse-power per hour, compared with a Clerk engine of 37.7 cubic feet.

8.5 Multi-stroke cycle engines of a more radical kind

Faced with problems of a difficult nature, there is seemingly no limit to man's ingenuity when making attempts to solve them; the number and diversity of solutions offered, being in direct proportion to the degree of complexity involved. In the early part of the 1880's an Englishman, James Atkinson (1846-1914) recognised the problems that had become apparent arising from insufficient expansion of the burning gases. He set about designing and building an engine which not only produced more frequent firing strokes than the Otto four-stroke engine, but gave a variable length of piston travel at the Inventions Exhibition, London in 1885 and is reported to have been designed, the patterns made and brought to working form in the space of one month[28]*.

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*This is highly questionable. The Atkinson engine was an extremely complex piece of machinery

That Atkinson was a gifted inventor and engineer there is little doubt. His later contributions to engine technology, whilst later employed by Crossley Bros., are sufficient testimony of his abilities. Born near Bolton, Lancashire, Atkinson's father was the proprietor of Hope Foundry, which at that time was amongst the earliest makers of locomotives in Lancashire[29]. Following an apprenticeship with Palmer Bros. of Jarrow-on-Tyne, he worked at the London and North Western Railway Works at Crewe as a draughtsman for three years, but returned to Tyne to work for the firm of Pattison and Atkinson, his brother. In 1877 James Atkinson started business on his own as a consulting engineer, having spent eight years previously with the National Boiler Insurance Co. of Manchester. It was in his consulting capacity that he became interested in gas engines, when in 1879 he patented a device for incandescent ignition using a heated tube[30]. This was followed in 1881 and 1882 by patents for engines working on the Robson cycle[31].

8.5.1 The Atkinson 'Differential' engine

This engine, Figure 8.10, had two pistons placed horizontally, but only one (on the right) served as a power supply to the crankshaft. That on the left served as a pump to draw in the charge and assist in expelling the burnt gases. The 'differential' or variable stroke was obtained by using the complex linkage system shown in Figure 8.11 and the working of the engine will now be explained by referring to this figure.

Diagrams (a) show the commencement of the cycle with both pis-

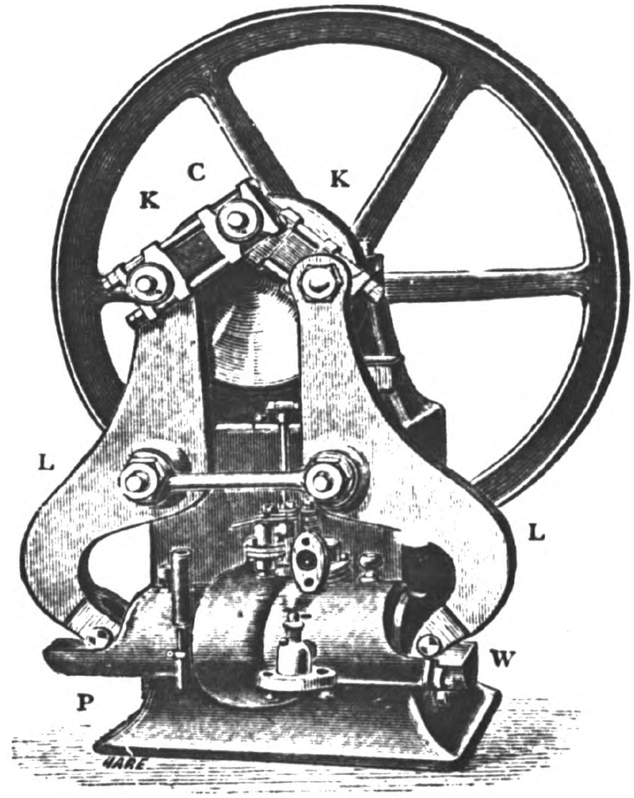


Fig. 8.10
James Atkinson's 'Differential Gas Engine' shown at the Inventors' Exhibition in 1885.

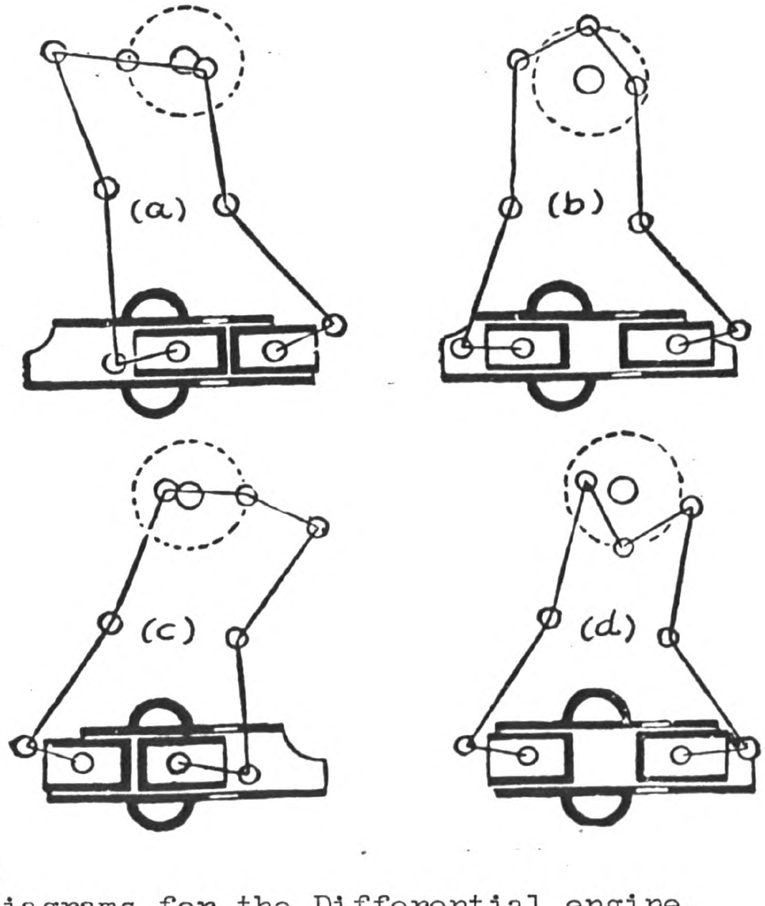


Fig. 8.11
Linkage diagrams for the Differential engine.
(see text for explanations)

tons close together at the extreme right and just about to separate with the left piston moving away. A charge of gas and air is then admitted between the pistons, via a lift valve. The completion of the inlet stroke is shown at (b) and completion of the compression stroke is shown at (c). At a pre-determined moment the left hand pump piston uncovers the ignition tube port and remains in that position until the power piston is propelled along the cylinder, on its expansion stroke - a distance almost twice that covered during the induction stroke. The position of the power piston at the completion of expansion is shown in diagram (d); the left hand piston now moves up towards it, pushing out the exhaust gases. A prospectus of 1885 for the differential engine shows that it was offered in sizes of 1, 2, 4, 6 and 8 horse-power nominal[32]. The following is an extraction:

hp (nominal)	1	4	8
Cost £	90	100	210
Speed (rev/min)	180	160	150
Space required (ft)	2½ x 3	3½ x 5	4½ x 6½
Weight (lb)	1200	2500	4200

The engine was manufactured by the British Gas Engine Co., London formed in 1883 by Atkinson who was the managing director[33], and trials on a two nominal horse-power differential lasting one hour gave a brake horse-power of 2.6 at 148 rev/min; and gas consumption of 25.8 cubic feet per brake horse-power per hour[34]. Other trials with the same engine produced 2.85 brake horse-power and a gas consumption of 23.4 cubic feet. This is probably the most economical two horse-power engine made at that time and, indeed, for a number of years to come. Ignition tube life was reckoned to be 180

Fig. 8.12
James Atkinson (1846-1914)

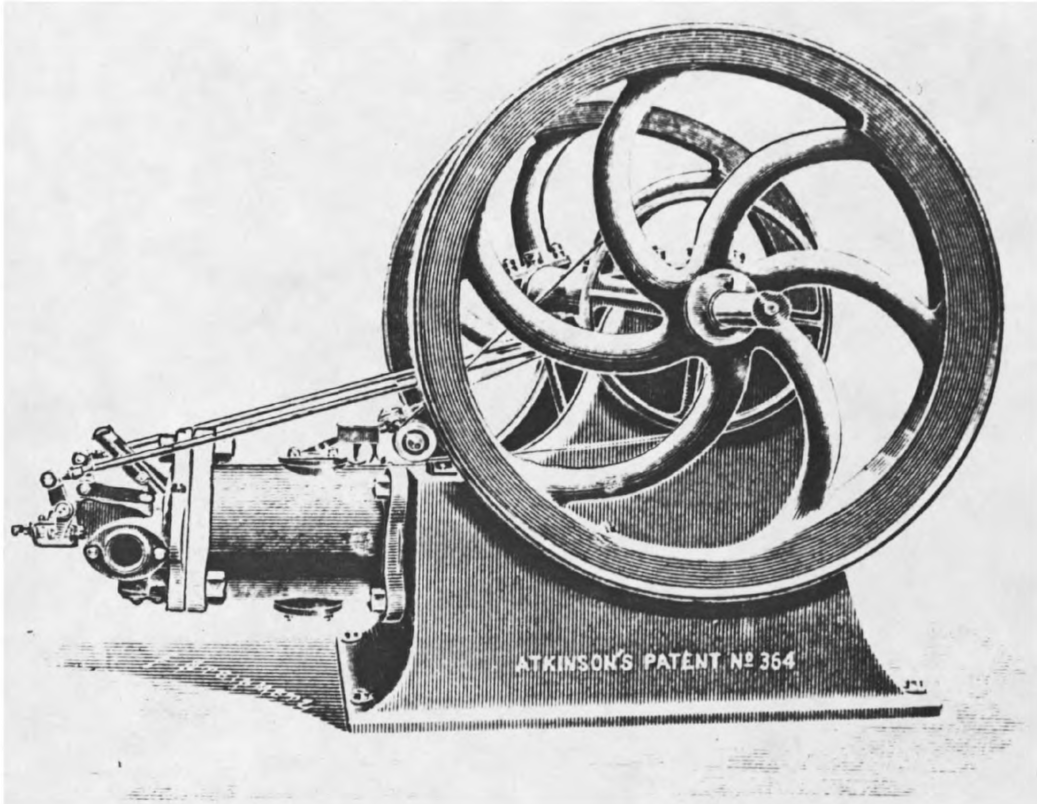
A pioneer of gas engines and the first man to successfully use an incandescent form of ignition in a compression engine. c. 1879.

hours. Although the differential used no cams, eccentrics or slides, it possessed a complicated link mechanism which required large bearing surfaces, even then the rate of wear was high. Its extraordinary economy of fuel, however, together with the ability to carry out an expansion stroke of double the length of the inlet stroke were attractive features of this engine and Atkinson set about simplifying the mechanical arrangement which gave rise to practical difficulties.

8.5.2 The Atkinson 'Cycle' engine

The 'cycle' engine was the next engine by Atkinson which retained the principal advantage of a variable stroke, but used only one piston instead of two. The first patent for the cycle engine is dated 12 March 1886, No. 3522 and Figure 8.13 shows the general arrangement with Figure 8.14 the four principal positions of the linkage. As in the differential engine, only one revolution of the crankshaft was required to complete the working cycle.

Diagram 1 shows the position of the pistons and link at the beginning of the cycle. All the products from the previous cycle have been expelled and a new charge is about to be drawn in. Crank C rotates in the direction shown and the piston moves to the position shown at 2. Due to the geometric arrangement of the crank and lever system, the piston at 2 is then at its limiting position. Further rotation of the crank C produces the compression stroke, see at 3. After ignition (by incandescent tube) the expansion stroke takes



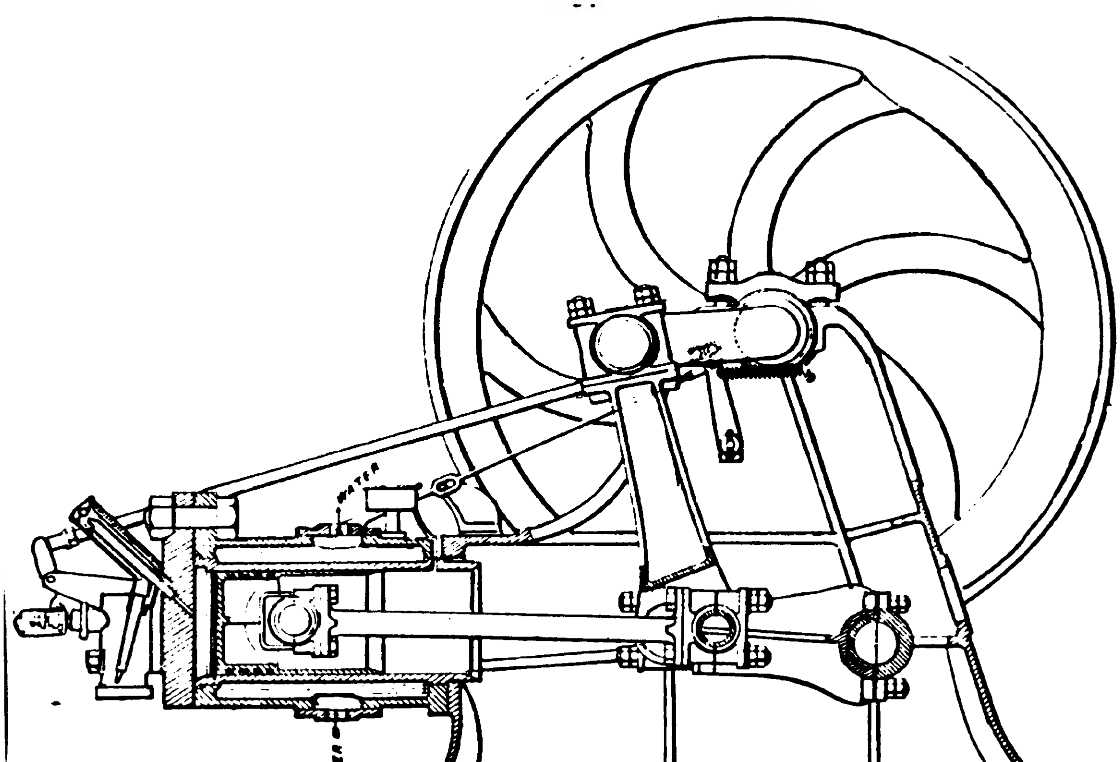
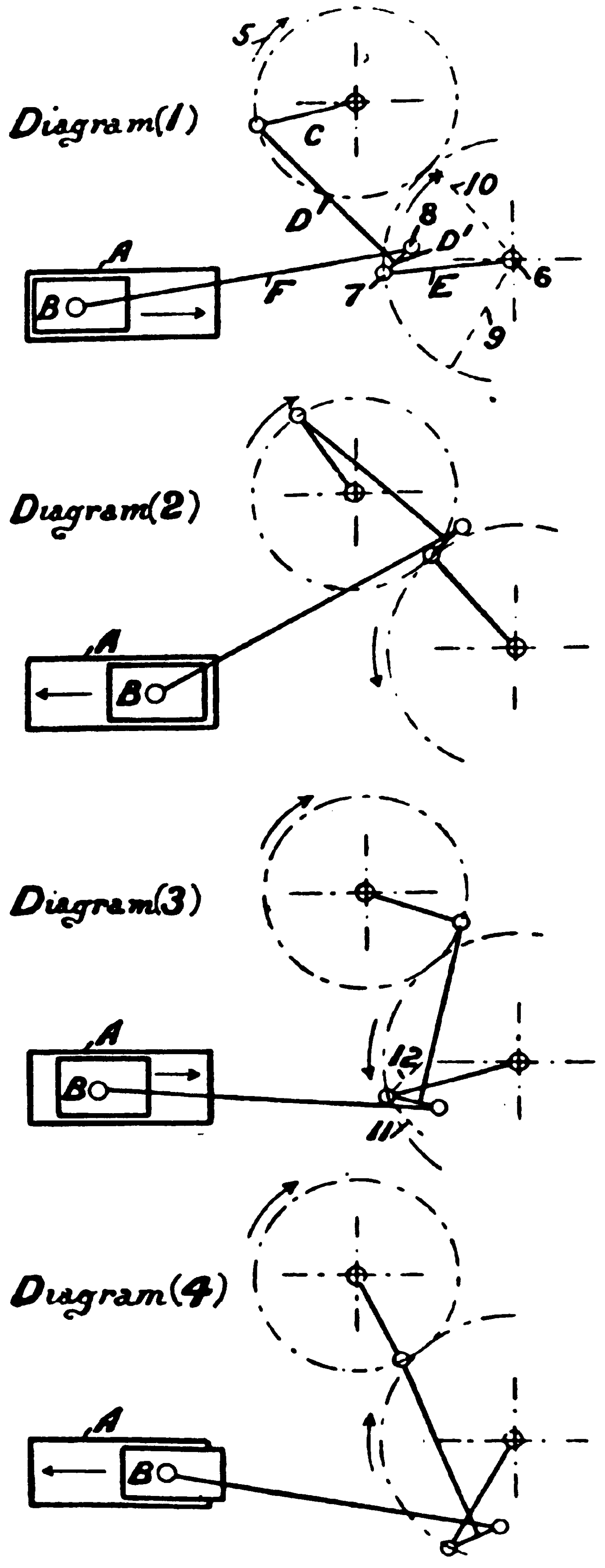
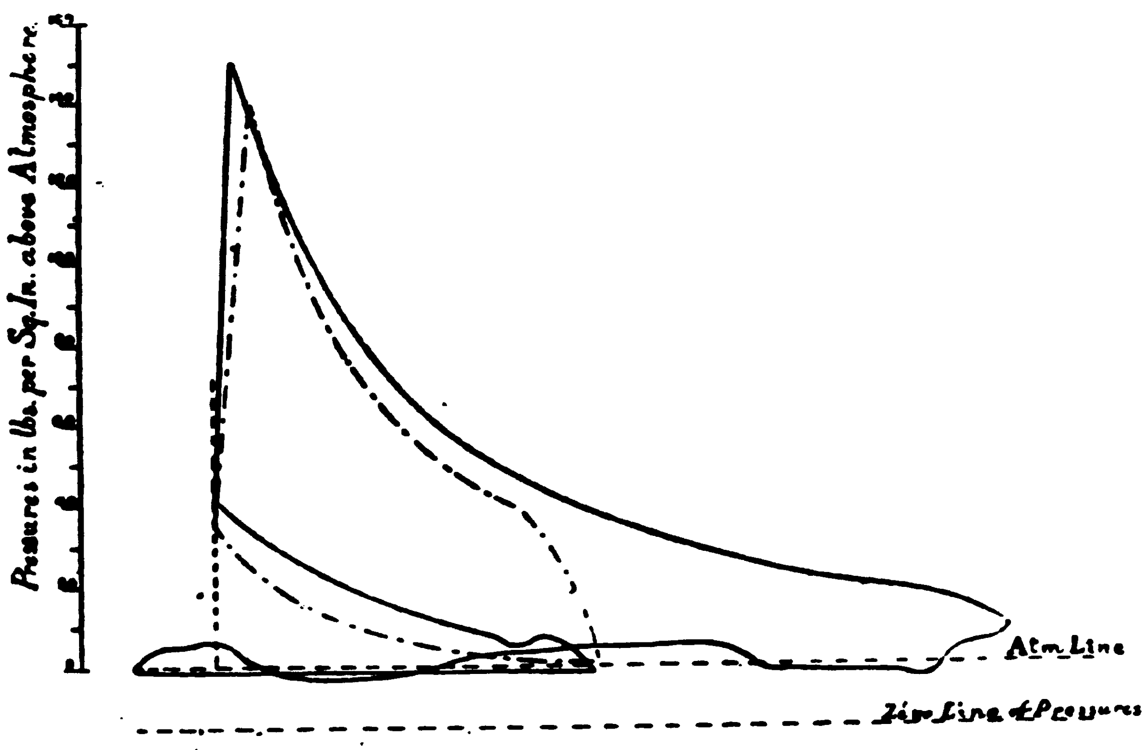


Fig. 8.13
The Atkinson 'Cycle' engine as used in the Society of Arts Trials of 1888.



8.14
Linkage diagrams of the 'Cycle' engine
(see text for explanation)



8.15
Indicator diagram of the Atkinson Cycle engine
(Society of Arts Trials 1888)
The dotted line is a diagram of a normal Otto
cycle diagram

place, moving the piston to the position shown at 4. The distance moved in inches by the piston during the various strokes for a six horse-power nominal engine was as follows[35]:

1 to 20 induction stroke	6.33
2 to 3 compression stroke	5.03
3 to 4 expansion stroke	11.13
4 to 1 exhaust stroke	12.43

It was this design of Atkinson engine incorporating the ingenious and extremely clever system of levers that was submitted for the Society of Arts Trials in 1888 (see Chapter Seven) and which was awarded the Society's Gold Medal. More than one thousand of them were made and sold by the British Gas Engine Co. between 1887 and 1893[36]. But despite its unrivalled economy of gas consumption, it never really became popular. Difficulties were experienced with the linkage which had five working pins, compared with two on the Otto engine. A further point with the cycle engine is that the piston in travelling twice the distance during expansion in only a quarter of a revolution of the crank, would possess an extremely high velocity. High piston speeds rightly were thought desirable, but the linkage mechanism of this engine was of a kind which could not be easily balanced and, accordingly, a balance mass is incorporated in the flywheel.

In producing an engine with variable stroke, Atkinson achieved what no other inventor has done since and he substantiated the theories that were held at that time regarding the advantage that could be obtained by (a) increased expansion and (b) a total scavenging of exhaust gases.

8.5.3 Atkinson's Utilité engine

In the last year of its existence (1892), the British Gas Engine Co. built an impulse every revolution engine according to the latest idea of James Atkinson. In many ways its working cycle was similar to the Clerk and Robson engine. One side of the piston acted as a pump to push air only into a receiver at a low pressure and from there would enter the opposite end of the cylinder through ports uncovered by the piston. This air was used mainly to clear out the burnt gases from the previous cycle. After doing so, some air would remain in the cylinder and as the piston returned to outer dead centre would first cover up the exhaust port and then begine to compress the residual air in the cylinder. At the same time, a separate gas and air pump would discharge a mixture, which was too rich in gas into the working cylinder. The correct explosive mixture was obtained by the latter mixing with the air already present in the cylinder*.

The utilité engine, like its two predecessors, incorporated an innovation which permitted maximum expansion. To achieve this, Atkinson placed a timed exhaust valve in the exhaust port, which would open only when the piston had greatly overrun the port. Expansion would thus continue until the piston had reached the extreme end of its stroke. In returning to compress the air previously admitted, the piston would assist the air to expel the burnt gases through the exhaust port, before covering it.

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* By admitting a rich mixture in this way the possibility of a 'back-fire' into the induction system was avoided

The introduction of the utilité engine came at a time when most manufacturers of gas engines, with what Dugald Clerk called 'wonderful unanimity' ceased to make two-stroke cycle or any form of cycle other than the Otto. This had been possible since the Otto patent expired in 1890. Atkinson must have realised the significance of the situation and after winding-up the business and affairs of the British Gas Engine Co., went to work for Crossley Bros. in July 1893 as chief engineer[37] at a salary of £600 per year. At Crossleys, Atkinson continued to display his inventive genious and almost immediately his name appears in the patent lists linked with that of Crossleys[38]. He was instrumental in producing the scavenge system using tuned exhausts.

The inventiveness and ingenuity of Atkinson earned him the respect of many leading authorities of his day, Dugald Clerk among them. As well as the Gold Medal awarded by the Society of the Arts, his cycle engine, after tests by the Scientific Committee of the Franklin Institute, Philadelphia was awarded the John Scott Legacy Medal, the first time it was awarded to anyone but an American[39]. In 1912, James Atkinson retired from Crossley Bros. He died in Surrey two years later.

8.6 Six and three-stroke cycle engines

The situation with regard to which type of engine cycle to use was a varied one indeed during the 1880's. The Otto four-stroke cycle, of course, was a dominant one, but its use was exclusive to Otto and his licensees. It was partly for this reason, therefore, and partly from the desire to improve upon it that many British makers of gas engines resorted to numerous designs based on the Robson and Clerk cycles. The more notable of these, such as the Campbell, the Midland, the Trent and the Stockport etc., which operated in a one impulse per revolution cycle, are described in Chapter Seven, section 7.6. It is interesting, now that a more comprehensive picture of working cycles has been obtained, to take a second look at these engines and to establish the various modes of thinking that were prevalent at that time with regard to the application of the cycles just mentioned.

Some manufacturers saw the need to use a separate pump which was used first to force in a gas and air mixture, followed by air only (this simple expedient has greater significance than appears at first sight and is discussed later). Others used the working piston to perform the combined operation of pumping and power. Receivers would sometimes be used through which the air or gas/air would pass before entering the working end of the cylinder and in other designs, the receiver would be replaced by simple ports or passages. These ideas, however, interesting as they are, were just variations on a theme. The intriguing aspect now is the reference made earlier to the desire by some manufacturers to admit first a charge of air only. Some ideas for doing this are now discussed.

8.6.1 The Beck engine

From the early 1880's onwards, engineers appear to have been quite divided on the issue of whether or not to admit air only first and, according to their particular belief - whether to retain exhaust gases as Otto did or clear them completely as Clerk advocated - would design engines which employed either of these extremes. The retention of exhaust gases, being an essential component of the Otto patent, meant risking an infringement. The 'unbelievers', however, those who did not subscribe to Otto's theory, sought to disprove it by making their own version of an engine - as close to the Otto as they dare - but in which some additional movements of the piston were used. The 'Beck' engine was the first example of this new cycle which required six strokes of the piston in order to produce one firing stroke.

The additional two strokes took place between the exhaust and inlet stroke, the sequence being as follows:

Stroke No.	No. of crank revolutions	Nature of work done
1 Admission of charge 2 Compression	one	negative
3 Expansion 4 Exhaust	two	positive negative
5 Admission of air 6 Discharge of air	three	negative

Trials of a later version of the Beck engine* of four nominal horse-power were made by Professor A.B.W. Kennedy, FRS,

* The first Beck patent, which was provisional only, was English No. 5531/1881

in London during 1888[40], which showed that the maximum speed was 212 rev/min and maximum power 6.3 brake horse-power with an average gas consumption of 26.79 cubic feet per brake horse-power per hour. It was designed by Arthur Rollason and built in Newcastle[41].

8.6.2 The Linford engine

Probably the first six-stroke cycle engine was that by Charles Linford of Leicester who featured in the patent litigation trial against Otto in 1881 (see Chapter Six). Linford had been making engines since 1876[42] until Crossleys began proceedings against him during 1880. A vertical cylinder, (Figure 8.16) contained two inwardly opposed pistons, each connected to a crankshaft by rocking levers. A third piston, positioned horizontally, acted as the charging and scavenge piston, being connected directly to the vertical working cylinder. The linkage system and general arrangement appears to be most cumbersome and one has difficulty in appreciating how it could work satisfactorily. A few appear to have been made and sold but Crossleys, having acquired one for tests in preparation for the impending patent trial, report its working as quite inferior to the Otto[43]. Anything less like the Otto engine and the Otto cycle of operation would be difficult to imagine, but Crossleys, having lost the first round in the High Court hearing, succeeded on appeal. Linford was put out of business and left for America shortly afterwards.

FIG. 5.

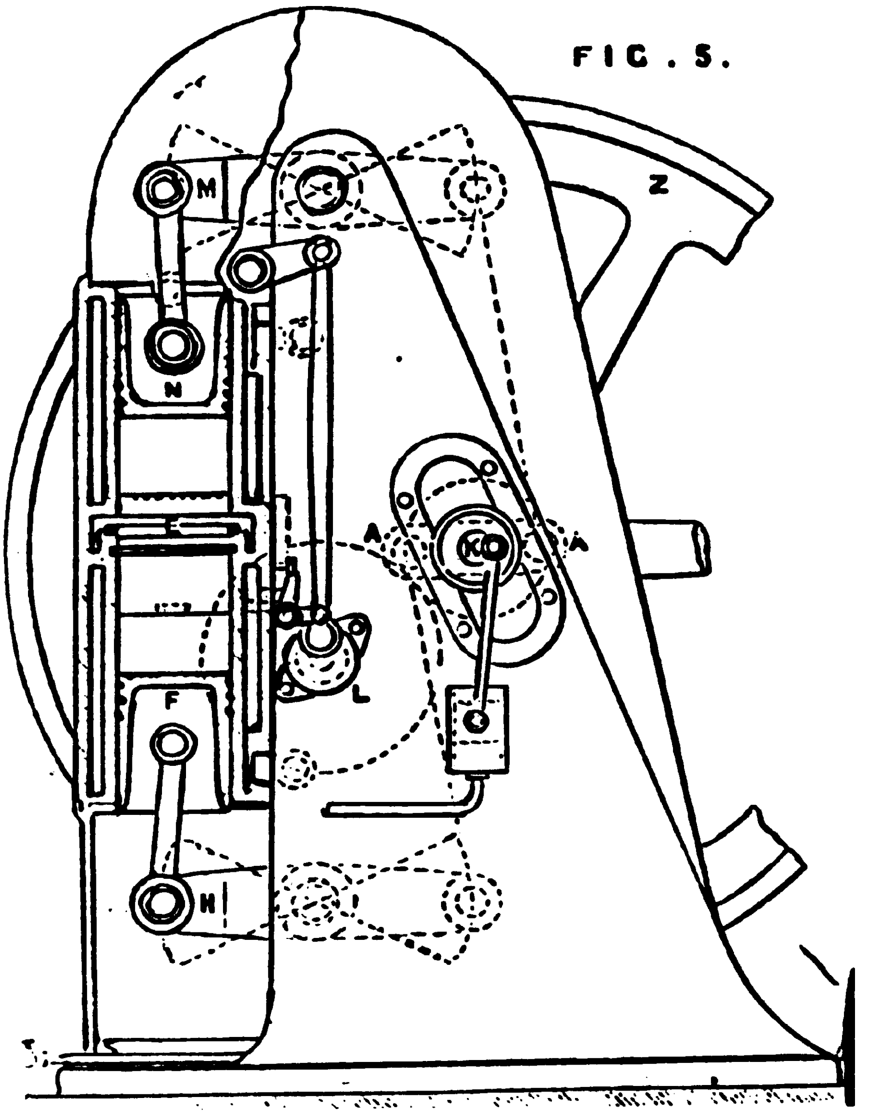

Fig. 8.16
The Linford 'six-cycle' engine which featured in the Otto-Linford patent trial during 1881
(See Chapter six, section 6.2)

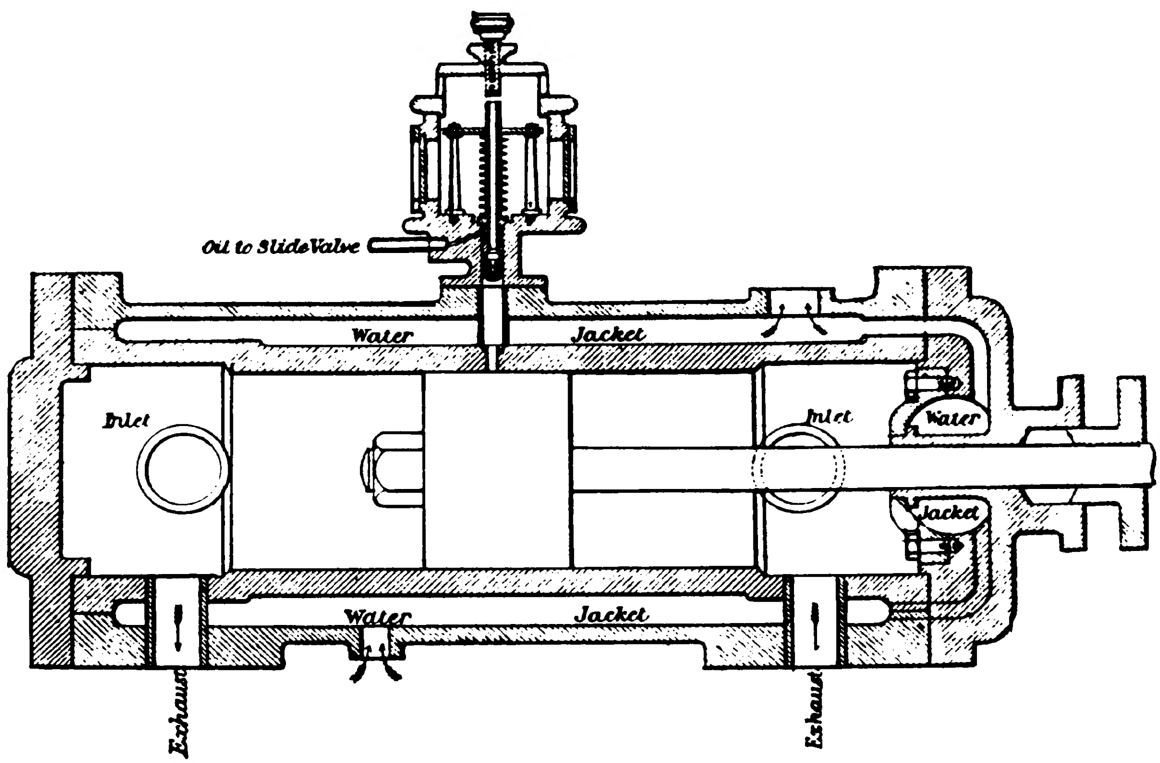

Fig 8.17 Cylinder of the Griffin engine as used in the Society of Arts Trials of 1888.

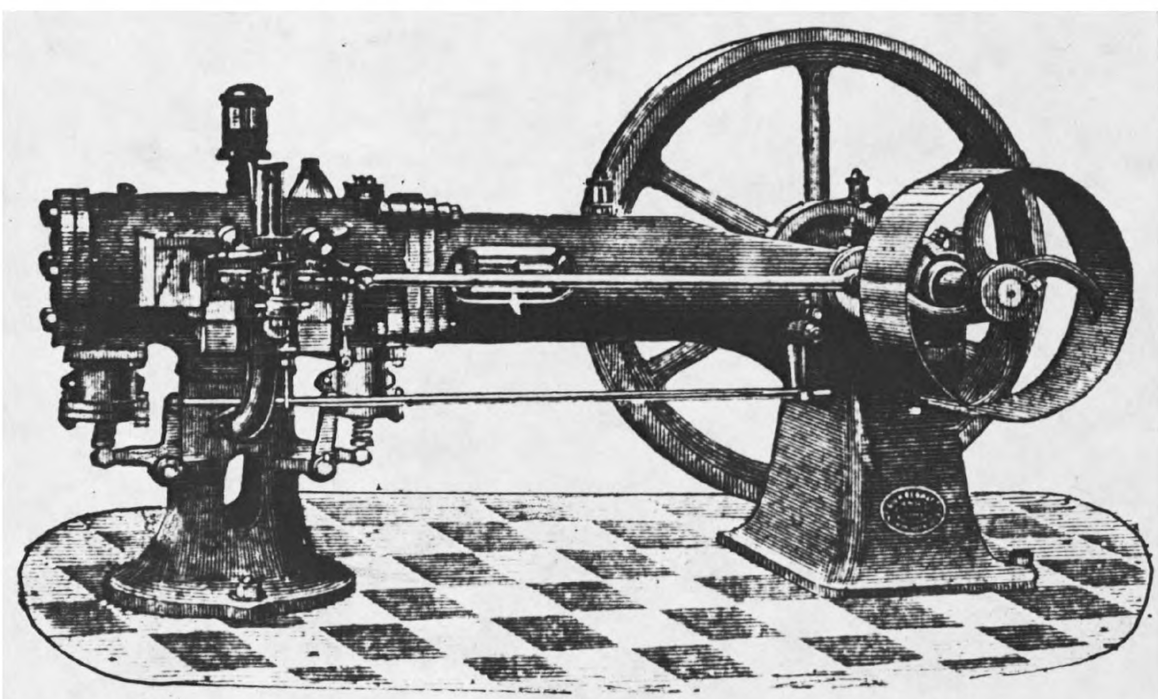

Fig 8.18 General view of the Griffin engine. It was double acting and gave two firing strokes for every six revolutions of the crankshaft. The cylinder was sealed at both ends.

8.6.3 The Griffin three-stroke cycle engine

An engine which was comparatively more successful during the early part of the 1880's was that of Samuel Griffin made by Dick, Kerr and Co. of Kilmarnock[44]. A diagram of this engine is shown in Figure 8.18. In effect, this particular engine was a double-acting engine. The cylinder was closed at both ends and combustion took place alternately at each end once every three revolutions of the crankshaft, thus giving one firing stroke to every one and a half turns of the crank. Figure 8.17 shows the arrangement of cylinder with the cooling arrangements for the gland packing and cooling of the piston rod.

It was this engine that was submitted by Griffin for the Society of Arts Trials in 1888 and it is interesting to note that the pressure on the piston rod side was fourteen pounds per square inch less than that on the opposite side - (this was attributed to the cooling effect of the piston rod). Tests, again by Kennedy carried out at Kilmarnock[45] show a gas consumption of 23.6 cubic feet per brake horse-power per hour, yet tests using London gas show 28.56 cubic feet*. When in use, the Griffin 'three cycle' was noted for its steady speed with extremely slight fluctuations under widely varying loads. This made it an excellent engine for driving dynamos 'without any appreciable blinking or unsteadiness in the light from the glow lamp'[46].

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* This London figure includes the gas used for ignition, whereas the former figure may not

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2895/1896

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40. Donkin <u>op cit (26)</u> p.56

41. English Patent 7427/1886

42. The First English Patent of Linford is 2824/1876. Up to the patent trial four more were registed, including 330/1880 for the six-cycle engine. An American patent 232987/1880 was also entered

43. F.W. Crossley '<u>Letters to Abel and Imray</u>' 9 February 1881

44. W. Robinson op cit (28) p.193

45. Ibid p.197

46. Ibid p.197

CHAPTER NINE

THE APPLICATION OF GAS ENGINES TO INDUSTRY

9.1 Benefits to Society

The contribution to the industrial and economic life of the nations which employed gas engines is one that appears to have been totally neglected by historians of technology; a mention of the Lenoir engine of 1860, followed by a passing comment of Otto's four-stroke engine of 1876, appears to be the sole consideration which has been given to the topic. It seems generally to be assumed also that, as regards the types of prime mover used, there was an immediate transition from the steam engine to the electric motor. In reality, the gas engine has been found to have had extensive use between these two other forms of prime mover, proving itself extremely useful and widely adaptable to the needs of industry*. Its range of application in the various trades, as shown by the list in Figure 1.1, is striking, but a full appreciation of the effectiveness of the gas engine in supplying industry with power can only be obtained from a study of the Technical Appendix, in which testimonials by users and lists of applications are given.

By the middle of the 1880's, nearly 27,000 Otto gas engines had been sold throughout the World and, at that time, these engines were presenting a serious threat to the continued use of the steam engine. Many established users of steam were replacing such engines with those which used gas;

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* To the author's knowledge, no definitive work has been published revealing the extent to which the gas engine served industry in the role of an important prime mover.

The "OTTO" Gas Engine.

CONSUMPTION OF GAS AND OIL; and ECONOMY COMPARED WITH STEAM ENGINES.

THE tested Consumption of Manchester Gas by these Engines when new, may be averaged at from 20·5 to 22 cubic feet per indicated horse power per hour for the larger, to 25 feet for the smaller sizes. This assumes the engine to be working nearly up to its maximum power. *But the consumption of Gas in practice must not be found by multiplying the maximum power by 22 feet per hour, as it will be generally greatly less than this, being regulated by a patented governor, and depending on the amount of work done by the Engine.* It is, therefore, best shown by a reference to our many Testimonials, in many of which the users speak of their experience of the economy effected. At intermittent hoisting work the average consumption of gas has been as low as 10d. per day, taken over three months, for a 3½-HP. Engine, with Gas at 3s. per 1,000 feet, and the Engine running all day. Our 16-HP. Engines will not compete with high-class steam engines in cost of fuel where the work is steady and remains at nearly full load all day, unless gas can be had at a very low price, or Dowson's Economic Gas be used. Large Gas Engines can be most advantageously adopted for intermittent work, such as Sawing, Hoisting, &c. With the Dowson Economic Gas these Engines can be worked at a consumption of about 1·3 lb. of Anthracite Coal per HP. per hour. Without, however, in all cases being more economical than steam engines in fuel, these large engines have advantages of their own, such as readiness of starting, the saving of attendance and of space, risk, smoke, &c., which have secured their adoption in many cases. It is not generally known that the consumption of coal by ordinary high-pressure steam engines reaches the large figure per indicated HP. which has recently been found to be the case. In his inaugural address before the Institution of Civil Engineers, on January 13th, 1885, Sir Frederick Bramwell, F.R.S., gave particulars of what had been found to be the actual consumption of a number of Steam Engines in Birmingham a short time before. He said as follows :—

"You would be astonished to hear, however, that in an investigation instituted last year by the Corporation of Birmingham when considering whether they should approve of a proposal to lay down power-distributing mains throughout their streets, it was found on indicating some six non-condensing steam engines taken indiscriminately from among users of power, and ranging from 5 nominal HP. up to 30 nominal HP., that the consumption in one instance was as high as 27·5 lb. per HP. indicated per hour, while it never fell below 9·6 lb., and the average of the whole was as much as 18·1 lb."

From this it is clear that Gas Engines are, even in fuel, less costly than small steam engines of usual type, with gas at 2/6 per 1,000, and coal at 7/6 per ton, to say nothing of their advantages in readiness of starting, decreased risk, decreased attendance and space occupied, together with absence of smoke, heat, and dirt. We believe the smaller sizes are always much more economical than steam engines, and have many other advantages besides.

OIL.—We guarantee these Engines to use as little oil as any similar machine. Interested persons have attempted to injure us by statements to the contrary.

TESTIMONIALS AND LISTS OF USERS.

OUR Testimonials and Lists of Users having very largely increased, we have lately, for greater convenience, divided them into separate Sections, any of which can be obtained on application. These will be found exceedingly useful to intending purchasers, giving, as they do, valuable information as to the various machines being driven, work done, gas consumed, &c.

CROSSLEY'S PATENT SELF-STARTING APPARATUS.

PRICES (WHEN *SUPPLIED WITH NEW* ENGINES).

6, 7, 8, 9-HP., & TWIN 4-HP., £20. | 12-HP. & TWIN 6-HP., £25. | 14 & 16-HP., £30.

New Exhaust Valve Extra when applied to Old Engines.

Lithographed Foundation Plans, *giving Sizes of Pipes, Meter, Stones, Engine Room, &c., are supplied, together with a Book of Instructions for working. Each Engine is sent off erected almost complete, only the Main Shaft, Fly-wheel and Pulley being taken off.*

GUARANTEE AS TO MAINTENANCE.—*We undertake to repair or replace any parts of these Engines which may be broken or suffer from undue wear within six months after date of delivery, unless such wear or breakage is caused by careless or improper treatment.*

Fig 9.1 (a)
Circular, December 1886, put out by the Crossley Brothers

others, who had not previously had the benefit of a prime mover, found that the gas engine provided power at a cost they could afford. Larger power gas engines became available, which meant that even greater trespass on the domain of the steam engine occurred*. The 1880's and 90's were certainly the hey-day of the gas engine, and in this chapter a few of the various industries which used them and the use to which they were put will be related. The information now presented has been largely collated from an untitled catalogue of users[1], which lists the practical applications of gas engines to 1888. (The relevant sections of this catalogue are reproduced in Volume Two, Appendix Three.) The various engineering journals have also been searched and articles appertaining to the applications that are subsequently described, have been included.

9.1.1 Machine tools in engineering workshops

The range of gas engine power available to prospective buyers towards the close of the 1880's is shown in Figure 9.1 (b) and in Figure 9.2 a bar chart shows how these variously powered engines found their way into the engineering world. The most commonly used engines which accounted for about 22 per cent of the total number is seen to be the 3½ nominal horse-power. This would indicate about seven horse-power and give an effective power, or output of nearly six horse-power. The ability of this engine to drive machinery appears remarkable. A testimonial[2] dated 11th May 1883,

* An influential factor here was the introduction of cheaper gases such as Dowson Gas. This aspect is discussed later in this chapter.

PRICE LIST OF THE "OTTO" GAS ENGINE,

(FOR DELIVERY IN MANCHESTER).

SINGLE CYLINDER HORIZONTAL ENGINES.

Nominal HP.	Approx. Indicated HP.	Price Without Water Vessel.	Price with Water Vessel.	Overall Dimensions (of Engine only.) Length. ft.	Length. in.	Breadth. ft.	Breadth. in.	Approx. Nett Weight of Engine. C.	Q.	Approx. Weight Packed Complete. C.	Q.	Standard size of Pulley. Diam in.	Wide. in.	Size of Fly Wheel. Diam. ft.	Diam. in.	Wide in.
*½	2	£60	£61 10	6	0	3	7	13	0	16	1	10	5	3	6	2¾
1	2¾	90	92 10	7	5	4	1	19	1	23	3	12	6	4	0	4¾
2	4	135	138 0	8	3	4	7½	29	1	34	0	17	6	4	6	3¾
3½	6	170	174 0	8	10	4	6¼	36	0	40	3	20	7	5	0	3½
4	8	180	184 0	8	6	4	3	36	0	40	0	20	7	5	0	4⅝
6	12	210	215 0	10	1¼	6	6½	59	2	65	3	24	10	5	6	5⅝
7	14	220	225 0	9	11	5	0	58	0	64	3	24	10	5	6	5⅝
8	15	250	256 0	10	1½	7	5¼	62	0	68	1	27	12	5	6	6½
9	18	260	266 0	10	0	5	3	65	0	71	0	27	12	5	6	6¼
12	25	300	310 0	10	4	7	4	91	2	98	1	36	12	5	6	6
14	33	330	Special Price to suit position.	10	9	7	0	125	0	133	0	48	14	5	6	6½
16	40	350		11	8	7	9¼	144	0	152	2	54	18	5	10	6

The speed of above sizes is 160 revolutions per minute, except the 1-HP. and ½-H.P., which run at 180 revolutions.
* Special Note.—This Engine should really be called a 1-HP. nominal, as the power was recently doubled.
The 12-HP., 14-HP. and 16-HP. Engines are fitted with two Fly Wheels.

DOUBLE CYLINDER HORIZONTAL ENGINES.

Nominal HP.	Approx. Indicated HP.	Price Without Water Vessels.	Price with Water Vessels.	Overall Dimensions (of Engine only.) Length ft.	Length in.	Breadth ft.	Breadth in.	Approx. Nett Weight of Engine. C.	Q.	Approx. Weight Packed Complete. C.	Q.	Standard size of Pulley. Diam. in.	Wide in.	Size of Fly Wheel Diam. ft.	Diam. in.	Wide in.
4	16	£240	£248	8	6½	6	3	69	2	75	3	24	10	5	2	7¼
6	24	330	340	10	6	6	4¼	103	0	114	0	36	12	5	8	6½

The speed of above sizes is 160 revolutions per minute.

SINGLE CYLINDER VERTICAL ENGINES.

Nominal Power.	Approx. Indicated HP.	Price Without Water Vessel.	Price with Water Vessel.	Overall Dimensions (of Engine only.) Height. ft.	Height. in.	Breadth. ft.	Breadth. in.	Approx. Nett Weight of Engine. C.	Q.	Approx. Weight Packed Complete. C.	Q.	Standard size of Pulley. Diam. in.	Wide. in.	Size of Fly Wheel. Diam. ft.	Diam. in.	Wide in.
5-MAN	1	£45	£46 0	4	8	3-sq.		9	0	12	2	10	5	3	0	3¾
1½-HP.	3	100	103 0	5	10	4	0	17	0	20	0	17	6	4	0	4½
5 „	9	185	190 0	7	3¼	3	10	30	0	34	0	24	10	5	0	4⅝

The speed of the 5-HP. Engine is 160 revolutions per minute; of the 5-MAN and 1½-HP., 180 revolutions.

Standard Driving Pulley, one spare Piston Ring, and one spare Spring, sent with each Engine FREE.
One spare Slide Valve is also sent with all sizes except the 5-Man.

CROSSLEY'S PATENT ELECTRIC LIGHT GOVERNOR
Fitted to Engines when required.

CROSSLEY'S PATENT CAST IRON GAS BAG
Supplied with all Engines.

Special quotations for larger sizes; also for engines combined with PUMPS, REFRIGERATORS, VENTILATING FANS, DYNAMOS, or other Machinery.

Terms on application for Cash, or on the Deferred Payment System.

Fig 9.1 (b)
Engine sizes, types, and prices of Crossley Engines, December 1886

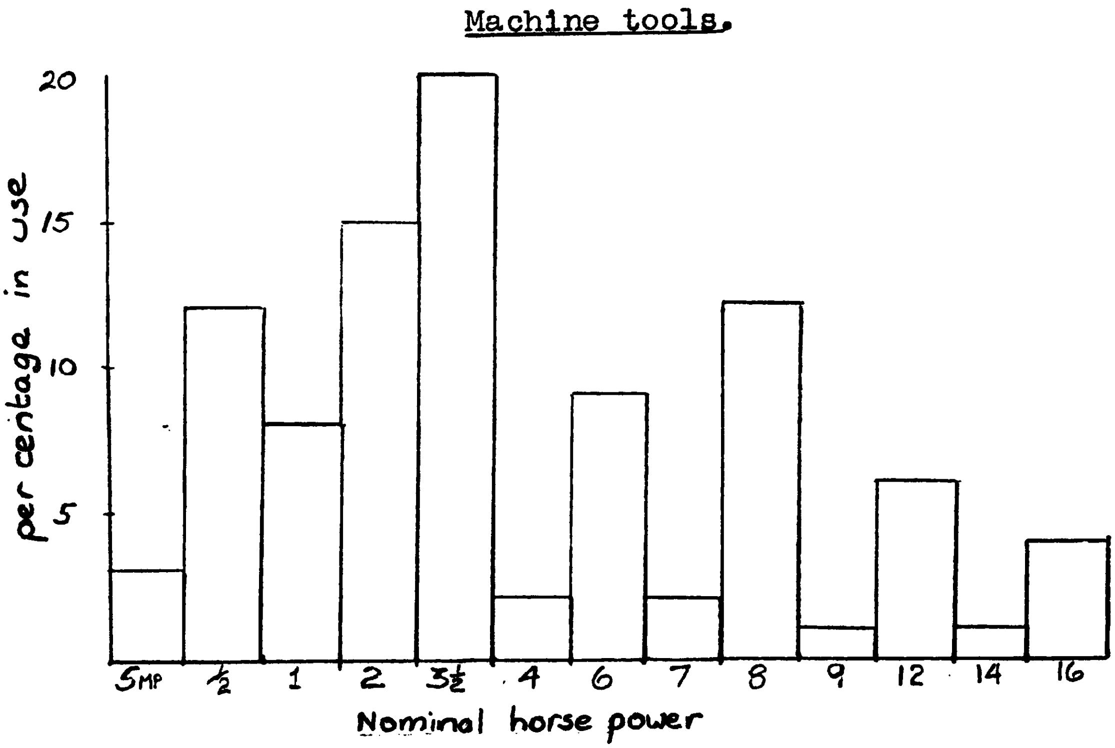
given by Mr. Thos. H. Hewitt of 6 Templeton Road, Finsbury Park, London to Crossley Brothers, states:

> '....... I have great pleasure in saying the 3½ hp Gas Engine supplied by you works in all respects to my entire satisfaction. The work it has to do is to drive a large planing machine, 6' x 3', fan for four fires, grindstone, large drilling machine, small drilling machine, circular saw bench, three lathes and will do a great deal more if required. It goes the whole day long with about ten minutes attention.'
>
> 'P.S. I am about to put a 10 in. screw cutting lathe and slotting machine in addition.'

Other testimonials for this size of engine describe a similar kind of usage.

Figure 9.2 (a) shows just how popular the lower power engines were. Engines in this range - of 3½ nominal and below - would be used by the small engineering establishments whose work would mainly be of a specialist nature. Such firms employing less than twenty people, would accept 'jobbing work' allocated to them by larger establishments. A few of them may well have been involved in the manufacture of machinery for the food and allied industries, such as those listed in Figure 1.1, but in the main the manufacture of machinery of this kind, which is still generally considered to be 'light engineering' would be carried out by slightly larger firms, who would use engines of eight and six nominal power.

The work described as 'heavy engineering' involved the manufacture of locomotives, boilers, large machine tools and marine engines and work involved in rolling mills. Firms carrying out work of this nature would require sixteen or twelve nominal power engines, which indicated forty and twenty-five horse-power, giving an effective or output power of



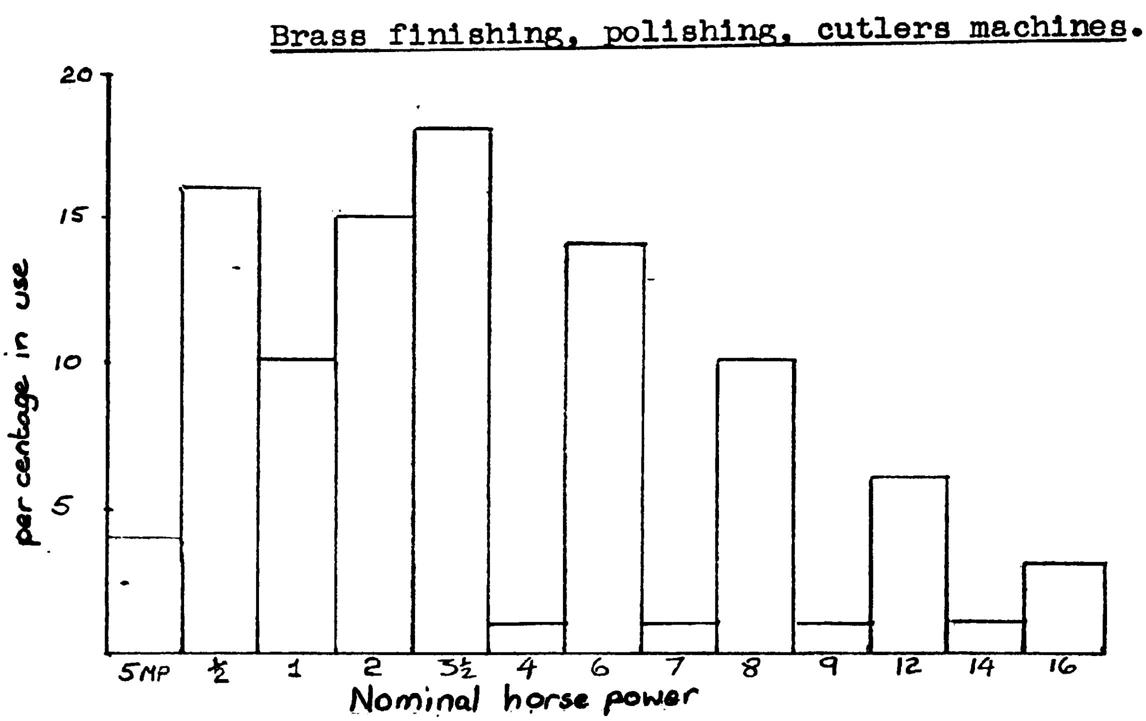


Fig 9.2 Bar-charts showing the percentage use of gas engines, 1877-1886 (data obtained from sales records of Messrs Crossley Brothers)

approximately thirty-five and twenty-two respectively*. Four, sixteen nominal horse-power engines supplying a total of 140 horse-power output were employed in the works of Sir W.G. Armstrong, Newcastle-upon-Tyne[3]. A great many of these large engines are seen to have been employed in Birmingham. Messrs Crossley Bros. themselves also set a fine example. At their Openshaw Works, six sixteen nominal horse-power engines were at work. Two twelve nominal power engines and one six (twin) was used to work the smithy fires and supply electric lights to the offices.

A testimonial[4], dated 24 July 1883 given by the Manchester Works, Ledsam Street, Birmingham describes the immense capacity for work of the sixteen nominal engines:

> '....... we have now had it at work for a little over two years and are so well pleased that we shall never think of having a steam engine again. The engine drives about forty lathes, eight planing machines, five shaping machines, five drilling machines, three boring machines and about thirteen other engineers tools.'
>
> James Archdale & Co.

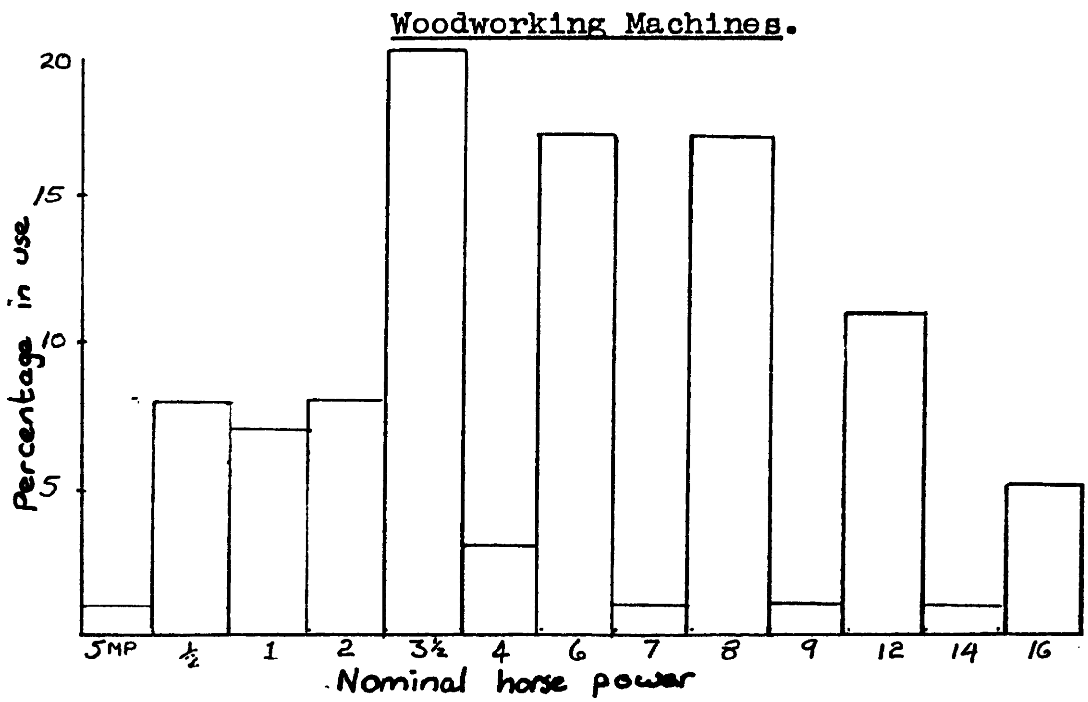
The testimonials given by users of gas engines throughout the range of available power bears witness to the superior operating costs that resulted when compared with steam engines. Low running costs, ease of starting, no wheeling away of ashes and drawings of coals, and the ability to dispense with an attendant's wages, were reason enough to explain the increasing acceptance of the gas engine. Gas consumption, of course, was dependent on the time for which the engine was in use. With intermittent work such as

* Calculated by assuming a mechanical efficiency of 0.85 for the larger engines

hoisting, the average consumption of gas could be as low as 6d. per day for a 3½ nominal engine with gas at 3s per 1000 cubic feet. With the larger engines of 14 nominal power using town gas at 3s per 1000 cubic feet, gas engines became more expensive to run than a steam engine and the Crossley firm was at pains to point this out[5]. Even so, the advantage remained still with the gas engine in terms of attendants' wages, maintenance, ease of starting and saving of space. For large engines, therefore, the use of Dowson gas was recommended, about 1.1 to 1.4 pounds of anthracite coal per indicated horse-power being required. A fuller description of the development and relative costs resulting from the use of this gas is given later in this chapter.

9.1.2 Wood-working machinery

The wood-working trade included cabinet-makers, carriage and ship builders, pattern-making and saw-mills, using mainly saws, planing machines, band saws, moulding machines and wood-working lathes. A surprising feature revealed by the bar chart, Figure 9.3 (a) is not only the number of gas engines that were used in the wood-working trade, but also the relatively large number of the higher power engines put to use. The demand, quite clearly in evidence, was for engines of the intermediate to higher power range. This is an interesting situation. It indicates that the wood-working industry was one highly dependent upon power - sawing through an eighteen inch thick oak or pine with a 42 inch circular saw is no mean feat - steam engines, of course, were available and a number burned sawdust in the boiler; examples of



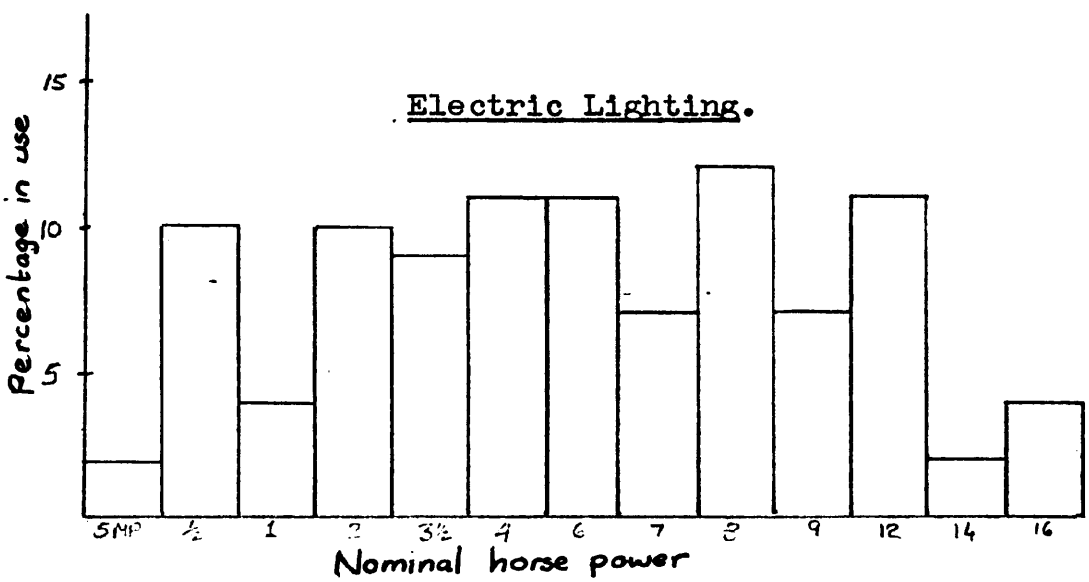


Fig 9.3 Bar-charts showing the percentage use of gas engines, 1877-1886 (data obtained from sales records of Messrs Crossley Brothers)

the use of steam engines in sawmills, however, are not abundant[6]. There is also the possibility that some sawmills used water power, but in the absence of such, the industry must, in the main, have been one which was very much labour intensive. The advent of the gas engine, therefore, must have been of great value to this particular trade and the descriptions given in the testimonials of the machinery that was worked by gas engines illustrates the dependence that was placed upon them.

A sixteen nominal horse-power engine is described by Messrs Aldin and Plater of London as driving

One 4 cutter (Worseman) planing machine cuts 9" planks on all four faces
One general joiner, takes up to 25"
One circular saw, 12"
One morticing machine
One iron punching machine
One fan for four fires
One trying up machine
One deal frame, six saws for 12"
One tenoning machine
Two drills for iron

Comparative running costs of steam and gas engines are given by the 'Steam Cabinet Works', Birmingham in a testimonial dated 19 November 1880. The sixteen nominal power engine (of the earliest type) is stated to have worked regularly for fifty-four hours per week.

> '.... it has given every satisfaction doing its work equally to steam if not better, as we have the same speed from morning till night. It is started quite easily as a steam engine. One man always starts it and the time it takes per week in attention is about three hours, not more, oiling and cleaning included ... the cost, I find is much lower than steam .....

Gas engine working to 16 hp	
Cost of gas for 54 hours	£1 10s. 0d
Oil and waste	1s. 6d
Man for cleaning and attendance	2s. 0d
	£1 13s. 6d

Steam engine (in best order) working from 8 hp to 12 hp	
Coal - per 54 hour week	£1 4s. 0d
Engine driver	16s. 0d
Oil etc.	1s. 3d
	£2 1s. 3d

(Note the steam engine is of less power)

Yours truly,
L. Field

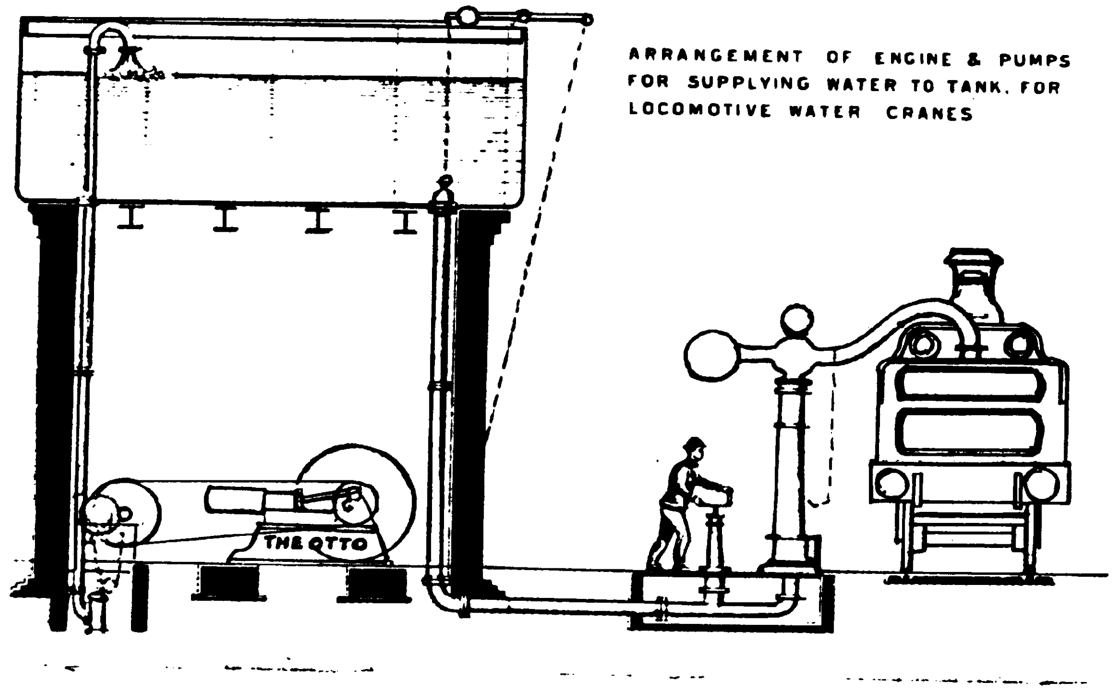
9.1.3 Pumping, water and sewage works Fog signalling and hoisting

The application of gas engines to general pumping work began in the 1880's when a number of local authorities throughout Great Britain installed them. The principal applications were in Waterworks and sewage works, but many seaside towns, notably in the Isle of Man, used gas engines to operate fog sirens. A list of such users, totalling eighty-seven, is given in the Technical Appendix[7]. One of the largest single installations was that at the Gloucester County Asylum which used two - twelve nominal power engines giving an effective power of about forty-two horse-power. A Dowson Gas Plant supplied the gas for these engines. A sixteen nominal power engine was used at Frith Hill, Godalming, Surrey, pumping 7000 gallons of water per hour from a depth of 187 feet into a tower of height 262 feet. The total lift was 449 feet. This also ran on Dowson gas and for a total running time of 86 hours per week, the cost was £1. 14s.

A decade later, as much larger engines became available, the number of authorities using gas engines in this way had increased considerably. At Ross, Hereford, a thirty nominal power engine was working and at Teignmouth, two sixteen nominal Crossley engines were in use, all driven by Dowson gas[8]. The Otto patent, having by this time expired, allowed other manufacturers of gas engines to make their contributions. At Kenilworth, the water for the town was provided by a twenty nominal, Clarke-Chapman engine; Atkinson engines were used at the Uxbridge pumping station. Messrs Tangye Bros. of Birmingham made the most notable contribution with a very large plant at the Sunderland Docks. This consisted of several 120 horse-power engines (effective power) capable of discharging 2,600 tons of water per hour[9]. A rather interesting use for gas engines was found by many General Post Offices for their pneumatic tube system. Dublin General Post Office had two sixteen nominal horse-power engines installed for such a purpose and the London, Submarine Telegraph Co. had two eight nominal horse-power engines doing similar work.

Similar applications to these in Great Britain took place in other parts of Europe. At Düren, Germany, two sixteen nominal horse-power engines were installed for pumping water to the town and at Coblenz, three similar engines were employed on identical work[10]. Both town gas and producer gas were used, with provision, using petroleum spirit, for starting in emergencies. The installation at Düren was capable of lifting 27,220 gallons of water per hour through 180 feet.

The ability of gas engines to be used for hoisting proved an enormous boon in warehouses. Such buildings for the most part, were multi-storey and if a steam engine was used, the boiler had to be placed outside the building which necessi-



Use of Otto gas engine for pumping water to header tanks

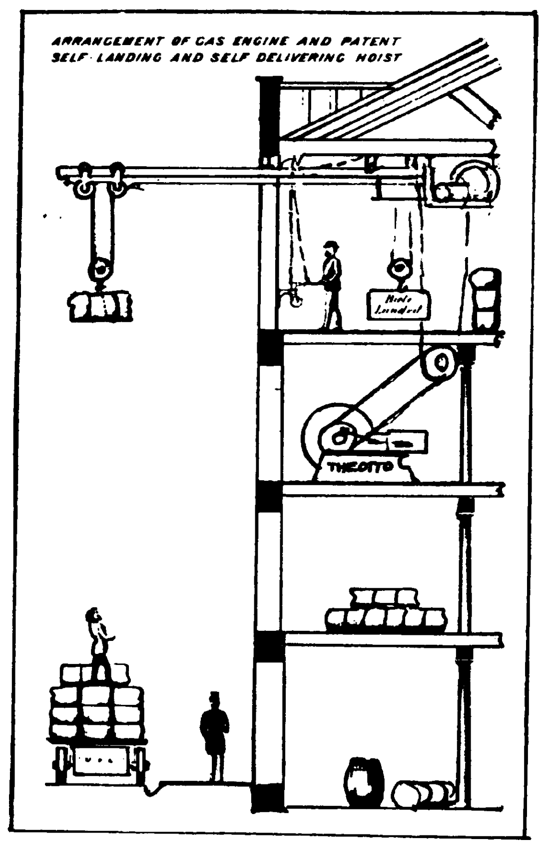


Fig 9.4 Arrangement of gas engine and patent self-landing and self-delivering hoist

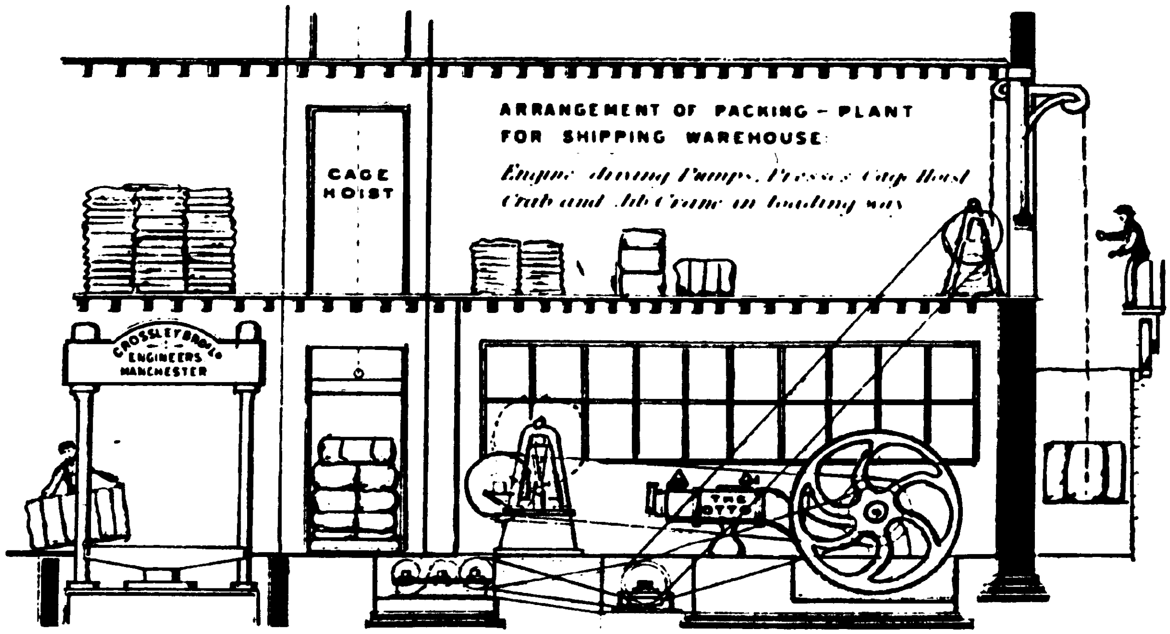


Fig 9.5 Arrangement of packing-plant for shipping warehouse. Engine driving pumps, presses, cage hoist, crab and jib-crane in loading way

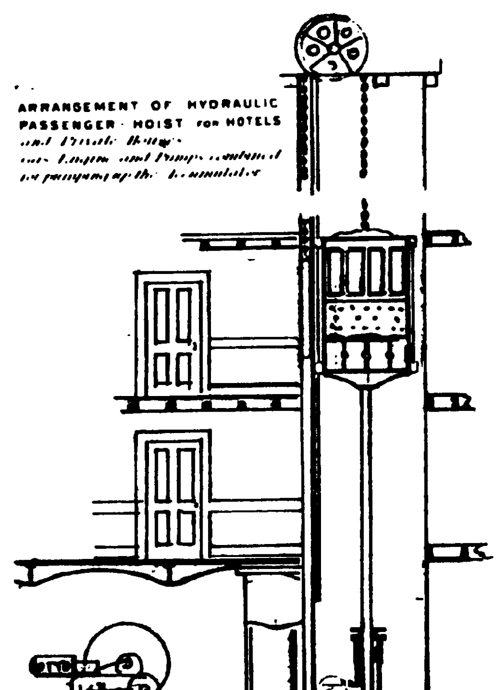


Fig 9.6 Arrangement of hydraulic passenger hoist for hotels and private houses

tated the use of steam pipes or shafting. If power was required on upper floors, as with hoisting, the cost of installing suitable transmission lines was considerable and so, also, was the power absorbed in the process by friction.

Gas engines could be placed on upper floors close to the work with the minimum of effort. All that was required was a single gas pipe and a water supply. Shafting was eliminated, the engine could be started and stopped at will to accommodate the intermittent nature of hoist work and, consequently, a large saving in overall running costs compared with steam engines occurred. Some examples of the application of gas engines for hoist work are shown in Figure 9.4 which is a typical warehouse situation and Figures 9.5 and 9.6. The latter was a hydraulically-operated lift used in hotels.

A selected list of Crossley-Otto gas engines used in Manchester Warehouses for hoisting, driving pumps and presses is given in Volume Two, Appendix Three.

9.1.4 Gas propelled tramcars

The use of gas engines to drive tramcars was believed during the 1890's to have great potential. One of the earliest references to the possibility, however, is that by F.W. Crossley is in a private communication to his engineer friend, F.P. Holt dated 14 May 1881[11], a copy of which is shown in Figure 9.7. The ideas disclosed in this letter appeared not to have been proceeded with, but are typical of the far-sightedness of the Crossley Bros. The first practical scheme was put into operation not until 1894 in Dresden.

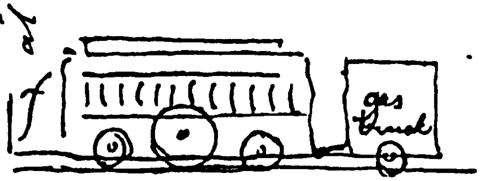
May 14 81

H. P. Holt. Esq.
21 Malcolm St
Cambridge

My dear Holt.

We'll go on Tuesday as you wish — all being well.

What do you think of the annexed idea for a separate gas truck for our



Tramway-Loco-car, mounted on two wheels only, & fixed by a pole to passenger car? It need not be possible to make it very light as it w.d carry nothing but gas, and would thus make room for outside passengers on the other car.

I think in some cases it might be very good.

Yours very truly
F. W. [illegible]

Of course this plan of gas truck w.d enable any quantity of gas to be carried, and the form w.d be the best possible for the gas holder & cheapest to construct. It c.d be run on and off the rails by a man and changed when empty for a full one — the man gripping it by the pole.

If compressed gas were ever used this would be a handy appliance for it. Half the truck c/b a compressed reservoir to keep through the descent at usual pressure. I fancy this might be potentially helpful perhaps

wire square box on the whole seems all that is wanted. The [illegible] very good to me just now. (Ck [illegible]) could be the pipe for filling it or coupl[illegible]

Ideas for using gas engines in this way were prompted by the fact that steam tramcars were found to be noisy and give off an objectionable exhaust. Electrically driven tramcars were considered, but the need to provide overhead cables was thought to be an obstacle and the greater expense of horse-drawn tramcars had come to be well appreciated. The relative costs of using these three forms, gas, electricity and the horse are stated as, one pence per mile for gas, two pence for electricity and three pence per mile for horse-drawn tramcars[12]. Another advantage of using gas-driven tramcars was that,for the town in general, the gas consumption over a twenty-four hour period would be fairly constant. During daylight hours, the tramcars would consume the bulk of gas produced at the local works, but during darkness usage would be mainly by householders.

The gas for the vehicles was drawn from the normal street gas mains and compressed by a permanently installed gas engine (sometimes at the charging point or on the tramcar itself) into reservoirs attached to the tram. Power from the engine was transmitted directly to the axles, thus reducing transmission losses.

In the first attempts with gas-driven tramcars in Dresden, objections were raised about the noise, vibration and smell and also the danger in carrying a store of compressed gas. The first three objections were quickly overcome and, as regards the danger involved, it was pointed out that the self-same method of storage had, for many years been extensively used for lighting railway carriages. To store the gas, six to ten receivers, giving a supply of 44 to 88 cubic feet, were installed to each vehicle. They would be placed beneath the floor and when charged would be capable of running a tramcar about eight miles. The fixed gas engine, of about eight horse-power, used to compress the gas would consume about 8% of this and would compress 2,000 cubic feet of gas per hour to a pressure of 120 pounds per square inch. Each charging operation would take about two or three minutes to complete.

The system of propulsion used both in England and Germany was that devised by Herr Lürig in 1893[13] and first used in Dresden during 1894. A friction coupling controlled by the driver was placed between the engine and the carriage. The carriage could then be stopped without the need to stop the engine and when stationary, the supply of gas to the engine would be almost cut off so that one cylinder was idle and the second cylinder made to fire every eighth revolution. To start the tramcar moving, a lever was moved to a second position (the first being that to obtain the standing position). A friction clutch would then be brought into operation and gas turned on; the car would then run at a speed of 4½ miles per hour. By shifting the lever to a third position, the full quantity of gas was turned on and a friction clutch of larger diameter brought into operation. The speed then increased to 9 miles per hour, the full speed. Cooling water for the engine was a gravityfeed system provided by a tank placed beneath the seats on the upper deck. On leaving the engine in a heated condition, the cooling water was passed through tubes which were exposed to the air flow as the tramcar was moving. A total of 30 to 36 passengers could be carried and each charge of gas was sufficient for a journey of eight miles.

The Dresden gas tramcar proved so successful that in November 1894 another system nearly three miles long was laid at Dessau. At the time, Dessau was already lit by electricity provided by gas engines and a plan to use electrically-driven tramcars was considered, but dropped in favour of the gas tramcars when it was realised that, in addition to the over-head cabling required, an additional generating station would also have to be built. When, eventually, it was laid and working, Professor A.B.W. Kennedy, one of the judges appointed by the Society of Arts to supervise the engine trials of 1888, made a study of the system and, as a result of his favourable report, the first line was laid down in England by the London Gas Traction Company between Thornton Heath and Croydon during 1895[14].

The second tramway in England to be worked by gas was that between North Blackpool and St. Annes laid in 1896. The distance was 7½ miles and fourteen cars, each capable of carrying fifty-two passengers and ran a total of 75 to 100 miles per day. Re-charging of the gas cylinders was carried out at the Central Railway Station. The Blackpool trams used eight nominal horse-power Crossley engines (approximately twelve horse-power output). The storage pressure of gas was 200 pounds per square inch and one charge of gas was sufficient for a fifteen mile run. The cost worked out at one penny per mile.

9.1.5 Electric light and power generation

In section 7.8 of Chapter Seven, an account is given of how separate developments in the fields of electrical engineering and engine technology converged during the early part of the 1880's to provide small, viable generating equipment suitable for use in workshops and public buildings. By 1886, the progress in both technologies had been such that nearly 250 public installations of electric lighting had taken place throughout Great Britain[15]. The Theatre Royal and the Prince of Wales Theatre, Birmingham had been lit with both arc and swan lamps by electric power, provided by sixteen nominal power engines and many retail shopping establishments provided themselves with electric light. The installations, which caught the public eye however, were the Brighton Electric Railways, which commenced operation on 4 August 1883. The supervising engineer was Magnus Volk, whose name is found to be linked with several other electrical installations. Full details of the railway are given in Appendix Three, Volume Two, but for convenience the relevant features are now given as follows:

The track was a quarter of a mile long with a gradient of 1 : 100. A 2 horse-power nominal Crossley engine was connected to a Siemens D5 dynamo (a 12 nominal power engine was later installed - possibly about 1887/88 and the track extended to one mile in length). From 4 August to 29 September 1883, a total of 24,000 people had been carried, the engine working ten hours per day and making six journeys per hour; the cost of gas for this period was £4 12s. at 3/3d per 1000 cubic feet. A similar installation was the Ryde

Pier Electric Railway, the Isle of Wight installed in February 1886. A 12 nominal power Crossley engine was used and the plant was put down by the Siemens Brothers of London and enclosed in an ornamental engine house, glazed all round with plate glass, forming a 'strikingly elegant structure open to the inspection of the public near the Pier gates'. A report of the installation mentioned that:

> 'on the last Bank Holiday, the Engine was kept running for 12 hours and carried 3400 passengers with a consumption of 2,800 cubic feet of gas. Each journey took 2½ minutes and the carriage travelled at 12 miles per hour.'

The electrical power delivered was 60 amperes at 110 volts, a motor being fixed to one of the cars.

The list of applications given in the Technical Appendix (Volume Two) provides a good deal of interesting information with regard to the kind of dynamos and type of lamps used and also the methods of application in the numerous installations which are listed as in operation throughout the country. It shows that electrical lighting, made possible by the use of gas engines, was used on a much larger scale than had previously been realised. The press extracts describing the lighting of Swan's house at Bromley, of Lord Randolph Churchill's residence in Connaught Place and that of W.H. Holmes in Newcastle, are quite revealing.

Two methods of producing the electric current were used, either the dynamo supplied the lamps - arc or incandescent - directly, or secondly, the dynamo was used to charge a series of cells from which the electric current for lighting was obtained. In the latter case, the charging process would be done during the day and, at night time, the batteries would be able to supply the current whilst the engine was idle. The most popular type of lamp is seen to be the incandescent and by far the largest installation was the General Post Office, Savings Bank Department, Queen Victoria Street, London which used 400 such lamps each of 10 candle power driven direct by a Maxim Weston dynamo. The engine used was a sixteen nominal horse-power.

The application of gas engines into domestic electric lighting in Great Britain provided immense social benefits and convenience and was in parallel to similar events taking place in Germany. Berlin Opera House was lit in 1880 with electricity generated by one of Otto's noted 'twin-engines' and shortly afterwards, Cologne Cathedral was lighted by electricity to celebrate its completion, again by a twin engine[16]. It was in Germany that major applications of gas engines to produce electric power on a much larger scale began; the first was at Dessau in 1886 where eventually engines of 120 brake horse-power were directly coupled to dynamos to produce electricity and light up the town[17]. In February 1889 the town of Schwabing near Munich was lit by electricity using a forty nominal horse-power Deutz-Otto engine running on Dowson gas manufactured from German anthracite. About the middle of 1892 the town of Morcambe was lit by nine arc-lamps and glow lamps equivalent to 1600 of eight candle power each. These applications and another at Longpont, Southern France, were the earliest examples of electric power produced by gas and optimism for a more extensive use of gas engines in this way was very high in Great Britain during the early part of the 1890's.

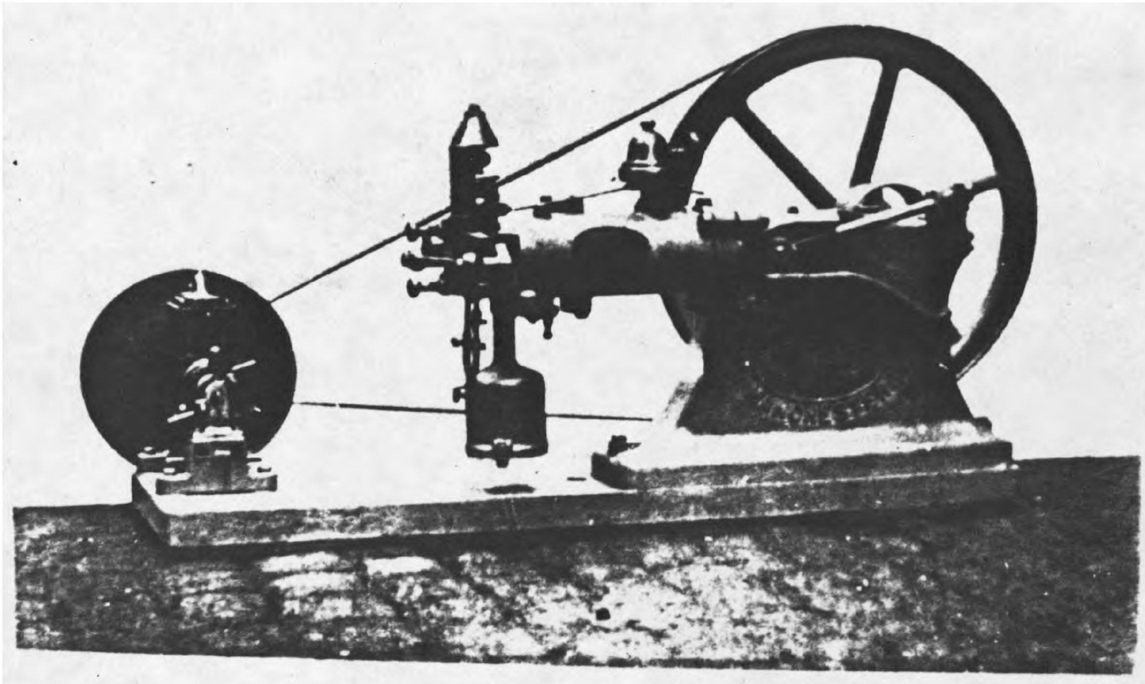


Fig 9.8 A ½hp nominal Crossley engine and dynamo arrangement. The engine has a slide valve and flame ignition, probable C.1882. An example of this engine can be seen in the North Western Museum of Science and Industry, ~~Manchester~~.

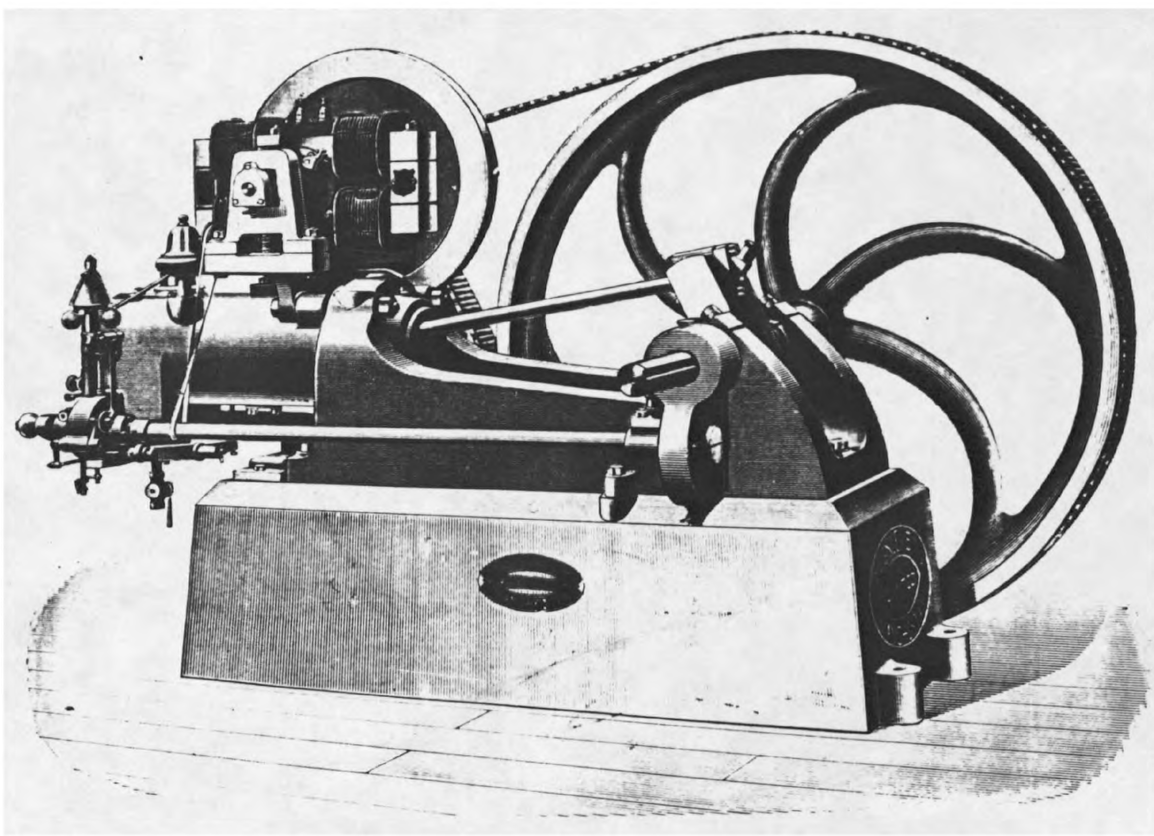


Fig 9.9 Crossley Engine of the 6, 8 and 12hp type with Gramme dynamo mounted. A slide valve and flame ignition is used, probable date, 1886.

The reason for considering gas engines for generation purposes was that numerous problems associated with the use of steam engines had arisen. In any twenty-four hour period, for instance, there would only be a short period of time during which a heavy demand for electricity occurred. For the remainder of time, demand was low but the steam engine and boiler would still have to be kept in a fired condition with the engines on part load. This meant that fuel consumption was excessive and the overall operating costs were high. Since the gas engine could be started and stopped at will with no consumption of fuel during the idle period, there was an obvious advantage to be gained if the technical problems (discussed later) could be overcome.

The plant at Dessau , which began generating in September 1886, was the first central station in the World to use gas engines. It was established by the German Continental Gas Co. in the belief that it would not only promote the use of their gas during the day time, but cheapen the production of light. In these aims it became successful and other electric lighting stations were soon envisaged. At the time of its opening, the largest gas engine made gave only 60 brake horse-power (a two cylinder version). To provide sufficient power, therefore, the engines used consisted of two 60, one 30 and one 8 brake horse-power with the dynamos driven by belting. Five years later, when much larger engines were available, the system was changed; the 60 horse-power engine was retained with the belting and one 120 horse-power engine was substituted for the others and coupled directly to the dynamos. By direct coupling in this way any tendency to slip was removed, but by far the biggest advantage was a great saving in floor space. This space-saving ability of gas engines meant that generating stations could be erected in the town which was to be served. Town centre land was expensive and the land requirements for a steam engine and boiler plant was considerably more than that for a gas engine. Another difficulty was that insurance companies would often refuse to provide cover for steam plant installations erected on congested industrial areas. Smoke from boilers was another irritating nuisance. The larger installation at Dessau included 62 arc-lamps and glow lamps equivalent to 4,000 of 16 candle power each. The speed of the coupled engine and dynamo was 150-160 rev/min and the output was 70 to 80 kilowatts per hour. Town gas was used on this installation and consumption was 39 cubic feet per kilowatt hour. Accumulators were used which was considered to be an advantage over a 'direct connection'. In the latter case, in order to produce an efficient unit, the engine output power has to be matched as nearly as possible to the electrical power requirement - to avoid wasteful part load running - an extremely difficult task in view of the variable electrical load.

The installation at Schwabing, a suburb of Munich, worked with Dowson gas and had 10 arc lamps and 300 glow lamps. A trial lasting 8¼ hours showed that with an average output of 22.5 kilowatts per hour, the fuel consumption was 3.3 lbs of coal per kilowatt hour, about half that when a steam engine was used.

Morecambe was the first town in England to be lit with electricity. Work began at Easter 1892 and by Whitsuntide, one engine was running using town gas. Three Stockport engines were used, each of sixteen nominal horsepower and a Dowson gasplant was installed. Records made between August and October 1892 showed that the weekly output was between 1.6 MW to 1.8 MW and that the total cost (including labour, oil and water, etc) using town gas was 2p per KW hr and when Dowson gas was used, the cost was 0.95d per kilowatt hour[18].

The paper by Dowson, reference 17, on the use of gas power for electric lighting, reveals a good deal about the initial technical and financial problems that existed in schemes to produce electric power using gas engines. Discussions as to what cycle to use in the engine and whether to use high or low tension current were particularly active. Further technical problems existed, also, with regard to the use of storage batteries and transformers and with regard to operating costs, several attempts were made to compare the illumination produced electrically and by gas light from a given weight of coal were made. But such estimates were not only difficult to make, they were often misleading. In gas-making, for instance, coke was produced which was sold as a by-product, thereby off-setting the overall cost of producing the gas, whereas in an electrical plant using steam, the coal was burned completely and no coke was produced. Similar difficulties arose when attempts were made to compare the operating costs of generating stations using steam engines and those using gas engines which ran on generator gas or even town gas. The obvious answer would have been to conduct a series of tests over a period of time and this was eventually done, but even then, comparisons proved difficult because of the widely varying requirements of individual communities, which the plant was to serve.

From the discussions following the presentation of Dowson's paper, it seems to be generally agreed that a dynamo driven by a gas engine was capable of producing more light than if the same amount of gas used was burned directly in the best Argand burner. It is also clear from the discussion that the crossroads had been reached with regard to the use of gas engine driven generators and some important decisions had to be made to determine future policy. As stated previously, optimism for a more extensive use of large gas engines for electrical generation was obviously high and there was a good reason for this. In Great Britain at that time (1892) the number of gas engines sold for electric lighting amounted to an aggregate of more than 7,000 nominal horse-power whilst, in Germany, the figure was over 11,000 horse-power. Dowson called for co-operation between gas companies, electricians and engine manufacturers to overcome the problems and so produce an economically viable generating station.

The following is a summary of the case for using gas as seen in 1892, and from it the dilemma facing engineers will be appreciated.

1. When town gas is used for driving the engines of an electrical station the gas consumption is about 50% less than the volume of gas required to give the same amount of light in ordinary burners.

2. When town gas is used, no boiler and no firemen are required and there are no ashes to remove; less ground space is needed, no accumulators are required except such as may be necessary to equalise the load of the engines and to provide for a small amount of storage. The engines can be worked in the most congested districts, close to where the lights are required and where boilers are not allowed.

3. When generator gas is used, the consumption of fuel under a full load can be at least 50% less than with steam power, and the loss due to steam boilers, not fully worked can be almost entirely avoided.

To some extent - perhaps not as much as he might have wished - Dowson's hopes were realised when three years later the Islington Agricultural Exhibition was lit by gas, showing what could be achieved. Five Stockport-Otto engines were used, all running off Dowson gas and what must have been the largest gas engine plant used in England for electrical generation, was that erected in 1896 at the Electrical Central Station of the Leyton District Council[19]. Four Premier gas engines each outputting 43.3 kilowatts and three Dowson gas generators were used with a gasholder of twenty feet diameter and ten feet high to store the gas. A Clarke-Chapman Plant installed at Newcastle-upon-Tyne was also subjected to tests where it was found to cost less than one penny per kilowatt generated at a full electrical load of 16 kilowatts[20]. But despite this potentially promising situation in the use of large power gas engines in Great Britain for central generating stations and other large scale industrial applications, progress lagged behind that made on the Continent and in America. Towards the close of the century, only seven stations were working in Great Britain, the largest having gas engines aggregating 650 horse-power and the largest single unit in use was one of 250 horse-power (see section 9.3.3). Two main reasons can be advanced to explain this; one was the fact that no gas producer was commercially available, which could make gas cheaply from any but expensive fuel such as anthracite; secondly, the gas engine manufacturers of Great Britain had once again lagged behind their colleagues in other countries in producing very large gas engines*. Consequently there had been an insufficient period of time to carry out trials which would have satisfied electrical engineers as to their suitability. A third factor, was the negative attitude of many local authorities to schemes of this nature.

At the turn of the century, although little had yet been done with regard to the use of very large gas engines, neither of the two main reasons given above were any longer acceptable. In the first instance, the Mond gas producer had appeared which succeeded in making gas, suitable for engines, from cheap bituminous coal or slack. Secondly, as a result of a greater appreciation of engine requirements, numerous engines of 500 horse-power and one of 650 horse-power were at work. Others of 1,000 and 1,500 horse-power were being built. In America about that time, the George Westinghouse Machine Co. were considering engines of 2,000 and 3,000 horse-power. Eventually, by about 1910 gas engines of a similar size were produced in Great Britain, the National Gas Engine Co. being an influential figure in this respect.

Returning once more to the smaller engine powers that were used for electric lighting, the bar chart, Figure 9.3 (b) shows some interesting features. Over almost the entire power range available at that time, c.1886, there is seen to be a rectangular form of distribution with regard to the powers of engines used. At the lower end, the two nominal horse-power engine was popular for private residences, a

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* Both of these facts are discussed more fully in section 9.3.3

choice of dynamo being available. A type most commonly used is seen to be the Crompton, with the Elwell-Parker, the Siemens and the Gramme also being well used. A 2 unit shunt, or compount Crompton dynamo would run at 1,400 revolutions per minute and operate about thirty incandescent lamps. A similar output from an eight inch compound Elwell-Parker dynamo is recorded with 30 amperes and 80 volts at a speed of 1,500 revolutions per minute. Examples of such applications are shown in Figures 9.8 to 9.10.

These dynamos appeared capable of much higher loadings since they are seen to be used with the larger and intermediate power engines. The four, six and eight nominal horse-power engines were used mainly by Banks, medium-sized business premises, entertainment centres, retail stores and the larger private houses. Amongst those listed in this category are The Royal Society, The Society of Arts, Mather and Platt Ltd. of Salford and the Art Gallery, Birmingham. The larger engines were used in major places of entertainment, large hotels and banks. The Theatre Royal and Prince of Wales Theatre, Birmingham each used two sixteen nominal horse-power engines with 300 light Ferranti alternating current generators and a Siemens exciter. The speed of the generator was 900 revolutions per minute with 220 and 200 incandescent lamps respectively being used to light up the theatre auditorium, vestibule and corridor and a few on stage. By 1893, the use of gas engines for electric lighting had increased to such an extent that Crossley Bros. had developed six highspeed engines - 300 rev/min - of powers 2.5 to 14 brake horse-power, specially for electric lighting. These included vertical and horizontal engines with prices ranging from £45 to £151.

9.1.6 Printing machinery

The printing trade was amongst the first of all users ever to put the gas engine to work driving machinery. The Otto-Langen Atmospheric engine was widely used by printers* and when the four-stroke engine became available in 1877, printers again found it admirably suited to their needs. The following extraction from a testimonial dated 4 October 1879 gives the reason why the gas engine achieved such favour with this particular trade[21].

> 'We heard such uniformly favourable resports of the advantages of your Gas Engine as compared with steam that, nearly a year ago, we took down a comparatively new 3½hp steam engine and boiler and had you put up a 2 hp Gas engine ..... Our place is now safe from any possibility of an explosion; the saving is very great in working. Our machines do better and more work than formerly. From the steady and uniform speed of the gas engine, we can run them fully an hour longer each day as there is no loss of time in getting up steam in the morning and after meals. With the exception of a thorough clean out, once a week, and oiling each morning, we find the Gas Engine requires no attention. Our Fire Assurance Premium has been reduced ..... and our machine room is now - what it never was before in summer - cool and comfortable. We can keep our place much cleaner than formerly and our neighbours have ceased complaining of smoke nuisance. The engine drives two Double Medium Wharfedales and we find runs at the same speed whether they are standing or one or both are on. Unless your engines have some defect or weakness which we have not, as yet, discovered, they must entirely supersede steam for work such as ours.....'
>
> Yours, R.D. Webb & Son, Printing Office
> 74 Abbey Crescent, Dublin.

It is mentioned in the footnote that the firm of L. Simon &

*L. Simon & Sons who introduced it into England in 1869 were then a firm of metallic printers. See Chapter Five

Son, Nottingham, at the time they introduced the Otto-Langen into England, were engaged in printing work. The first German atmospheric engine delivered to Manchester (No. 154) was also to a printer, Sydney Smith of Stretford and it is recorded in the list of testimonials referred to above, that the second four-stroke engine made (No. 1301) was sold to the Castle Printing Works, 12 Preeston's Row, Liverpool in March 1877*. Many provincial newspapers are listed in the testimonials - the following is an extraction.

Morning News, Belfast	Sept.1884	16 hp
Leeds Daily News	June 1883	16 hp
Dundee Advertiser	Jan. 1885	16 hp + 3 others
London City Press	June 1883	12 hp
London Evening News	June 1883	3 - 12 hp
Irish Times	Sept.1884	2 - 12 hp
Dublin General Advertiser	Oct. 1878	8 hp
Devenport Independent	Nov. 1880	6 hp
Ayr Observer	July 1884	3½ hp
Northern Chronical and General Advertiser North Scotland	July 1884	3½ hp
Derby Gazette	Oct. 1878	3½ hp
Irish Farmers' Gazeteer	Oct. 1879	3½ hp
West of England Express	Oct. 1878	3½ hp
Coventry Herald	Oct. 1878	3½ hp
Blackpool Times	Nov. 1877	3½ hp

Unfortunately, a full list of printers using gas engines is not given in the Catalogue of Users by Crossley Bros., only a few testimonials being quoted. It is not possible, therefore, to construct a bar-chart and so make an assessment of the distribution and use of gas engines amongst printers.

* The first four-stroke engine No. 1300 also in March 1877 was to Henry Rogers, East Harnham, Salisbury. It was used to drive three pumps in a chalk mixing mill

9.1.7 Users of engines for organ blowing

Most of the principal Cathedrals and Churches throughout Great Britain by the year 1890 had Crossley gas engines installed to work the organ bellows. In 1885, a two nominal power engine was installed in Westminster Abbey and in St. Giles Cathedral, Edinburgh, a 3½ nominal was installed prior to 1884[22]. St. Paul's Cathedral used a similar engine and Manchester Cathedral used a one nominal power engine.

The use of gas engines to replace manual labour which had previously been used to work the air bellows of the organ, presented numerous practical and mechanical problems. The engine, although described as 'silent' and, indeed, to a large extent it was, had to be sited so as not to be the least bit audible to a congregation, (see Figure 9.11). If noise was likely, brick enclosures were built. Mechanical linkages, blowing gear and shafting would often be required also. It was in overcoming problems of this nature that the Crossley Brothers excelled. They possessed experience in many other fields of engineering such as that with lifting hoists, hydraulic pumping gear and presses. If a blower was not available for a particular situation, therefore, they would simply make one. If the application of a gas engine to a church (or for that matter to anything that required one) presented particular problems, they could overcome them in a thoroughly practical manner. Evidence of this can be found in correspondence concerning the erection of organ-blowing equipment in churches and cathedrals[23] from which it can be seen that each application was very much an individual affair. A list of churches in Manchester and

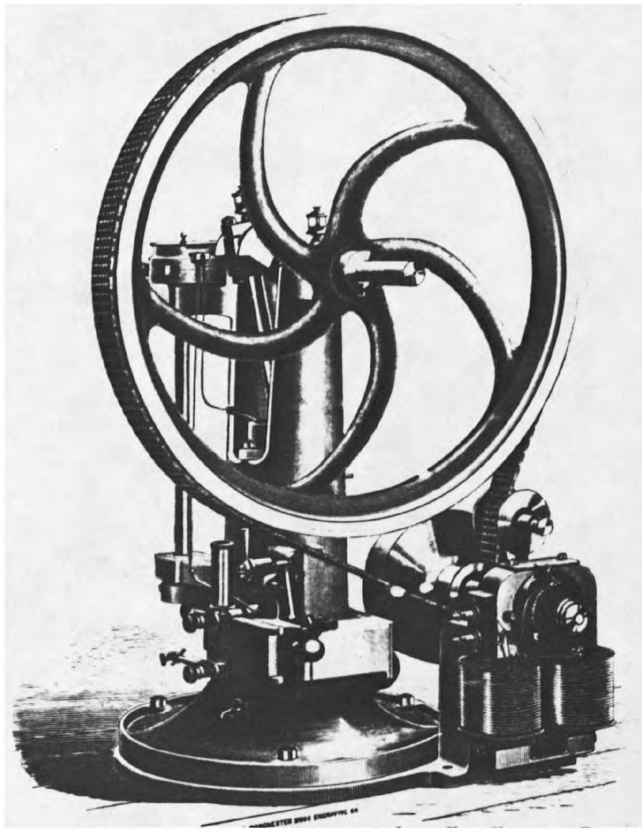

Fig 9.10 A 5-Man power vertical Crossley engine with dynamo 1886. Slide valve and flame ignition. Capable of supplying six 20-candle power or ten 10-candle power swan lamps. Price complete £75. Engine only, £45

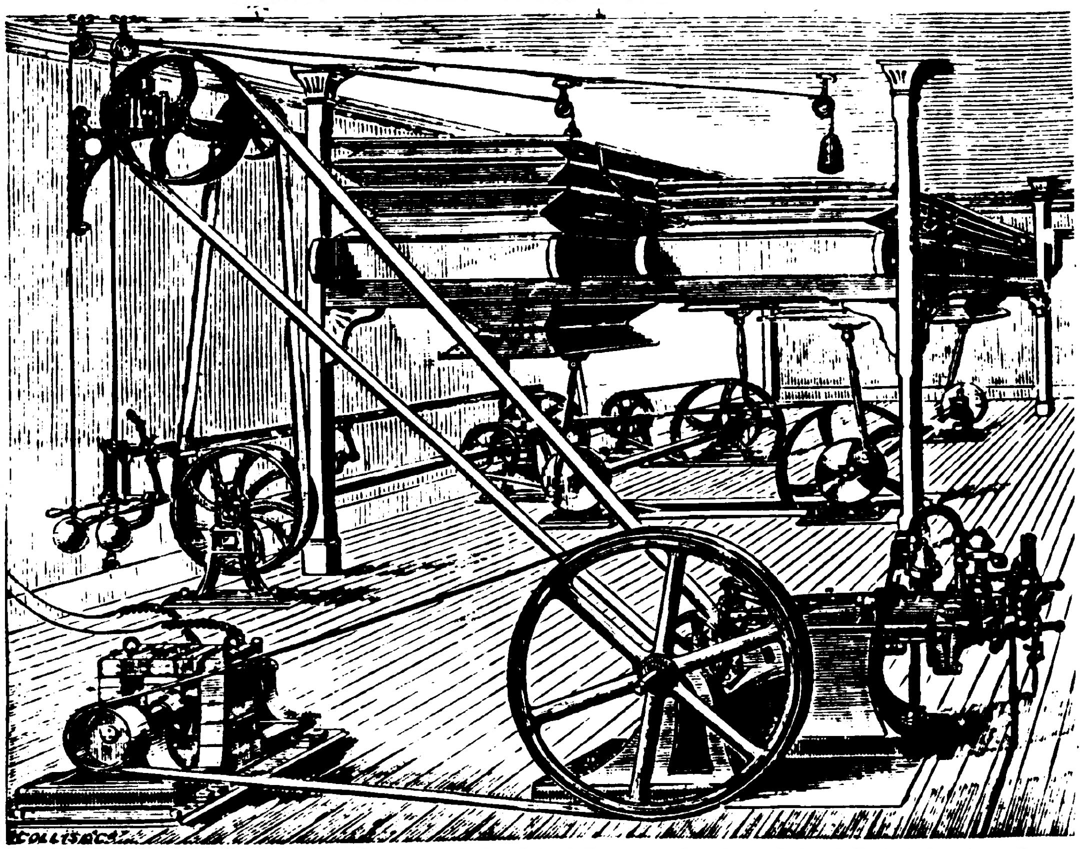

Fig 9.11 Arrangement for organ blowing by Crossley Brothers C.1883 as used in Cathedrals and large churches. Note the generator which is being driven at the same time.

Name of Church	HP	Date	Engine No.
St. Michaels, Macclesfield	1	Feb 1885	8122
Holy Innocents, Fallowfield	½ Vert	Jan 1890	15172
New Free Church, Moss Side	5 Man	Sept 1885	8907 *
Chorlton Rd, Congregational	½	May 1897	30312
Methodist Chapel, Stocksteads	½	Aug 1902	44615
Wakebarn Baptist Chapel	5 Man	June 1890	16010
Baptist Chapel, Staincliffe	5 Man	Aug 1885	8825
M. Spencer (Churchwarden)	5 Man	Nov 89	14911 **
Congregational, Bacup	½ Vert	-	19214
J. Sidebotham, Bowdon	1	May 1879	2239 ***
A. Cora Bowdon	5 Man	June 1891	17130
Parish Church, Bowdon	½	Feb 1892	18720
Westleyan Chapel	1	June 1899	36033
Parish Church, Burton-on-Trent	3	-	37451
Parish Church, Cheadle	5 Man	Oct 1893	22413
Parish Church, Eccles	1	Sept 1890	16420
Westleyan Chapel, Haslingden	½	Dec 1885	9228
Mount Macnaut Chapel, Leek	½ Vert	June 1891	17675
Lichfield Cathedral	2	Mar 1894	6881

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* The 5 man-power engines were vertical

** Returned to works in 1893

*** F. W. Crossley lived in Bowdon

surrounding districts, which installed gas engines to feed the organ with air, is shown. In total, ninety-three cities and towns in the United Kingdom had Crossley gas engines in places of worship. The engine sizes used of course were small - less than three horse-power nominal and many of the space-saving vertical engines are seen to be used. In a number of cases a larger than necessary engine would be installed and the surplus power used to drive a generator to light the church with electric light.

9.1.8 Corn grinding and fodder chopping

The emphasis that has been placed up to now on mechanical invention, innovation, scientific theory and theories of combustion has obscured the fact that, during the period being discussed, the horse occupied a dominant position as a mode of transport. Before goods could be transported by rail, for instance, they would have to be conveyed from factory to station; deliveries of raw materials from wholesalers to retailers would be done by horse and carriage and a good deal of public transport was horse drawn. Horses of course require to be fed and the extent to which the necessity to provide them with food became an industry in itself, can be judged from the number of engines that are listed as being employed in this particular field. It is by far the largest number of the categories shown. The uses found for the gas engine in this agricultural work were mainly chaff and hay cutting, corning grinding and crushing, seed cleaning and oat crushing. Many engines, installed primarily for this work, performed dual tasks such as hoisting and electric lighting, in addition to the milling.

Corn grinding and fodder chopping.

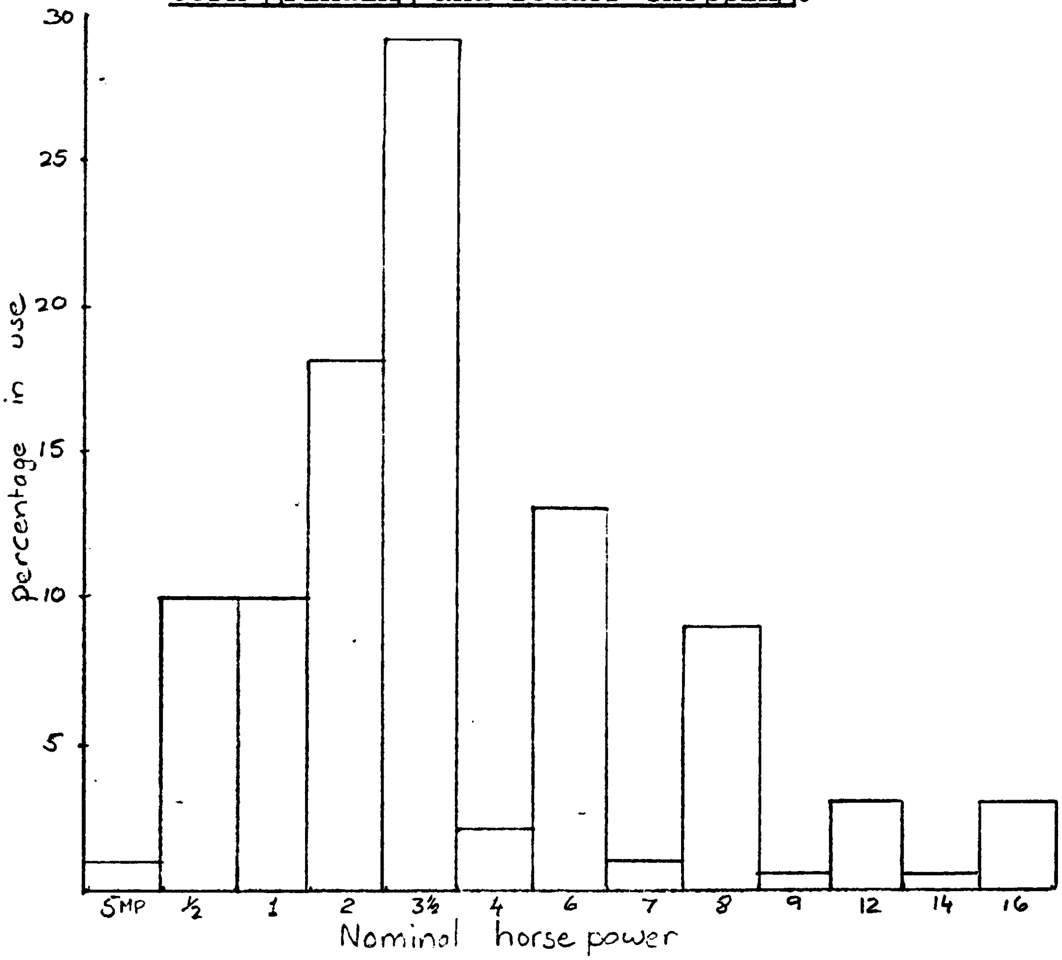

Fig 9.12 Bar-charts showing the percentage use of gas engines, 1877-1886 (data obtained from sales records of Messrs Crossley Brothers)

The bar chart, Figure 9.12, which has been constructed, shows the distribution of engine power in this particular industry. The number of larger engines - above eight nominal power - is small by comparison. More popular were the intermediate powers of six and eight nominal power. The number of 3½ and smaller nominal power engines used is striking. A number of these were used by bus and tramway companies to mechanise the feeding of their horses, but in the main the small engines were used by millers, in their corn mills.

9.1.9 Other uses

The list of gas engines uses so far presented namely for driving machine tools, wood-working machinery, dynamos, pumping equipment, tramcars, printing machinery, organs, chaff cutting machinery and hoisting equipment, represents the major industrial applications of stationary engines. In addition to these, were numerous other industries, using a smaller number of engines, who provided essential services of industry and for the public in general. Among the foremost of these were the gas companies, manufacturing gas for illumination and for power. A selective list of these is given in appendix , which shows that 126 cities and towns throughout the United Kingdom, used gas engines to drive scrubbers, washers, exhausters and pumps. What is described as 'meat chopping' presents another hitherto unknown but revealing source of use by butchers with approximately 250 engines being listed. Most of these, as may well be expected are in the low power range with a great many five man-power engines shown as being used. The principal task of these smaller machines appears to be that of driving machinery for sausage-making, mincing and meat sawing. Larger engines of two nominal power and above, would also be used to drive refrigerators, which Crossley Brothers would supply, being agents. A number of Co-operative Societies are seen to be included in the list of 'Grocers' machinery' many of whom used the largest power engines. These establishments would then, in addition to the use of electric lighting, take on the work of coffee grinding, sausage-making, hay chopping, hoisting and baking.

The textile trades, which have always been thought of as the domain of the steam engine, are also seen to have derived benefit from use of the gas engine. The list of users given shows that very few large engines were used, the bulk of users, therefore, must have been made up of the smaller to medium-sized establishments. Many favourable accounts of the ability of the gas engine to drive looms can be seen, the following of a six nominal power engine is an example:

> 'The 6 HP engine you supplied us a year ago, we are happy to say, is working admirably. Previously, we have been tenants at three different mills under steam, but for steadiness and uniformity of running the Otto far surpasses our former experiences. We have ten Dobcross Looms with two beams each, weaving heavy backed worsted coating, Beaming Machine, Winding Machine and Warp Drying Balloon and the exhaust pipe is used for drying the warps on the balloon. We run the engine from 6 am to 8.30 pm and the cost of gas is about 13s per week and for the same machinery, we would have to pay, as tenants, 30s. per week.'
>
> Ainley Haig & Co. Lindley, Huddersfield
> May 1883

The cotton industry included the manufacture of engine packings and lampwicks, but the textile industry, in general, contained a variety of allied trades such as cloth cutting, ropes and twine, wool-sorting, hosiery, cap and bonnet manufacturers, glove-making and a host of others all of which were able to increase their production by the use of a gas engine.

Two other trades, so far not mentioned, who benefited from the use of gas engines, were the boot and shoe trade and those industries employing sewing machines. Both of these present an interesting situation, since it is evident from the list of users, that they had become highly dependent on the gas engine as a prime mover, but little reference can be found, that either had previously used steam engines as a source of power.

One possibility, suggested by the testimonials quoted above, is that manufacturers engaged in these trades, unable to afford the initial outlay and running costs of a small steam engine, would rent a small section of larger premises*. Some form of manufacturing activity would be taking place in these premises and a steam engine, probably a large one, would already be installed. A rental for the property would then be charged and also a payment for the use of the steam engine to drive the smaller traders' own machinery. Such an arrangement would help to explain how some manufacturers could overcome their power problems, but the system has obvious disadvantages. It would, for instance, be very restrictive in that there was bound to be a shortage of suitable premises that could be rented. The luckless small trader would

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* 'Room and Power' mills were quite common in the textile industry

also be totally at the mercy of those involved with the main pre-occupation of the premises with regard to when he could have use of the steam engine, to say nothing of the transmission difficulties. The situation, therefore, although providing some means of allowing goods to be produced was not conducive to expansion.

In the absence of a gas engine, a potential manufacturer wishing to set up in business thus had three possibilities. One, that he acquired premises of his own and became entirely dependent on manual labour. Two, that he invested in a steam engine of his own and, thirdly, that he should rent a portion of a larger establishment as described above. But none of these alternatives, for reasons already pointed out, would be totally satisfactory. Amidst such circumstances, the appearance of the gas engine must have been very welcome. Its initial cost was a little higher than a steam engine and boiler installation, but when in service possessed many advantageous features with regard to running costs, maintenance, fire risk and convenience of starting. To an individual contemplating setting up a manufacturing business, the acquisition of a gas engine meant that the power supply problem was solved. He could then obtain suitable premises with freedom to expand if circumstances were favourable. This would largely explain the appearance and growth during the 1880's of the countless manufacturers in the trades already mentioned. The increased production of goods has obvious benefits to society.

9.2 Numbers of gas engines in use 1896-1900

Towards the end of 1896, a circular was sent out to most of the leading gas companies in the United Kingdom[24]. It requested the superintendent to furnish information regarding the number of gas engines which were at work in the city, town or village served by that particular company. A total of 438 companies replied. The census which appears to be the only one of its kind, reveals that cheaper rate town gas was available to users of large gas engines. At that time, the London districts were served by three large gas companies, the Gas Light and Coke Co., The South Metropolitan and The Commercial. These three companies between them reported that, at the beginning of 1897, 4,600 gas engines from ½ man power to 100 horse-power existed*. In Paris, where gas was much more expensive than in Great Britain, only about 2,300 engines were in use representing an aggregate of about 1200 horse-power. Birmingham was next with 1,480 engines, Glasgow 1,235, Liverpool 1,050, Manchester 1,000, Leicester 571, Sheffield 517, Bristol 452, Bradford 432, Belfast 571, Nottingham 300, Halifax 250, Dublin 262 and Sunderland 230. In fifty other small towns, from 150 to 200 engines were at work, sixteen towns had from 100 to 150 engines each and thirty-seven towns had between 50 and 99 engines. Other towns and villages had from 1 to 50 engines.

In January 1897, the total number of gas engines at work in Great Britain was 25,700. Throughout France and Belgium

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*Although not specifically stated, these were probably nominal horse-power the figures for the principal towns and cities were Lyons 775, Bordeaux 296, Roubaix 250, Lisle 207, Rouen 95, Nice 88, Fourcain 85 and Toulouse 35. All these figures relate to engines which were driven by gas supplied by gas companies, that is, not worked by gas manufactured on the spot such as by the Dowson Process. Germany is listed as having made and sold a total of 32,000 gas engines.

9.3 Larger power gas engines

9.3.1 The use of gases other than town gas

An important factor in the development of large power gas engines which appeared during the last decade of the nineteenth century, was the use of what may generally be termed generator gas as an alternative to town gas. Although quite suited to use in engines, town gas proved expensive even at the 1885 gas prices of 1/8d per 1,000 cubic feet* when used in engines above thirty nominal horse-power employed on continuous running, the limit being determined by the cost of running a similarly powered steam engine. Above that power the steam engine proved more economical to run than the gas engine and, consequently, restricted the wider application of the latter. By the late 1880's this situation began to change : numerous methods of producing cheap gas became available which were continually improved to produce a better and cheaper gas for engines. So rapid

*Gas prices varied widely throughout the country. The price quoted above is for Manchester and Birmingham and is exceptionally cheap. An average and more general figure was 3/3d per 1,000 cubic feet

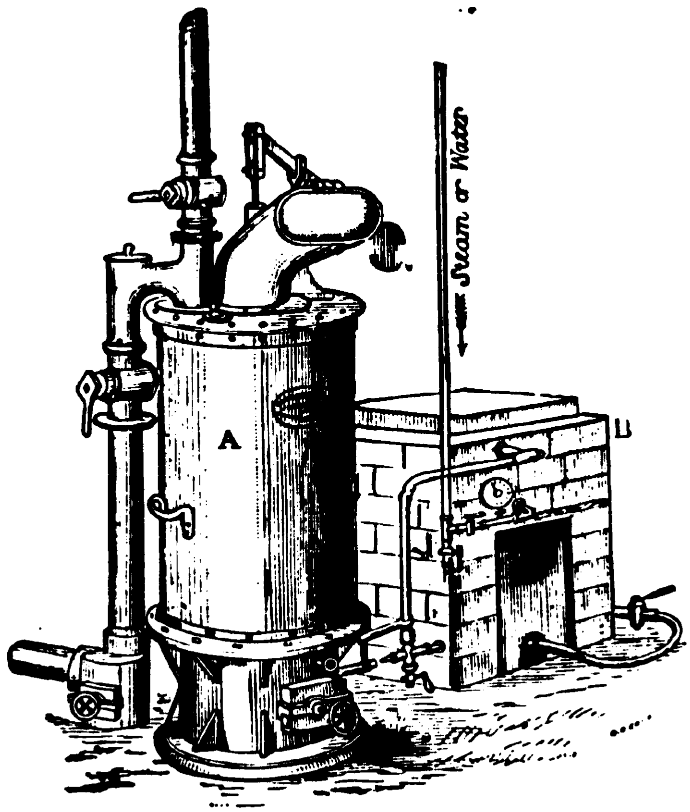

Fig 9.13 Dowson gas producer for engine sizes up to 25 nominal horse power. Recommended by Crossley Brothers. Sold with the engine as a complete unit

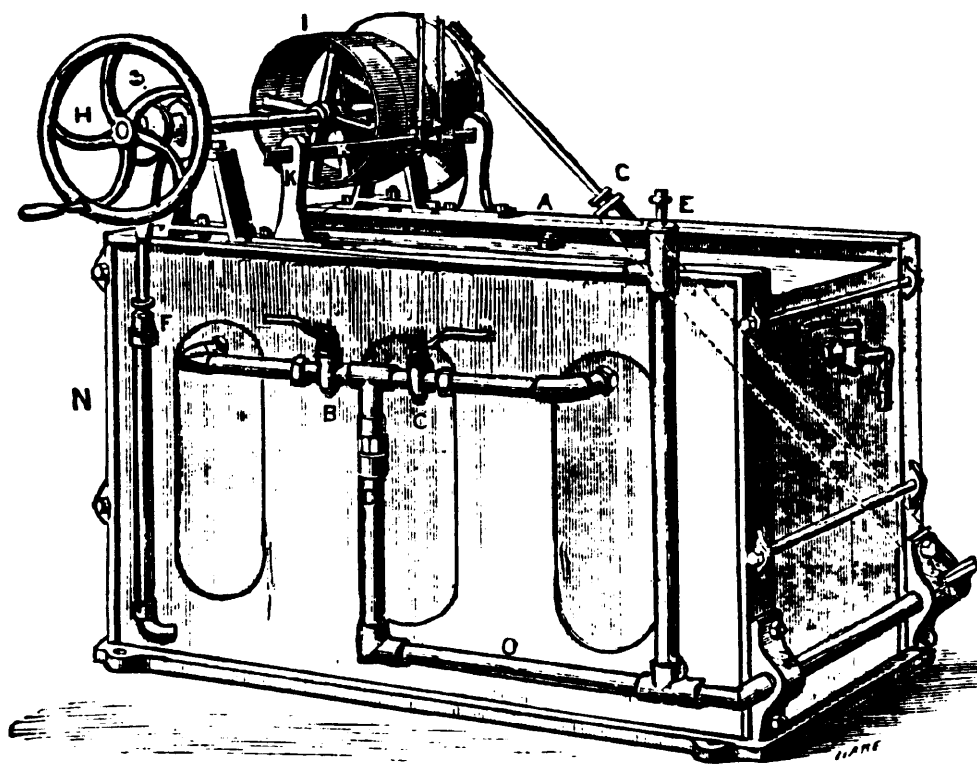

Fig 9.14 Petroleum vapour plant marketed by Crossley Brothers C1886. A $3\frac{1}{2}$ nominal horse power gas engine was used to drive it

was the development in this particular technology - more so on the Continent where coal was relatively expensive - that the larger manufacturers of gas engines offered gas generator sets to be used with their engines, together with precise details of running costs (see Figures 9.15 (a) and (b)).

The methods by which such gases could be produced had long been known. In the early part of the 1850's experiments were made in which air and steam were alternately blown through heated coals[25]. If air only is used, the combustible gas produced is mainly carbon monoxide - not entirely suitable for use in engines. When steam is blown through, a quantity of hydrogen is also produced, which is highly beneficial when added to the carbon monoxide previously formed. The disadvantage, however, is that the glowing coals are cooled by the steam and have to be revitalised by a further blast of air. This alternate application of air and steam was not totally satisfactory, since it produced a variable gas composition. The remedy used was to inject the air and steam simultaneously and this was the basis of all producers that were used with gas engines. The gas so produced was a little inferior to water gas - the name given when steam only was used, but it was suitable for use in engines and had the great advantage of being a continuous process. As well as its use in engines, generator gas was found suitable for heating purposes in almost every case in which coal gas was used, but since it had poor luminosity it was not used initially for illumination. At a later stage, generator gas was carburetted with oil vapour or naptha, which enabled it to burn with a luminous flame.

THE DOWSON ECONOMIC GAS.

Process of Making Gas.

This Gas is made rapidly by passing a small jet of superheated steam, mixed with air, through red-hot anthracite contained in the generator. There is no exterior fire, and the cost of repairs is trifling. The apparatus is simple and easy to work. To make 1,000 cubic feet only 15 lbs. of anthracite and about 7 pints of water converted into steam are required. The Gas is cleansed by passing through a washer and scrubber. For ordinary purposes no chemical purification is necessary.

No bituminous coal is suitable for this process, but with special precautions coke, and some kinds of lignite, can be used.

Cost of Gas.

The average cost of this gas, with fuel costing 12/- a ton, when made on a moderate scale, as in the apparatus shewn on front page, is about 2½d. per 1,000 cubic feet, including an allowance for the wages of attendant, repairs, &c.

About four times more of this gas than of ordinary lighting gas are required to develop the same heating power—the price of 2½d. should, therefore, be multiplied by 4, or say 10 *pence*, for the equivalent of 1,000 cubic feet of lighting gas, which usually costs 3s. to 4s. When made on a large scale the cost of the gas is much less, as the production of gas is greater, with about the same expenditure for wages, &c. For instance, with a large plant at the well-known Cocoa Works of Messrs. Van Houten & Son, in Holland, the certified cost of the equivalent of 1,000 cubic feet of lighting gas is *only 6½d.*, when made from coal costing about 16/- per ton.

Economy over Coal Fires.

The Architects of the Gloucester County Lunatic Asylum have reported that with the Dowson Gas System the coal consumption for heating water, cooking, &c., is about half that required for heating by coal fires. *(See "BUILDER," 16th June, 1883.)*

Economy for Motive Power.

Many users of the Dowson Gas, in connection with Gas Engines, have certified that the fuel consumption is under 1½ lbs. per indicated H.P. per hour. *(See Testimonials, pages 4—6.)*

Cleanliness.

This gas is free from tar, and cannot burn with a smoky flame. There is no deposition of soot, even when the object to be heated is placed over or in the flame.

Insurance.

The Insurance Offices treat this gas in the same way as ordinary lighting gas.

Guarantee.

The Company undertake to repair or replace any parts of the apparatus they sell, which may be broken or suffer from undue wear, within six months after the date of delivery, unless such breakage or wear is caused by careless or improper treatment.

SPECIAL COMPACT PLANT.

This consists of a Gas Generator, combined Steam Boiler and Superheater, Washer, and a combined Scrubber and Gas-holder with Wrought Iron Tank for same, and all necessary pipes and connections up to Outlet of Gas-holder. The whole occupies a height of about 14 ft. and a ground space of only 8 to 10 ft. × 10 ft., according to the size of Generator used.

When required a governing arrangement can be supplied, by means of which the production of gas can to a certain extent be regulated automatically, to suit a varying rate of consumption.

This Compact Plant is suitable for any Generator up to the K *size (producing* 6,000 *cubic ft. per hour), provided the rate of consumption is regular. If it is not regular, or if a larger Generator is required, the size of the Gasholder should be increased.*

ESTIMATES ARE GIVEN TO SUIT THE REQUIREMENTS OF EACH CASE.

Fig 9.15 (a) Circular issued by Crossley's C.1888

DOWSON ECONOMIC GAS.

AS A GENERAL RULE, IT MAY BE ASSUMED THAT
THE CAPITAL OUTLAY FOR THE DOWSON PLANT
WILL BE COVERED IN ONE TO THREE YEARS
BY THE ECONOMY EFFECTED OVER THE COST OF COAL GAS OR RAW FUEL.

Price List of the Special Compact Plant.

Size of Generator.	Maximum Rate of producing Gas per hour at 1½ in. pressure.		Size of Gas Engine suitable for		PRICE OF SPECIAL COMPACT PLANT COMPLETE.				EXTRA for Feed Pump for places where the water pressure is insufficient to feed the Boiler. (The pressure required is from 30 to 50 lbs. per square inch, according to size of Generator) £7.
	Cubic Feet.	Cubic Mètres.	H.P. nominal. (approx.)	H.P. indicated. (approx.)	On Rails at Lincoln.	F.O.B. Grimsby.	F.O.B. London.	F.O.B. Liverpool.	
A	800	23	4	7	£125	£128	£130	£129	
B	1,000	28	6	10	138	141	143	142	
C	1,200	34	8	13	150	153	155	154	
D	1,500	43	9	16	160	163	166	165	
E	2,000	57	12	22	170	174	176	175	
F	2,500	71	..	26	175	179	181	180	
G	3,000	85	14	30	180	184	187	185	
H	3,500	99	16	36	185	189	192	190	
J	4,800	136	20	45	195	200	203	201	
K	6,000	170	..	60	205	210	214	212	

When the Gas is to be used close to the Gas Plant, it is desirable to have Cooling Pipes on the outlet of the Gas-holder. The cost of these is £5 to £8, according to size of Pipes.

SPECIAL COMPACT PLANT.—This consists of a Gas Generator, combined Steam Boiler and Superheater, Washer, and a combined Scrubber and Gas-holder (6 ft. diam. × 6 ft. deep) with Wrought Iron Tank for same, and all necessary Pipes and connections up to outlet of Gas-holder. The whole occupies a height of about 14 ft., and a ground space of only 8 to 10 ft. × 10 ft., according to the size of Generator used.

When required a governing arrangement can be supplied, by means of which the production of gas can to a certain extent be regulated automatically, to suit a varying rate of consumption.

This Compact Plant is suitable for any Generator up to the K *size, provided the rate of consumption is regular. If it is not regular, or if a larger Generator is required, the size of the Gas-holder should be increased. Estimates are given to suit the requirements of each case.*

THE COST OF ERECTING THE SPECIAL COMPACT PLANT IS ABOUT £15.

EXPORT.—The extra cost of packing the Special Compact Plant for Export, is from £5 5s. to £7 per set, and the weight when packed is from 3½ to 5½ tons, according to the size. For places abroad where there is no representative of the Company, complete Working Drawings are sent for the erection of the Plant ordered, the parts are carefully marked for putting together, and full instructions are given for working the apparatus.

The DOWSON GAS is made by passing a mixture of steam and air through incandescent fuel. There is no external fire, as for ordinary gas retorts, and no skilled labour is required to work the apparatus.

The wages of Attendant, and the Repairs, are about the same for the Gas Plant as for a Steam Boiler of equal power.

GUARANTEE.—*The Company undertake to repair or replace any parts of the Apparatus they sell, which may be broken or suffer from undue wear, within six months after the date of delivery, unless such breakage or wear is caused by careless or improper treatment.*

THE DOWSON ECONOMIC GAS & POWER COMPANY, LIMITED,
Offices:—3, GREAT QUEEN STREET, WESTMINSTER, LONDON, S.W.

Fig 9.16 (b)

The most successful pioneer of cheap gas production in Great Britain was Joseph Emerson Dowson[26] (1884-1940) whose ideas in 1878-79 were an improvement on the first notable methods used in 1860-61 by William Siemens, the only other notable attempt in Great Britain* being the Wilson producer which appeared about the same time as Dowson's[27]. The Dowson gas plant generator became widely used in Great Britain and succeeded also in Continental countries in spite of numerous other possible alternatives. Apart from its great advantage in being able to supply cheap gas - approximately 2½d per 1,000 cubic feet[28], (Figure 9.15 and 9.16) the Dowson plant was extremely compact. In 1888, the available range of Dowson gas plants is shown in Figure 9.14, the limit then being 6,000 cubic feet of gas production. A decade later, the size available had increased to one capable of supplying 20,000 cubic feet to engines of fifty nominal horse-power.

The disadvantages of Dowson gas were that it required anthracite or other expensive coals; it contained approximately 25% by volume of poisonous carbon monoxide; its heating value was only one-quarter that of coal gas and it could not be used for the ignition flame in slide valve engines. It was, however, quite suitable for heating the tubes on tube ignition engines. In addition, the combustion properties of Dowson gas were somewhat more difficult to deal with, since it had a much slower flame speed and required less air than coal gas. The latter problem was overcome by increasing the size of the gas passages or by restricting the air

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* This is in contrast to development on the Continent where several schemes were being considered

supply. To compensate for the slow flame speed a higher compression ratio than that used with coal gas was required.

Table of comparison - coal gas and Dowson gas[29]

	Coal gas		Dowson gas	
	% Vol at 0°C and 760 mm	Heat energy released per 100 litres (CHU)	% Vol at 0°C and 760 mm	Heat energy released per 100 litres (CHU)
Hydrogen H_2	51.81	159 559	18.73	57 689
Methane CH_4	35.25	329 167	0.31	2 899
Olefiant gas CH_4	3.53	52 664	0.31	4 633
Carbon monoxide CO	8.95	27 854	25.07	77 992
Carbon dioxide CO_2		-	6.57	
Oxygen O_2	0.03	-	0.03	
Nitrogen N_2	0.38	-	48.98	
	100.00	569 264	100.00	143 213

The fuel used to make Dowson gas was mainly anthracite, but good quality gas coke could be used. The bituminous coals, normally used for producing illuminating gas were not suitable since the by-products (tar and bitumen) were particularly troublesome to deal with. With anthracite, depending on the region from which it originated, the average coal consumption per indicated horse-power per hour, was approximately 1.51 lb. When coke was used the consumption, as stated by the Crossley Bros., was less than 2 lb per indicated horse-power per hour and with coke at 7/6d per ton, the cost of producing the gas for the engine was less than 0.08d per indicated horse-power per hour[30].

As the low cost advantage of Dowson gas became generally appreciated, many tests were carried out to determine overall plant operating costs for medium and large installations. Notable of these were those carried out at the Paris Exhibition of 1890 by Professor Aimie Witz on a Simplex engine from France and at the Severn Tweed Mills at Newton, where two trials extending over six days were made on four Crossley engines indicating 250 horse-power. J.E. Dowson himself made a thorough test on a Crossley-Otto of nearly 120 indicated horse-power at Messrs Mead and Co., Flour Mills, Chelsea[31]. In none of these tests (and the many others that are listed in the reference quoted above) was the coal or coke consumption greater than 2 lb per brake horse-power and was often much less. During the latter half of the 1890's, Messrs Crossley Bros. ran the whole of their engines at the works in Openshaw - totalling 500 horse-power - on Dowson gas.

Two of the most informative and well-conducted tests performed on engines using Dowson gas were carried out in 1895 and 1896. The first was at a mountain railway in Zurich where two fifty nominal horse-power Crossley-Otto engines were used to drive generators supplying electrical current for the railway[32]. The second conducted by Professor Meyer, who was considered a leading authority at the time on the subject of such gases, was at the Basle Water Works, Switzerland where a 160 brake horse-power Deutz-Otto engine was installed[33]. In both tests, a complete analysis of the gas produced was made, coal and coke consumption was carefully monitored and performance details of the engines over many hours running were taken. Experiments were also carried out to minimise the variations in composition of the gas produced by varying the temperature at which the generator operated. The main purpose of the second test was to show that coke, which was cheap and easily obtained from gas works, could be used to produce a gas which was satisfactory for use. The conclusions that were made confirmed that there was every possibility of this being done.

Dowson gas power plants working in England up to the end of 1897 included - one of 950 indicated horse-power at Blackpool, twenty-four others ranging from 200 to 870 indicated horse-power and thirty-eight from 10 to 45 indicated horse-power[34]. A similar picture emerged from France. Twenty-four Dowson gas plants were in use at the beginning of 1896 used mainly for the production of electric light. Of these twenty-four, there were eight stations with a total of 386 indicated horse-power and sixteen stations with a total of 1622 indicated horse-power.

9.3.2 <u>Suction gas producers and blast furnace gas</u>

Instead of forcing the air through the incandescent fuel as in the Dowson process, the piston of the engine could be made to suck it through during its induction stroke. This was the basis of suction gas plants which many of the larger engine builders such as Crossleys, Tangyes and Deutz made available to industry. To remove the particles of grit and ash that would inevitably be drawn into the engine, filters were fitted, but no attempt at washing or scrubbing the gas was made whatsoever.

Blast furnace gas, as the name implies, was a product of the iron producing process and a pioneer in the use of such gas to run engines was an Englishman B.H. Thwaite. The process, of course, was precisely that of the Dowson gas generator. The air blast was forced through the incandescent coke, iron ore and limestone used in the iron-making process and, in doing so, produced a gas which was rich in carbon monoxide. Previous to its consideration for engines, the gas was used for heating purposes in other areas of the iron-producing plant and in producing steam for the steam engines to drive the blowers. The increase in size and number of blast furnaces meant that sufficient quantities of 'high furnace gas' as it was sometimes called, were being produced and, consequently, thoughts were given to using it for motive power.

The economical advantages resulting from the use of high furnace gases were proved beyond question[35], with the leading authorities on the subject, both on the Continent and in Britain* being in total agreement. Most significant was the realisation that it now became possible to run engines of extremely high powers. Engines of 1,200 and 1,500 indicated horse-power being considered. The sudden discovery, that 'waste gases' could be used for such purposes, gave new impetus both to the engine technology and to gas-producing methods. The first recorded use of such gases appears to be in England when B.H. Thwaite worked a Burt-Acme engine of thirty horse-power at Wishaw Iron Works, Glasgow in 1895[36]. The engine was used to provide electric light for the works. A few other isolated instances of the use in Great Britain of high furnace gases can be found, but on nothing like the scale used on the Continent where its use began at about the

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* The extent to which high furnace gases were used in Britain was considered to lag behind that on the Continent

same time. Many of the well known engine builders there, such as Simplex, Cockerill, Öechehaueser, GDF and Körting began serious experiments, which were conducted by the eminent men of gas engines, such as Meyer and Witz.

Although by 1899 the use of blast furnace gas to drive large engines was considered still to be in its infancy, the trials and practical applications that, up to then, had been made, had proved entirely acceptable. Optimism for extending the power and use of such engines for the iron-making and other industries which produced such gases was high. Many major gas engine firms in England, such as Crossleys, National Gas Engine Co. and Tangyes responded. Bryan Donkin, who made a study of the systems used on the Continent summarised the situation in 1899 as follows[37]:

> 'Most of them have dynamos on the crankshaft generating electricity for power and light, at different and distant parts of the iron works ..... The gases must be drawn continuously from the top of the furnace and forced through the scrubbers with the holders and, for this purpose, various methods have been adopted - steam jets, fans, air propellor, pumps etc. ..... Hitherto, the blowing engines have nearly always been driven by steam and they are large and costly. If the best use is to be made of waste furnace gases they should be burnt in gas engines driving the air compressors and pumps direct as is done at Seraing (Cockerill's Works). Such an arrangement will be much more economical than the present slow-running steam engines with their cumbersome beams and cranks, their boilers to keep in order, the condensing water required and all the usual long steam pipes, causing loss of heat by condensation and a poor heat efficiency ......'

9.3.3 Mond Gas

It has been mentioned earlier in this chapter, section 9.3.1 that the Dowson gas production process possessed a disadvantage in that it required for its manufacture, anthracite or other expensive coals. For engine sizes up to 100 horse-power (indicated) the operating costs of a Dowson plant were found to be acceptable, but for the sizes of engines likely to be needed in central generating stations, the initial high cost of this fuel made the installations commercially uneconomical. In 1879 Dr. Ludwig Mond (1844-1940)[38] a German chemist who became a naturalised Englishman, began experiments to produce a suitable gas cheaply. By about 1900, when very large gas engines began to appear, an increasing interest was taken in Mond gas.

The main difference between this and other gases was that it used cheap bituminous coal, or slack: much larger quantities of steam were used, which gave the gas a richer hydrogen content (and thus higher calorific value) and further, the ammonia produced was largely recovered, making the whole process quite a profitable one. Mond carried out his later experiments at the firms of Messrs Brunner, Mond and Co. Winnington, Cheshire where a 400 horse-power Crossley engine - the largest that Crossleys had then made - was installed to generate electricity* for an electroplating plant[39].

It is clear from the enormous amount of discussion related to the subject of Mond gas and large gas engines (reference 38) that it was receiving the most earnest attention. As

*The dynamo (directly coupled) was made by Mather and Platt of Salford and delivered 2,250 amps at 110 volts well as test details of the 400 horse-power Premier gas engine at Winnington, (which was tested while running on Mond gas) details of many Continental and American installations are given, including an estimate for running a central generating station of 20,000 horse-power. Cost comparisons of steam and gas power operated plants are given and on all counts the latter comes out more favourably. At that particular time, therefore, the future of the gas engine as a major prime mover was assured; it is also clear from the discussion referred to earlier, that it was the beginning of the end of the era of the steam engine. By the year 1920, single unit engines of 2,000 brake horse-power were commonplace in Great Britain and one installation put down in 1916 consisted of seven 1,500, two 1,000 and two 750 brake horse-power engines, a total of 14,000 brake horse-power running on Mond gas[40].

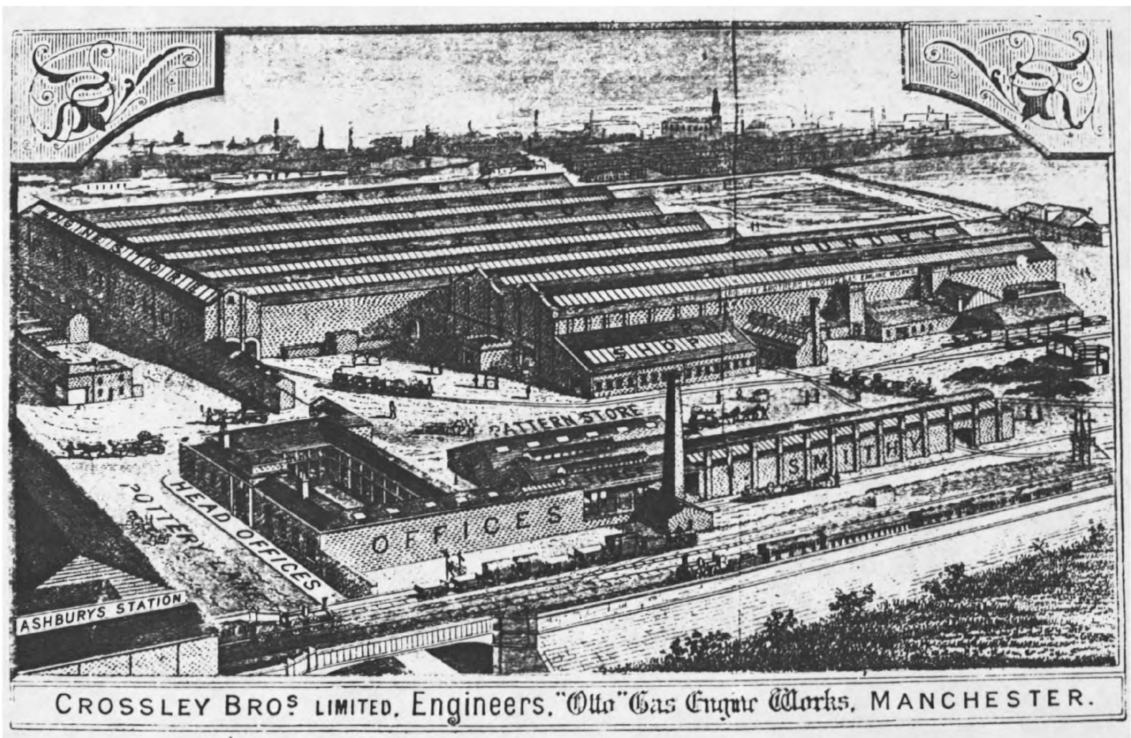

Fig. 9.17
The Crossley Brothers Works, Pottery Lane, Openshaw in 1884.

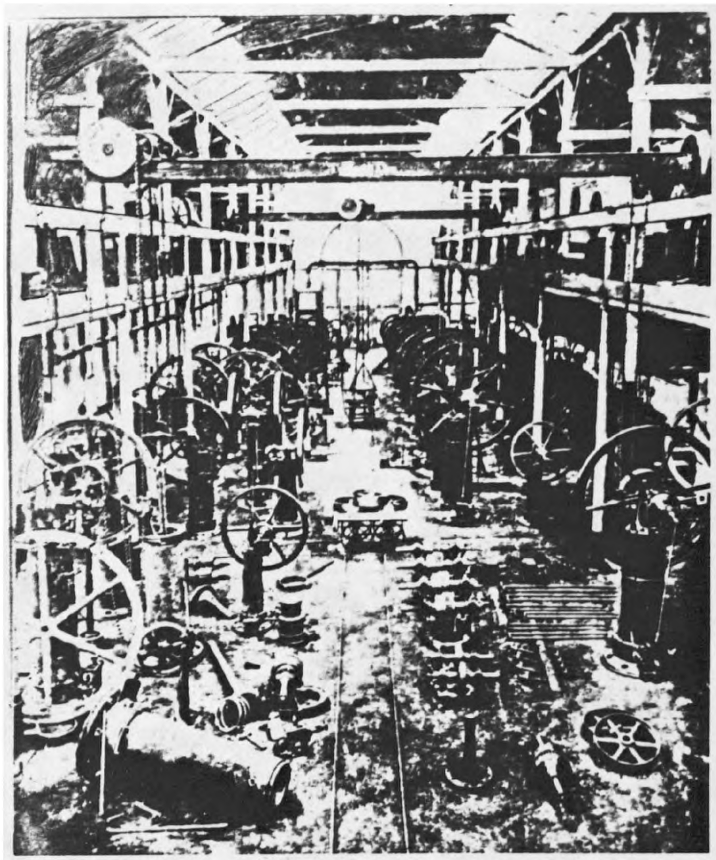

Fig 9.18 Assembly shop, Gasmotoren Fabrik, Deutz 1875

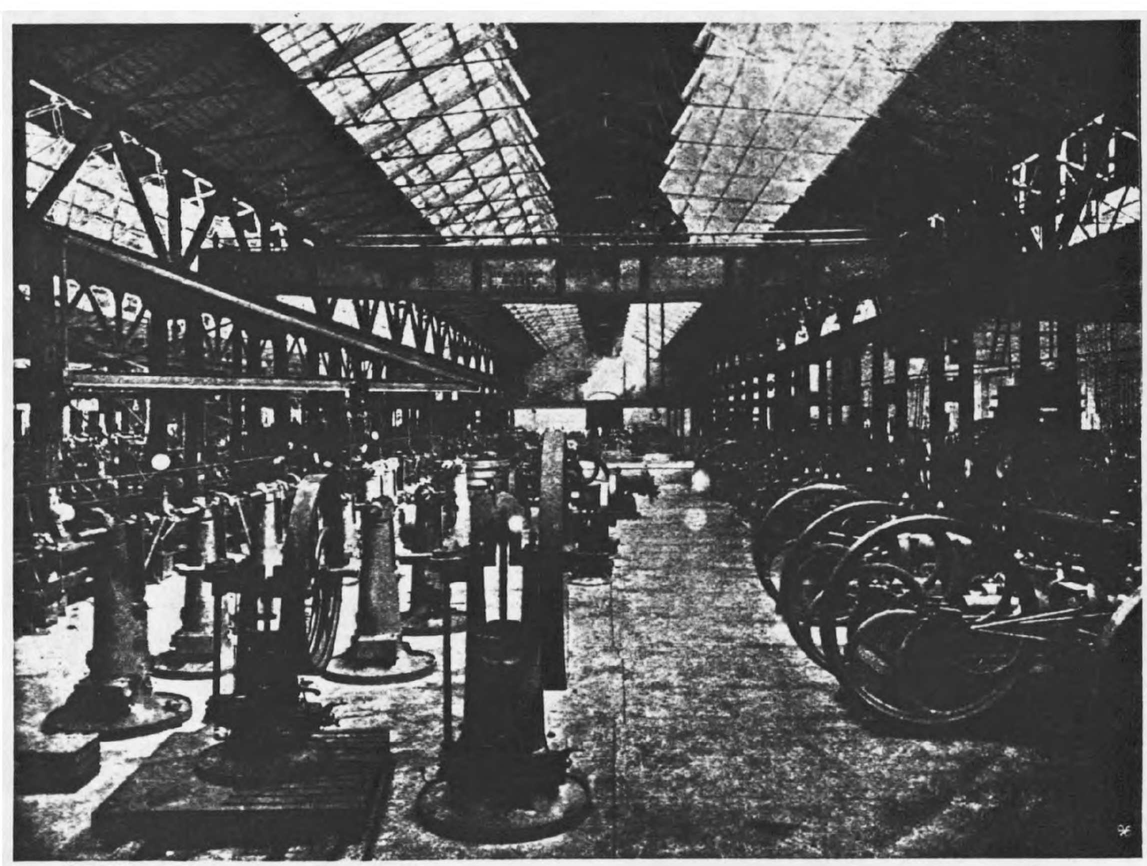

Fig 9.19 Assembly shop, Crossley Brothers, Manchester C1886

Fig 9.20 View of Foundry, Crossley Brothers, Manchester, C1886

Fig 9.21 Planing and drilling shop, Crossley Brothers, Manchester, C1886

Fig 9.22 Francis William Crossley (1839-97)

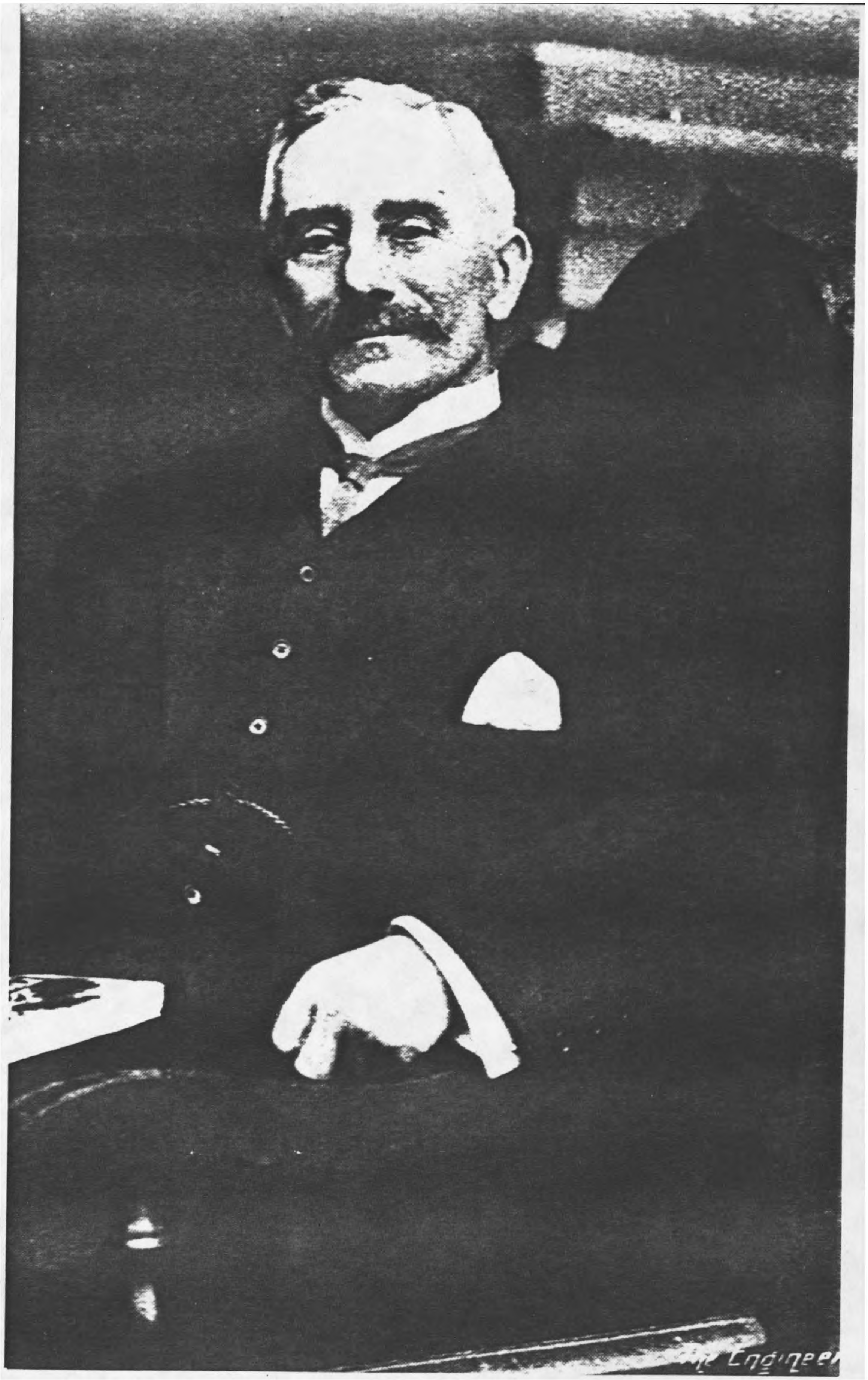

Fig 9.23 Sir William John Crossley (1844-1911)

References - Chapter Nine

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2. Technical Appendix Three, page 2 of 'Engineers' Tools' section

3. Ibid

4. Ibid

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6. The testimonial supplied by the 'Steam Cabinet Works' Birmingham Vol. 2 op cit (2)

7. Crossley-Premiuer op cit (1) under the section entitled 'Local Boards and other Public Bodies' dated c.1887

8. B. Donkin Gas, Oil and Air Engines (London 1900) p.421

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15. Technical Appendix op cit (2) The list given by Crossley Bros. does not include applications for electroplating and for experimental work requiring electricity supply.

16. Friederick Sass, Die Geschicte des deutscher Verbrennungs-motorenbaues von 1860 bis 1918 (Berlin 1962) p.71

17. J.E. Dowson 'Gas power for electric lighting' Proc. Inst. Civil Engineers (Vol. CXII) 1892-93 pt II pp.2-11. This paper by Dowson and the accompanying discussion is most informative as regards the ideas and problems associated with the use of gas engines for

producing electric power. For a brief summary of Dowson's paper, see Donkin op cit (8) pp.91 and 240

18. Dowson op cit (17) p.36

19. Donkin op cit (8) p.103

20. William Norris A Practical Treatise on the Otto Cycle Gas Engine (London 1896) p.248

21. Technical Appendix op cit (2)

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24. Donkin op cit (8) Appendix p.484

25. F.J. Rowan 'Gas Producers' Proc. Inst. Civil Engineers Vol LXXXIV (1886) p.2

26. Papers by J.E. Dowson on the subject of generator gas include: 'On the Production and Uses of Gas for Heating and Motive Power' Journal of Society of Arts 22 Feb. 1882 'Cheap Gas for Motive Power' Proc. Inst. Civil Engineers pt.III p.311 'Gas Power compared with Steam Power' Proc. Inst. Civil Engineers Vol LXXXIX pt. III

27. William Robinson Gas and Petroleum Engines (London 1896) p.375

28. Ibid p.385

29. Ibid

30. Ibid p.390

31. Donkin op cit (8) p.174 and Appendix A p.454 See also Dowson op cit (17) pp.11-17 pp.27-43 The latter includes tests of the engines installed at Messrs Mead and Son Chelsea; The Severn Tunnel Co; Spicer's Paper Mills at Godalming; a number of foreign installations in France and Germany; Crossley's works at Openshaw and the engines used at Morecambe.

32. A brief account of the Zurich test is given in Donkin op cit (8) pp.174-175. A full account is given in Zeitschrift des Vereines ... Band 39 (1895)

33. Donkin op cit (8) p.175

34. Ibid Appendix F p.484

35. Ibid pp.198-218

36. Ibid p.209

37. Ibid p.216 See also Appendix A p.456 for details of engine tests using furnace gases

38. Herbert A Humphrey 'Power Gas and Large Gas Engines for Central Stations' _Proc. Inst. Mechanical Engineers_ Vol. I (1901) pp.41-247 p.51

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40. _National Gas Engines for Large Powers_ p.80 A Handbook issued by the National Gas Engine Co. c.1920. Archives North Western Museum of Science and Industry, Manchester For examples of earlier Continental practice see Percy R. Allen 'Recent Developments in Large Gas Engine Design'

CHAPTER TEN

A RESUMÉ

10.1 Phases in development

It is the intention in this chapter to survey the period 1791-1900 as a whole and, in so doing, to identify and describe significant events and certain phases, or patterns in development that have been shown to exist. Also examined, is the possibility of inter-acting influences between the individuals concerned with regard to their ideas. These patterns, referred to above, were often of a haphazard nature in that, while exhibiting a particular trend, there would often appear what, at first sight, seemed to be an abrupt change of general thought. On closer investigation, however, many of these apparent diversions proved to be the work of inventors whose ideas were ahead of the material and other technologies of the time. Several years were to elapse before their ideas became usable.

10.1.1 The period 1791-1860

Although it produced no singularly successful engine, the experimental period was an essential component of the later and more obvious achievements that occurred with engines. It is best described as the apprenticeship of engine making during which trial, error, exploration and learning all took place. Virtually every possible idea with regard to design, mode of operation and fuel was tried during this period. The first recognisable phase within this time is that to c.1830, distinguishable because efforts to produce gas engines up to that time were generally concentrated on producing a vacuum followed by the utilisation of atmospheric pressure to produce the working stroke. With this in mind four men - Rivaz, Cecil, Brown and Morey all had the same idea. Brown produced the world's first gas engine which was applied to industrial use, but Rivaz was the first, in 1807 with a working and more sophisticated application of Street's idea of 1794. The designs of these gas engines - a beam with cylinder at each end - were obvious copies of steam engine practice at that time, but the gas engines of the 1820's by Cecil, Brown and Morey show many ingenious devices related to the gas and air admission and means used for ignition.

Despite the great similarity in working principle (and even design) of the engines by Cecil, Brown and Morey there is no evidence to show that anyone of them were aware of the work of the other two, or, for that matter, of Rivaz. They quite probably were - a good deal of publicity and correspondence resulted from Cecil's demonstrations of his engine in 1820 and the whole country became aware of Brown's attempts in 1824. Situations such as this, in which the ideas of one individual are reflected in those of another, can be seen throughout the whole period under review, the Otto-Beau de Rochas and Otto-Barsanti and Matteucci connections being just two other outstanding examples.

The enthusiasm for motive power using inflammable fuels during the 1820's (and, indeed, prior to that date) was very great. No doubt an influential factor here was the developments in the gas industry. Gas production techniques were in their infancy at that time; its quality and cost left much to be desired, but expectations for its future were high. At the time of Brown, however, the optimism with regard to the use of coal gas was perhaps a little premature. This may well explain why attempts were made by Davy, Faraday and Brunel to use carbon dioxide in the late 1820's and why Brown attempted to make his own gas.

In technological terms, a second phase beginning in the 1830's was more eventful. The beam disappeared and gas engine designs then included a connecting rod, crankshaft and flywheel as shown in the arrangements suggested by Wright in 1833 and by Barnett in 1838. Conical seated valves, operated by either suction or pressure, as required were used. In contrast to the former ideas involving vacuum, suggestions were made that the pressure considered necessary to produce the driving force on the piston, should be obtained directly from the explosion or combustion of the fuel. Compression of the charge within the working cylinder was hinted at by Wright, who also foresaw the need for cylinder cooling and speed regulation. Barnett, on the other hand, made positive suggestions with regard to compression and devised a flame ingnition system that was sound in principle and used thirty years later by Hugon and later still by Otto. The cumulative effect of these worthwhile ideas meant that substantial progress had been made with regard to producing a commercially successful engine. If one looks for the foundation of modern engine technology, then it is the 1830's and the ideas of Wright and Barnett that it can be found.

With promising proposals of this nature, it would have seemed but a short step to achieving a working engine that was economically viable. This failed to happen, however, until a further thirty years had elapsed. In fact, the contributions by Wright and Barnett were the last of any significance to be made in Great Britain. Subsequent developments and progress came next from Drake of America, who produced the first working horizontal engine in 1843 operating on the non-compression cycle and, later from Italy, followed by France. The contributions by each of these three countries, although coming surprisingly close to a design and mode of operation that later became successful, were really an adaptation of the ideas of Wright and Barnett. The performance of the American engines, however, was disappointing and a great deal of time and energy was given then and indeed to well into the 1860's in trying to make the non-compression cycle acceptable in performance, as well as in economy. These attempts were never totally successful* and the difficulties that were experienced, almost certainly influenced the Italians, Barsanti and Matteucci in their decisions to revive the vacuum and the atmospheric idea once more, first put into working form by Rivaz in 1807. Their vertical engine was a departure from the general ideas of the time and thus an example of the diversions referred to earlier. It failed to reach the production stage (perhaps for reasons concerned more with personal misfortune rather than technical deficiency), but the basic idea was sound, being revived once again by Otto in 1866, this time with outstanding success.

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* The reasons being discussed in Chapter Three

10.1.2 The period 1860-1876

The distinctive features of this second pattern of development which began with the Lenoir engine of 1860, was an earnest desire to utilise the direct force of the expanding gases to propel the piston on its working stroke, which involved the non-compression constant volume cycle of operation. It may be recalled from chapter four, that in the closing stages of 1850's numerous suggestions were made as to how this may be done. Lenoir's engine, in addition to making use of these suggestions, embodied the best of all the ideas that, up to then, had been tried. It worked better than any previous engine that had attempted to use the same non-compression cycle and the main reason for this was the excellent workmanship in manufacture and assembly given to it by the builder, M. Marinoni of Paris. In so doing, many defects in running that had resulted from bad workmanship with previous engines, were eliminated. The basic problems associated with the efficient and smooth working of gas engines, thus became exposed. Unfortunately, these problems, mostly concerned with ignition and explosion shock, were not easily overcome and the failure to do so gave rise to feelings of disillusionment, when it seemed that the gas engine was unlikely to live up to its early promises.

The French involvement and contribution during the 1860's was particularly notable. Pierre Hugon of Paris produced his vertical engine in 1863 and because it used a flame method of ignition, was an improvement on the troublesome ignition used by Lenoir. Two years later, Hugon produced a horizontal engine, the working cycle in all of these engines being identical. It may be recalled also, that Otto, in his early experiments, made a model of the Lenoir engine and also attempted to use the same cycle.

Such, therefore, were the engines in use for six or seven years beginning in 1860. In spite of their defects they began to make inroads as a servant to industry and had not yet another of those abrupt changes appeared - this time in the shape of the Otto and Langen atmospheric engine - would probably have made a more substantial impression than they did. The timing of the introduction of the German atmospheric engine was unfortunate for Lenoir and Hugon. The difficulties that the latter were experiencing in the running of their engines had come to a head and dissatisfaction with regard to their working was becoming ever more widespread. The unbelievable gas consumption of the Otto-Langen engine - about one-third that of the Lenoir - was the basis of its success. All engines operating on cycles other than the atmospheric principle were thus driven off the market.

The Otto-Langen engine enjoyed nearly ten years of success during which time slightly less than five thousand were sold throughout the World. In pausing to reflect upon the significance of this engine, it is seen to have had both a beneficial and a detrimental effect on future developments with regard to engines. The former is concerned with its undoubted ability in providing industry with power, amply discussed in chapter five. But the latter is concerned with the possible effect that the success of this engine had upon discussions that began in 1862 regarding the potential advantages of compression. At that time, Beau de Rochas and

Street	1794	Non-compression explosion engine, followed by vacuum which produced the working stroke
Lebon	1801	Constant pressure combustion engine
Rivaz	1807	Non-compression explosion engine, followed by vacuum which produced the working stroke
Cecil	1820	ditto
Brown	1824	A vacuum engine but no explosion
Morrey	1826	Non-compression explosion mixture followed by vacuum which produced the working stroke
Wright	1833	Non-compression explosion engine. Explosion stroke was the working stroke
Barnett	1838	ditto
Drake	1843/55	ditto
Perry	1846	ditto
Barsanti & Matteucci	1857	Non-compression explosion engine, followed by vacuum which produced the working stroke
Lenoir	1860	Non-compression explosion engine, Explosion stroke the working stroke
Beau de Rochas	1862	Suggested the four-stroke engine
Hugon´	1863	Non-compression explosion engine Explosion stroke the working stroke
Otto and Langen	1867	Non-compression explosion engine
Otto	1876	Four-stroke compression engine

Figure 10.1 Names, dates and type of engine proposed 1794-1876

Million of France, Schmidt of Germany and Siemens of England had all voiced their favourable opinions for its use. The journals of the day gave their opinions a good airing and much discussion took place*, but the outstanding success of the Otto-Langen quite overshadowed the debate on compression that was taking place and nothing further was done to put these newly invented ideas into a practical form.

10.2 Significant events 1876 - 1900

10.2.1 The four-stroke engine

The last quarter of the nineteenth century was a period of intense activity in the field of engine technology. It began with the almost apologetic introduction by Otto of his four-stroke engine in 1876, but such was the momentum of its progress that by 1900, it had become well and truly established as a leading prime mover for industry. The year 1876, therefore, was the beginning of an irreversible reaction which has continued to the present day.

Two intriguing aspects accompanied its introduction. One, to some extent an academic issue, is whether or not Otto was aware of Beau de Rochas' ideas on compression and a working cycle, put forward in 1862. The other concerns the erroneous theories on which the four-stroke engine was believed to work. It seems unlikely now that a satisfactory explanation will ever be found to the first point. No reference to Beau de Rochas can be found in any of Otto's work; he never mentions him in any of the patent trials or in letters which he (Otto) wrote and yet never, at any time,

*At the time Beau de Rochas' thoughts were buried in an obscure pamphlet and appear not to have been heeded did Otto state that he was aware or otherwise, of Beau de Rochas tract of 1862. When all speculation on this is put aside, however, the fact remains that it was Otto who put the 'paper engine' of Beau de Rochas into a practical and successful form.

The second aspect relating to the mistaken theories and beliefs that were put forward to explain how its four-stroke engine worked, had a pronounced effect on both immediate and later engine developments that took place. No one was quite sure how it actually did work, including Otto himself and from these uncertainties, a theory of stratification evolved which was held to be the reason for its smooth, silent and shock-free performance. It was a plausible theory and in the absence of any scientific evidence to counteract it, convincing. It held for something like five years before its weaknesses were exposed, but in the meantime greatly influenced by the ideas of Otto and of the Crossley Brothers with regard to engine details such as valve timing, methods of gas and air admission, design of combustion chambers and exhaust gas retention.

The inability to effectively explain how Otto's new engine worked gave rise to some confusion when Otto, in the explanations that he offered, kept changing his mind. On the one hand, he would be propagating his opinions of how combustion occurred according to his first patent, that is, gradually as a result of admitting first air followed by air and gas in increasing richness. But then in a later patent mentioned a homogenous arrangement which is suggested gives a more rapid combustion. To add to this confused situation are the results of the author's investigations of Otto's original experimental engine. These show that although some attempt was made to achieve the method of admission referred to by Otto, the mechanical arrangement of the slide valve, parts and governor control cannot be considered to reflect entirely his ideas related to combustion. A possible explanation for these inconsistencies is that since Otto was engaged almost continually in patent battles of one kind or another, he was bound to adhere to his original claims made in the 1876 patent of which no doubt he was aware, were not easily disproved.

10.2.2 Progress from uncertainty

In spite of all the false notions that accompanied the appearance of the first four-stroke engine, it became a notable success. Indeed, it was largely from a desire to either prove or disprove the conflicting theories with regard to its working that scientific interest was aroused during the 1880's. At first, experiments were carried out using closed vessels in which various dilutions of gas and air were ignited, the maximum pressure in each case being recorded. These simple experiments were followed by others in which the pressure of the inflammable mixture had previously been raised. Attempts were also made to assess the form of heat dissipation within the cylinder, these ultimately led to an appreciation of the need to reduce the surface area that was exposed to the burning gases - a factor which was slow in gaining acceptance. Gradually, the value of compression emerged and acknowledgement was made that compression was the basis of the successful Otto four-stroke engine. There is no denying that, as a result of this experimentation, some quite valuable progress in understanding was made of the fundamental principles underlying the operation of a gas engine. It does appear, however, from the Report of the Gas Engine Research Committee in 1898, that this experimentation was hampered by a lack of suitable instruments and a good deal of it was not done on engines at all, but on simulations of the working cylinder arrangement. The cumulative effect of this work meant that by the early part of the 1890's the requirements necessary for an economical and efficient engine had come to be broadly appreciated.

Another and quite significant feature of the 1880's was the effect the Otto patent had upon efforts that were made to produce other working cycles. Michael Faraday once remarked that more was learned from mistakes than from success, and this would seem to be true in the case of gas engines. The vast amount of exploratory work that was done to produce an internal combustion engine that would give a firing stroke every revolution although largely negative, was extremely valuable. It caused attention to be concentrated on the parameters involved in engine performance; the nett effect of this work was that limitations on design were appreciated and probably most significant of all, the absolute supremacy of the four-stroke cycle of working became appreciated. The latter was the reason why, with what Dugald Clerk referred to as 'wonderful unanimity', those that had been involved in the search for something better, abandoned their attempts and reaped the fruits of their former labours by making four-stroke cycle engines.

The mechanical improvements that appeared are another feature of the late 1880's and early 1890's. The replacement of the slide valve and flame ignition method in 1888 by the tube ignition, the most notable. They had the immediate effect of allowing compression ratios to be raised with a consequent improved economy and thermal efficiency. This in turn meant that shapes and designs of combustion chambers were examined to determine the most desirable form. The cross-head and slide was dispensed with and bevel gears used to drive the side shaft were replaced with worm gearing. Another important feature at this time was found to be desirable for engines of twenty horse-power and to avoid accidents absolutely necessary on engines of higher powers.

A summary of the significant events related to gas engines during the last quarter of the nineteenth century would be incomplete without reference to their contribution to industry as a form of prime mover. The results of this investigation has shown this to be far more extensive than has formerly been believed. By the year 1900, Crossleys alone had manufactured and sold more than 40,000 engines since 1876 representing an aggregate of nearly 549,000 indicated horse-power. No figures to show the contribution of other manufacturers are available, but bearing in mind the rapidly increasing engine power sizes that became available during the 1890's, the horse-power figure just quoted could easily have been doubled. Of the various uses such as driving machine tools, woodworking, printing, textile, pumping and agricultural machinery, etc. probably the most oustanding was its union with electrical machinery. The advantages of this merger, which again appears to be one that has been entirely unappreciated, cannot be over-estimated. The gas engine itself derived great technical benefits as a result of this combination and so also did the electric dynamo machines. At first, electric lighting was used on a domestic scale; it was then quite soon adopted for lighting public buildings and theatres. This was followed by the setting up of Central Generating Stations; as engine sizes increased cheaper gas became available and improvements took place with generators.

The installations of Central Stations in Great Britain has been shown to have lagged behind that of the other industrial nations, principally America and the Continent of Europe. The reasons for this are not easily explained. The requirements for such stations were basically a supply of cheap gas, large engines of 500 horse-power and over, and a far-sighted policy which would have encouraged engineers to pursue the idea. The situation in both Great Britain and the Continent with regard to the first requirement, was quite promising. The Dowson process began in Britain followed by the Mond process which, again, began in Britain and about the same time the Thwaite process using blast furnace gas was used; once more in Britain. The use of these processes, however, became more widespread in other countries and only when they had proved their usefulness, were they adapted more widely in Great Britain. By that time, several years' experience had been gained by the countries that had been using them. This general reluctance to embark upon similar schemes in Great Britain, to some extent, is explained by the second and third requirements, previously mentioned. Engines of 500 horse-power and over were not generally available in Great Britain until about the turn of the century. Manufacturers appear to have been extremely cautious on this point. One reason was that they felt the difficulties associated with running very large engines - efficient cooling of the piston, pre-ignition, combustion chamber design and valve positioning - had not been satisfactorily overcome. Their caution was commendable, but in the main unacceptable, since very high power engines were already in use in America and on the Continent.

10.3 To Dr. N.A. Otto - tribute

The present day forms of the internal combustion engine are the result of the labours of many men - Langen, Reuleaux, Otto, Lenoir, Daimler, Maybach and Benz being just a few of those, whose pioneering efforts paved the way for later advances. At first, internal combustion engines were more wasteful of heat than the steam engine, more delicate and troublesome in the extreme and only available in small and trifling powers. In contrast, by the 1890's it had become four times more economical than its steam rival and firmly established as a safe and reliable prime mover. This commanding position which the gas engine enjoyed at the turn of the century, was due to the patience, energy and extraordinary inventive talent of Nicolaus August Otto. Prior to his invention of a working four-stroke engine, using compression, the thermal efficiency of engines of the Lenoir and Hugon type was less than five per cent with a power limit of about three horse-power. Otto's engine of 1876 raised this instantly to eight horse-power and shortly afterwards to sixteen. The thermal efficiency was raised also to fifteen per cent.

Otto devoted more than half of his life to work on engines and even in his final years his creative and ever-fertile mind was actively engaged on improvements in design. Had Otto not created the four-stroke engine, doubtless someone else would, but the distinguishing feature of Otto's sensitive nature - and one that merges constantly as one studies his work - was his staying power; a will that refused to be deflected from the task in hand. Many other workers, it may be recalled, having a germ of an idea, abandoned further attempts when difficulties were encountered. Professor Adolf Slaby of Berlin, whom Otto regarded as a great friend, remarked in his Obituary address about the numerous experiments and sketches that Otto had communicated to him:

> 'It is impossible to contemplate this collection of rejected engines without being made to realise anew that genius takes wings to leap over great gulfs but that lasting success may only follow after, over the bridges painfully and solidly built by hard work.'

The Faculty of Philosophy of the University of Würtemburg in recognition of Otto's work, awarded him an honorary doctorate with the citation:

> 'To that inventive and highly intelligent man, Nicholaus August Otto, who distinguished himself by inventing an engine which bears his name and which is of great assistance to industry.'

In acknowledging the honour, Otto replied:

'In long years of work and study, I have, it is true, attained great successes in the construction of gas engines, yet I believe there are others, worthier than I to receive such an exalted distinction. I have always regretted and do so now most especially that in my youth, I received little more than an elementary education and never had the advantage of a more academic training.'

Otto's work continues. The engine factory that began as a tiny workshop in the Servasgasse, is at the present day, a huge engine manufacturing complex of great economic and technical importance. Countless thousands of manufacturers are turning out engines on which improvements are still being made.

In the engine exhibition hall of the Deutsches Museum, Munich a tablet situated above a model of his first four-stroke engine reads:

HIS ENGINE WITH COMPRESSED FUEL MIXTURE FIRST THOUGHT OF IN 1861 AND PERFECTED IN 1876 AT DEUTZ NEAR COLOGNE BROUGHT TO A CLOSE THE PERIOD OF FORERUNNERS AND FOUNDED THE ENGINE TECHNOLOGY OF THE WORLD

SUGGESTIONS FOR FURTHER WORK

In the absence of a definitive work involving the history of internal combustion engines, the opportunity has been taken in this thesis to make a comprehensive study of the topic. Three possibilities now exist for further study.

One would be concerned with N. A. Otto and his efforts that led him to produce his four stroke engine. So little is known of this aspect of Otto's work and yet the four stroke engine seems generally to be accepted as 'something that just happened'. To shed light on what Otto really did would involve a detailed study of the archives of the Klöckner Humboldt Werkmuseum, Deutz, Cologne and the experimental engine exhibited in that museum. A good deal of correspondence is known to have taken place between Otto and Franz Reuleaux in Berlin and also between Otto's partner, Eugen Langen, and Reuleaux. These communications should be studied, particularly that which took place during 1873-76. So also should the Directors' Minute Books, which may yield evidence of important Board decisions affecting the four-stroke engine. Another potentially promising field would be the patents taken out by Otto during the early 1870's. Most of these are not registered in Great Britain, France or America, but in the various states of the then German Empire and also Austria. It may be recalled that Otto's friend and adviser, Franz Reuleaux, who thought well enough of Otto to encourage him, was a patent examiner and would often suggest where best to take out the patent.

A second field of study involves the ideas of Beau de Rochas related to the working of a heat motor. Upon reading the description of how consecutive strokes of the piston should be carried out, it seemed to the author that they were too good to be true. It must be here pointed out, that two attempts to gain access to the original Beau de Rochas Tract contained in the British Library proved unsuccessful. As far as the Beau de Rochas tract was concerned, therefore, reliance was placed on translations which can be found in various journals. The accuracy of these is not unduly questioned, but it must be borne in mind that such translations were made some years after the introduction of the four stroke and one cannot totally ignore the effect of pre-suggestion. There is, too, the unexplained absence of Beau de Rochas during the intensive patent battles. From all accounts, he was a publicly minded person and it seems inconceivable that he would have missed the opportunity to assert himself and his claims. Various French writers have put forward numerous suggestions as explanations, but in the author's experience, nationalistic pride appears as a dominant factor and such reasons as are made should be treated cautiously.

The third field of study would cover the sociological and economical effects of the use by industry of the internal combustion engine. Again, little to nothing has been done on this topic yet, as pointed out in the thesis there is overwhelming evidence of the use of gas engines which, quite certainly, had a far reaching effect upon the national output of consumable goods. Such work may well be more suited to the economic historian and it is hoped that in this respect, the contents of this thesis may be of some assistance.

A HISTORY OF GAS ENGINES

1791 - 1900

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VOLUME TWO

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VOLUME TWO

TECHNICAL APPENDICES

This Volume contains four separate appendices.

Appendix One is a detailed account of the experiments that were carried out by the author, during the course of his research, on three old gas engines. These engines, which are now displayed in the North Western Museum of Science and Industry, Manchester, were discovered to be inoperable when a conversion of the gas supply to the Museum took place from 'town gas' to 'natural gas'.

The experience proved extremely beneficial in providing first-hand experience of the construction and operation of gas engines of that era. The engines are once more workable and now demonstrated daily to the public. Copies of the Report have been circulated to the Provincial and National Museums in Great Britain and also to those in Germany who, as a result, have succeeded in overcoming the difficulties associated with running their own gas engines on natural gas.

Appendix Two is a collection of the agreements that were made between 1868-70 involving N.A. Otto and his associates at the German factory in Cologne and two firms in England, Messrs Louis Simon and Son of Nottingham, and Messrs Crossley Brothers of Manchester. These agreements, until now, have been unavailable in Great Britain and were obtained by the author during a study visit to the Klöckner Humboldt Werkmuseum, Deutz, Cologne in 1977. They have been translated from the original handwritten German and from them the story of how the internal combustion engine was introduced into England from Germany during 1868 can be described.

Appendix Three is a reproduction of a collection of testimonials from users of Crossley gas engines between 1877 and 1887. This particular source has only recently come to light and mainly because of the interest it has aroused with respect to the extent which gas engines were used, is given here in its entirety. It may well form the basis of a further study related to the economics of operating prime movers, by showing the scale (previously quite unappreciated) and usage of gas engines by a variety of industries.

Appendix Four is a copy of the English Otto Patent, No. 2081 of 1876 for the four-stroke engine issued to Charles Denton Abel, a patent agent of London.

CONTENTS VOLUME TWO

APPENDIX ONE

TABLES, PHOTOGRAPHS AND DIAGRAMS

APPENDIX ONE

A report describing the experiments carried out and the modifications that were made enabling three historic gas engines exhibited in the North Western Museum of Science and Industry, Manchester to run on natural gas.

SUMMARY

This report describes the experimentation carried out and the work found to be necessary in order that three gas engines, each employing a different principle of working, would run using natural gas (or North Sea Gas) as a fuel. The three engines involved were (i) a Robinson four-stroke using hot-tube ignition manufactured c.1900; (ii) an Otto-Crossley horizontal four-stroke single cylinder with slide valve and flame ignition manufactured c.1887 and (iii) a vertical Otto-Langen atmospheric engine also with slide valve and flame ignition, manufactured by Crossley Brothers, Manchester c.1875. Prior to conversion, the engines were operating for demonstration purposes on hydrogen based town's gas taken from the normal mains supply.

The properties of natural gas (see Table I) which were found to have the greatest significance were:

(i) the stoichiometric air/fuel ratio
(ii) the flammability limits
(iii) the flame speed
(iv) the ignition temperature

Broadly speaking, therefore, the modifications consisted of initially obtaining a satisfactory air/fuel ratio, either by increasing the quantity of air supplied to twice the normal amount or, alternatively, reducing the quantity of gas supplied by half, this ratio has then to be retained within the restrictions imposed by the flammability limits of the natural gas. Secondly, to advance the ignition timing if possible to counteract the slower flame speed of

natural gas and, lastly, in the case of the hot tube ignition engine, design a burner and ignition tube which would enable the high temperature to be attained which is necessary to ignite natural gas.

Several tests were carried out to obtain the most satisfactory air/fuel combination for each engine and, since it is not practical to increase the quantity of air supplied (without an auxiliary supply, that is) it became necessary to restrict the quantity of gas that is supplied. The most successful means of achieving this was by reducing the size of the gas supply ports at a point as near as possible to the engine cylinder. Inherent, however, in the quantity of gas supplied is its pressure in the mains pipe and many tests were made before a satisfactory relationship between gas pressure and supply port area was obtained.

A further problem which had to be overcome in the case of the Otto-Crossley was that of obtaining the necessary conditions for easy starting, as distinct from those required to keep the engine running at its normal speed. At cranking speeds, piston speed is low, hence the quantity of air drawn in is less and the amount of gas required must therefore be correspondingly less. If no attempt is made to achieve a reduced gas supply for starting, the cylinder will quickly overfill with gas and the flammability limit will be exceeded with no possibility whatsoever of a start.

As a result of the experiments and tests, the characteristics of each engine are now fully understood. Drawings and models made of the slide valve have enabled a thorough understanding of their operations to be obtained and the engines can now be started and run satisfactorily using natural gas as a fuel.

The author wishes to express his sincere thanks to the Director of the North Western Museum of Science and Industry, Dr. R.L. Hills for allowing the work to be carried out and also for his interest during the experiments. To the Senior Technician, Mr. S. Barnes and Technicians, Mr. H. Applebee and Mr. J. Taylor for their assistance and co-operation without which the task would have been that much more difficult and finally to the Industrial Development of North West Gas, Stretford, for their advice and assistance in producing a suitable burner for the ignition tube on the Robinson engine.

INTRODUCTION

The three gas engines are installed in the North Western Museum of Science and Industry, Grosvenor street, Manchester and up to the time of conversion in July 1975 were used for demonstration purposes, being connected to the mains supply of hydrogen based town gas. This gas has approximately 50% hydrogen by volume corresponding with the gas which is distilled from coal and for which the engines were originally designed to work. It is easily ignited, has a high flame speed and wide flammability limits of between 4 to 40% gas in mixture and from these considerations, there is no difficulty whatever in starting and running the engines when using this gas.

Natural gas used in Great Britain on the other hand, consists of approximately 92% methane (CH_4) and has properties which may be considered contrary as far as a fuel for internal combustion engines are concerned to those listed above. It requires nearly twice the volume of air per unit volume of gas before combustion is possible, its flame speed is one-third that of hydrogen and will burn only when within the limits 5% to 15% gas in the mixture. In practice this gives an air/gas mixture ratio of between 8 and 12 : 1 - a very restricted range, when compared with town gas, which can be used in the ratios 4 : 15 of air to one of gas. The volume of gas admitted into the engine per stroke must, therefore, be reduced by about half that of town gas which, when attained, creates a mixing problem, due to the absence of any appreciable length in which mixing of the air and gas can take place. The difficulties of getting gas engines of these and similar types to start and run satisfactorily using natural gas have been experienced by various people whom upon conversion from town's gas to natural gas suddenly find themselves with perfectly good engines - some of which previously were doing useful work, and some being used as working exhibits - which cannot be made to run. This in itself would appear to warrant an investigation as to the causes of the difficulties to prevent the 'uselessness' of these engines leading to their extinction - a number of which almost certainly being of historic interest.

Before experimentation began, consideration was given to the possible use of alternative fuels. Simulated town gas is readily obtainable in bottled form at a pressure of 2000 lbf/in^2, giving about 200 cubic feet of gas at standard pressure and temperature. This is sufficient for about 6 to 8 hours continuous running of the vertical engine and something like only 2 - 3 hours with the horizontal Crossley engine under no load conditions. The use of such bottled gas would mean that no modifications would be required to the engines, but various high and low pressure regulating and reducing equipment would be needed, continuous replenishment involving expense would be necessary and consideration would have to be given to safe storage.

Low pressure gas - propane and butane available in container form - was considered as a further possibility. These gases, however, exhibit similar characteristics, only moreso, with respect to air requirements and flame speed as those of natural gas, continuous and frequent replacement would still be needed, but from a storage point of view would be easier to handle and more acceptable as regards safety.

From a consideration of these factors, the advantages of using a readily available source of gas are appealing and it was decided that attempts should be made with this, starting with the flame ignition system of the horizontal Otto-Crossley. A condition imposed at the outset was that any modifications carried out should not detract from the historical character of the engines and further, that all modifications must be reversible.

TABLE I

COMPOSITION OF SOME NATURAL GASES *

	Dutch	Saharan	Typical North Sea	Methane
CH_4 (Methane)	81.76	86.5	91.8	100
C_2H_6 (Ethane)	2.73	9.42	3.5	-
C_3H_8 (Butane)	0.38	2.63	0.8	-
C_4H_{10} (Propane)	0.13	1.06	0.3	-
C_5H_{12} (Pentanes & higher)	0.16	0.09	0.33	-.
CO_2	0.87	-	0.43	-
N_2	13.96	0.3	2.8	-
Helium	0.01	-	0.04	-
Cross CV in Btu/ft^3	896	1146	1035	995
Specific gravity	0.643	0.644	0.607	0.55
Wobbe No.	1095	1400	1305	1344
Burning velocity cm/s	33.0	37.1	35.6	35

* supplied by the Industrial Development Centre, North West Gas, Stretford, Manchester.

TABLE II

PROPERTIES OF METHANE AND G4 TOWN GAS *

	Methane		G4 Town Gas	
Gross calorific value	995 Btu/ft^3	37.05 J/cm^3	500 Btu/ft^3	18.63 J/cm^3
Specific gravity	0.5	0.55	0.47	0.47
Wobbe Index	1344 Btu/ft^3	50.1 J/cm^3	730 Btu/ft^3	27.22 J/cm^3
Stoichiometric Air/gas ratio	9.52	9.52	4.3	4.3
Products at S.T.P.	10.57^3/ 1000 Btu	0.284 cm^3/J	9.8^3/ 1000 Btu	0.264 cm^3/J
Maximum burning velocity	1.115 ft/s	0.34 m/s	3.28 ft/s	1.0 m/s
Spontaneous ignition temperature	1300°F	977°K	1100°F	866°K
Maximum flame temperature with air	3540°F	2222°K	3600°F	2256°K
Limits of inflammability expressed as:				
(a) % Gas in mixtures	5 - 15%	5 - 15%	4 - 40%	4 - 40%
(b) Fraction of stoichiometric air requirement	2.1 - 0.7	2.1 - 0.7	5.82 - 0.58	5.82 - 0.58

*Data supplied by the Industrial Development Centre, North West Gas, Stretford, Manchester

The Horizontal Otto-Crossley Engine

Engine details

Cylinder bore diameter	4¾ ins
Stroke	9½ ins
Swept volume	168 ins^3
Combustion space volume	112 ins^3
Compression ratio	2.5 : 1
Speed	160 rev/min
Brake horse-power	4.5
Mode of ignition	Flame in slide valve
Flywheel diameter	3 ft 6 ins
Governor	Hit and miss principle
Town gas consumption	30 ft^3/bhp hr
Engine number	15104

Valve and timing details

Admission port setting:	Opens 33° before inner dead centre Closes 30° after outer dead centre
Exhaust valve setting:	Opens 45° before outer dead centre Closes at inner dead centre
Ignition port setting:	Opens 7° before inner dead centre
Gas inlet valve:	½ ins diameter x ⅜ ins lift
Exhaust valve:	1¼ ins diameter x ⅜ ins lift

General Description

The year of manufacture is c.1887 and as such represents one of the last engines of this slide valve type to be made. It was originally sold to a firm of letter makers, Messrs Miller and Richards, Edinburgh where it was put to

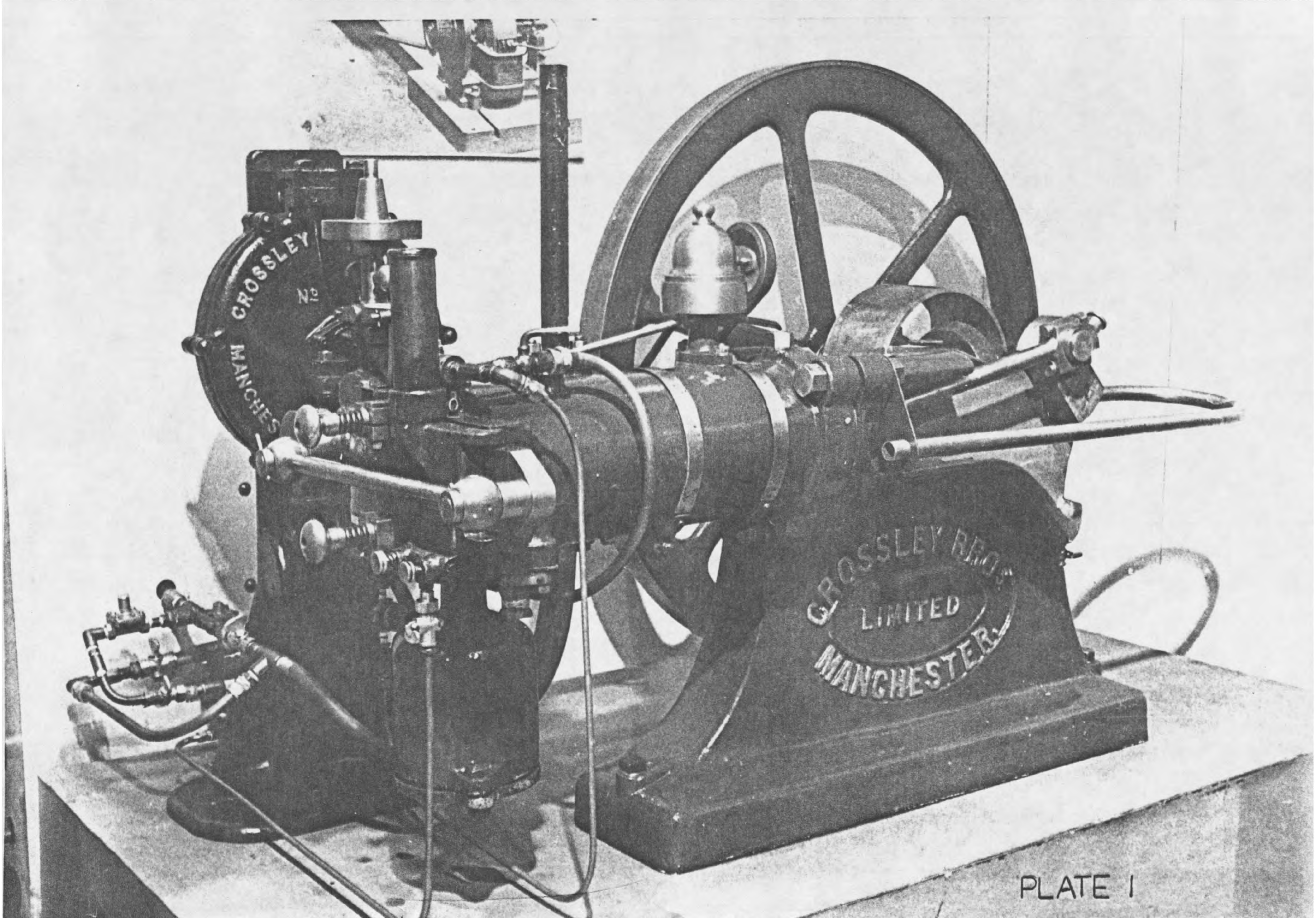

PLATE I

work in the foundry.

The basic components such as piston, connecting rod and countershaft are a model of simplicity in design. The cylinder is surrounded by a water jacket. A cast iron piston is fitted with three pegged rings and the piston rod is connected to a cross-head and thence to the crankshaft. The use of a cross-head was popular in steam engines, its purpose being to relieve the piston of any side-thrust forces.

A shaft running at half engine speed is situated on the left-hand side of the engine, when viewed from the slide valve end (in this respect its design differed from many Otto engines in which the counter-shaft was position on the opposite side) and is driven by bevel gears - an improvement on the earlier spur gears from the engine crankshaft. An eccentric at the opposite end operates the slide valve and a gear situated on this shaft drives the centrifugal governor shaft. The lubricator and exhaust valve are also operated by this shaft.

The arrangement of this gearing and eccentric is such that if any alteration in ignition timing is required, it would involve a major modification.

The slide valve is of cast iron and is sandwiched between the cylinder face and outer cover, machined in it are a number of ports and holes accurately positioned so as to obtain a regulated supply of gas and air and to effect ignition of the cylinder charge. One end of the slide valve (nearest the counter-shaft) is concerned with the admission of gas and air, the other end controls the ignition (see Figures 2a to 2c). In the slide valve cover and cylinder face are ports which, at the correct time, will coincide with those in the slide. To prevent leakage past the slide valve faces, two springs with adjusting nuts press the slide valve cover firmly against the slide and cylinder face. It is essential however to have slide valve faces which are perfectly 'bedded' to the cover and cylinder face.

A chimney is placed on the outer slide cover in the base of which is a stationary pilot light. After a few minutes, the chimney becomes heated by the pilot light and a strong convected current of air is created; the purpose of this is two-fold:

(i) it provides a supply of air to the gas burning in the igniting post which ignites the main cylinder charge;

(ii) it serves to scavenge or clear the igniting post which after an ignition will contain burnt gases

Gas supply

In the days of its manufacture, the engine was supplied with gas from the mains which was probably at a static pressure of 3 or 4 inches water gauge. Between the engine and the mains gas pipe is situated a device known as an antifluctuator valve - commonly called a gas bag - which is a flexible container from which the engine draws gas. Its purpose is to provide a reservoir so that the pulsating effect of the engine when running is not communicated to the mains pipe, which would result in fluctuations in supply to surrounding premises. In the absence of such a device, a vessel of about 2 cubic feet capacity will suffice with the inlet and outlet connections at opposite ends.

Figure 4 represents the system that was developed and used during the tests carried out; it provides for a supply of high pressure simulated town's gas as well as for natural gas and is so arranged that a change-over from one gas to the other can be made whilst the engine is running.

After conversion to natural gas, the static pressure of the museum premises was 8 inches water gauge - which is too high a pressure to be fed direct to the engine - it is necessary to reduce this by the use of governors, both for the engine and ignition supplies. The tests carried out to determine the operating pressures most suitable for running are described in the section 'Adjustments made with engine running'.

Operation of the slide valve

To obtain the working principle and precise timing details of the slide valve, a full scale perspex model of the cylinder face, slide and cover was made. The positions and sizes of the ports were then marked on the perspex. By this means, the alignment and connections of the various ports could be clearly seen. The action is as follows:

With the piston at the inner dead centre position beginning the induction stroke, the slide begins to move from left to right (Figure 2a). During this first stage of slide movement, the model showed that the gas check holes came first into communication with the gas supply ports.

The forked passage, therefore, would first be filled with gas only, which would then enter the cylinder a fraction of a second before the air ports aligned*, allowing then a mixture of air and gas to enter through the forked passage, as it aligns with the explosion port.

With the slide valve now in the extreme right position and about to return, the igniting port is filled with a small quantity of gas from a separate supply, air, convected through the passage B (Figure 3a) mixes with this gas which is then ignited as it passes the stationary pilot light in the slide cover. Continuing to burn within the port it is cut off from atmosphere, receiving then a separate gas supply to sustain it from a groove I in the cover. At the inner dead centre position on compression stroke, the flame burning in the igniting port communicates with the explosion port shooting a tongue of flame into the main cylinder charge. Before this occurs, however, there is one small but important event that takes place without which ignition would not occur.

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*This is in direct conflict to the ideas put forward by Otto in his patent No. 2081 of 1876, in which he states quite clearly that air only enters first, to be then followed by a mixture. This he believed, quite erroneously, that by this arrangement, stratified layers consisting of burnt products next to the piston, in intermediate strata of air and a third strata of highly combustible gas nearest the slide would be retained during the compression stroke; this concept was abandoned during the 1880's, its being finally accepted that a homogenous mixture did in fact result.

The interpretation that is put in this contrary situation, therefore, is that Crossley Bros. have chosen to introduce the gas first, in order to neutralise the burnt gases remaining in the cylinder from the previous stroke.

Just before ignition the cylinder charge is compressed to about three atmospheres, hence when the igniting port was uncovered, the dying flame within it would almost certainly be extinguished. To prevent this, a small passage (Figure 2b and 2c) communicates the cylinder to the T shaped slot in the slide (Figure 3), a fraction of a second before ignition, allowing a small quantity of ignitable mixture at a higher pressure to revitalise the ignition flame, equalising the pressure of gas in this port with that of the main cylinder charge, so that a strong flame will project into the cylinder. Engines employing slide valves but without compression do not need such a device.

Flame adjustment

The successful operation of this flame ignition was found during tests to be dependent on:

(i) the height of the pilot light flame; too small a flame will not ignite the gas in the igniting port, too large a flame causes too forceful a current of convected air which results in burning at the base of the chimney (see Figure 3c) and not in the slide cavity. A height of between 1¼ and 2 ins was found to be quite tolerable.

(ii) the quantity of gas admitted to the igniting port; this was found to be much more sensitive than the flame height. With too much gas, some of it remains unburned when the slide returns after an ignition and on contact with the pilot light results in a small explosion, shooting outwards, extinguishing the pilot light. If not enough is supplied, the flame in the igniting port will burn out before it reaches the communicating passage to the cylinder and an ignition will be missed. An approximate position can be obtained by first turning the engine so that the slide is in the igniting position, the gas supply to the slide valve is then increased slowly until it is heard to ignite in the base of the chimney.

(iii) a satisfactory purging of the igniting port before a new charge is introduced into it. This is dependent on the convected air flow created by the pilot light and chimney dimensions. Removal of the chimney results in products of the previous cycle remaining in the cavity and thus a weak flame to carry over for the next cycle.

Preliminary maintenance

Apart from slight scoring of the cylinder and a worn exhaust valve guide, the mechanical condition of the engine was good. Certain work of a minor nature was carried out and consisted of bedding the slide faces, re-seating the exhaust valve and removing the heavily encrusted carbon deposits from the explosion port. The timing details were obtained by attaching a 360^{o} protractor to the crankshaft and carefully noting the opening and closing angles of the various ports by detecting the resulting pressure drop when air was blown through the appropriate passage.

Attempts to operate the ignition using natural gas

After ensuring the existing pilot light jet could be adjusted to a suitable height with acceptable stability, it was decided to remove the piston and check by looking along the cylinder, if the flame in the slide was carrying over to the explosion port.

When the gas supply to the igniting port was turned on, it was noticed immediately that any attempt to open the control valve beyond a half that when town gas was used produced a vigorous burning at the base of the chimney. The reason for this was not fully understood at this stage. Attempts to get the flame to carry over in the slide and emerge into the cylinder were unsuccessful, despite great

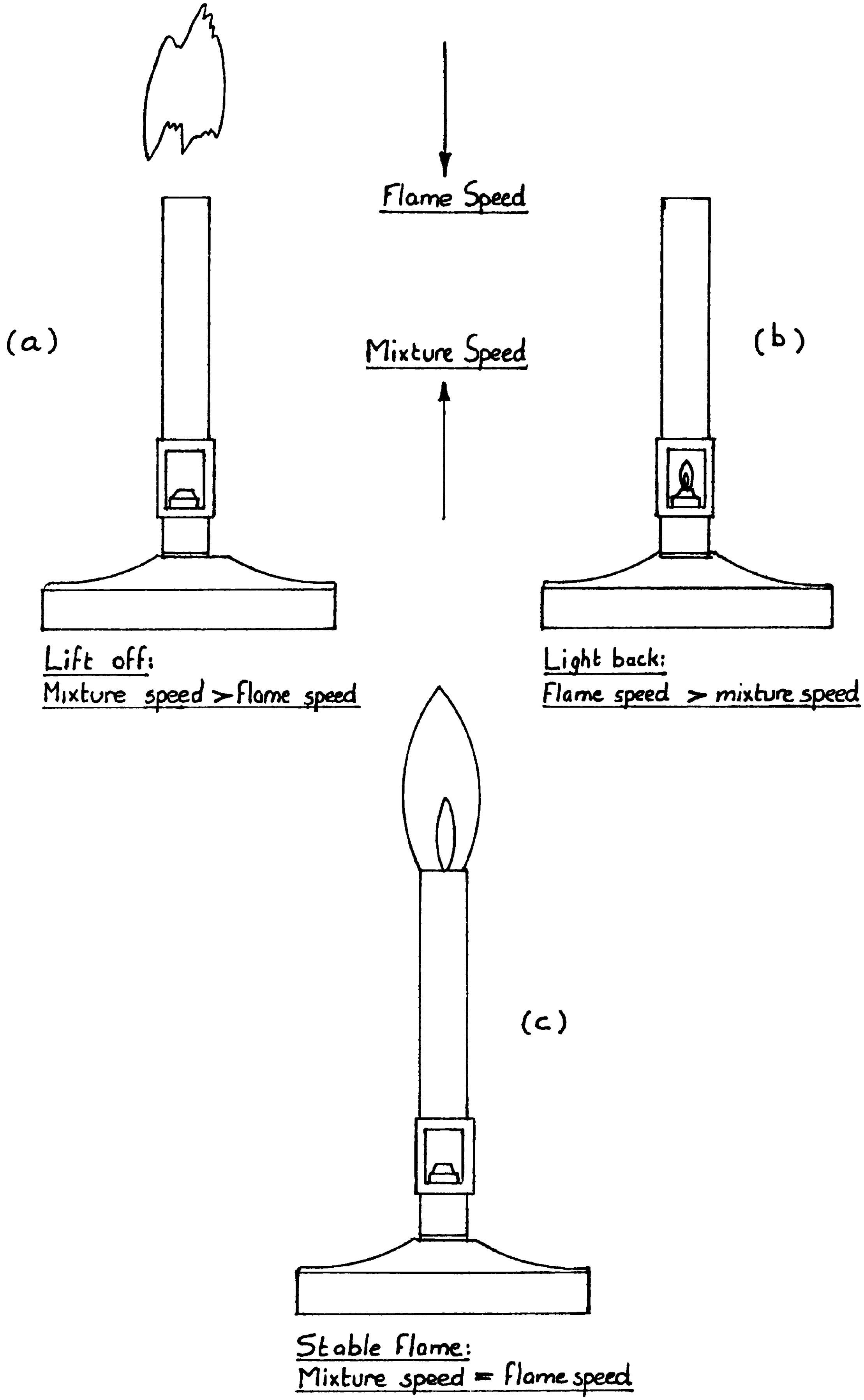


FIG.1. FLAME STABILITY

care taken to adjust the valve and it became clear that a closer investigation of the manner in which the flame was transported within the slide was required. As a means of experimenting, however, the chimney was removed, thereby reducing the air flow through the igniting port, and the engine turned slowly, the igniting flame was then visible and was seen to burn at the top of the port; it was thought to be a much weaker flame than that obtained with town gas and doubt was felt that with the chimney removed, the igniting port would be insufficiently cleared of the products of the previous cycle.

A number of tests were then carried out using chimneys of various heights, adjusting the valve controlling the gas delivered to the slide very carefully. All attempts to get the flame to carry over, however, were unsuccessful.

With a chimney 1½ ins high, the flame was visible, but showed identical features as regards position and strength to those when no chimney was used. As the chimney height was increased, the flame was seen to burn closer and closer to the upper edge of the port, disappearing when the chimney was 4 inches: the original chimney was 6 ins in length.

To make a closer investigation of the ignition flame characteristics, the retaining clamps and springs holding the slide in position were removed and the outer cover and slide withdrawn slightly; the gas pipe was left attached. A perspex cover, the same size as the cylinder face plate was then placed on the engine side of the slide valve, the three components, cover, slide and perspex then lightly but firmly held in place with clamps. By looking through the perspex plate, the igniting port could clearly be seen as the slide was moved gently across, the cause of the failure of the flame to carry over was seen immediately.

Instead of the gas burning upon contracting the air as it emerged from the T-shaped slot (Figure 3c) it was seen to be burning at the base of the chimney only, consequently when the port was shut off from atmosphere, no flame was contained within it - only unburned gas. If the pressure of the gas supply was reduced to the extent that a small flame could be seen to burn in the port, it burned itself out (due to insufficient quantity) before it reached the igniting port.

The reason for the blowing out of the pilot light on the return stroke of the slide whenever natural gas was tried on the ignition was also explained. The port, containing as it did, due to a failed ignition, a supply of unburned gas, would ignite quite forcefully on contact with the pilot light and the air available in that region, the minute explosion then would extinguish the pilot light.

The tendency of the flame to 'lift' or separate from the jet in the igniting port is clearly similar to that shown in Figure 1a. It is characteristic of the slow burning velocity of natural gas and the situation is by no means helped by the vigorous but very necessary current of air which passes through the igniting port. There exists a possibility that an improvement would result if the size of the hole through which the gas emerges into the igniting port was reduced, but it was decided at this stage to obtain a supply of simulated town gas to be used on the ignition system.

<u>The engine cylinder on natural gas</u>

Table II shows that natural gas requires approximately twice the quantity of air for combustion compared with town gas, but to increase the air supply would involve the use of a compressor, regulator valves, etc, - considered to be an undesirable solution - the only remaining course of action is to reduce the available gas flow by about half of that previously used. A restrictor was, therefore, placed in the pipe between the antifluctuator and the engine and attempts made to start the engine by adjusting the valve in small amounts with the gas pressure adjusted to 3 inches water gauge.

Despite careful manipulation of the restrictor and gas pressure all attempts to produce a start at this stage were unsuccessful. The only indication of any willingness was an irregular firing when the gas supply pressure was about 1 inch water gauge.

Attention was then given to other possible methods of restricting the gas supply. It was felt that with the present position of the restrictor even as close to the engine as possible, there was still a large volume of gas present in the passages etc. within the engine and able, therefore, to pass through the gas check holes in the slide valve, the sizes of which were suited to town's gas. After several more unsuccessful attempts to obtain a satisfactory setting of the restrictor, it was decided to remove the slide valve and make careful measurements of the air port and gas check holes to determine whether or not a relationship between the two existed and to investigate the possibility of reducing the size of the gas check holes. These were as follows:

Air port (ins)		0.39 x 0.814
hence area	=	0.3175 ins^2
Gas check holes		3 holes each 0.44 ins dia.
hence area	=	0.0488 ins^2

The ratio of air port/gas is therefore 6.5 : 1.

An analysis of Openshaw gas of 1890 was then obtained from reference (1) and the stoichiometric air/fuel ratio calculated. This proved to be 6.2 : 1.

Modification to the gas check holes

Whilst the sizes of the gas and air ports are used to provide regulated quantities of gas and air for admission into the engine, it cannot be concluded from the result obtained above that the actual ratio of gas to air entering the engine cylinder will be 6.5 : 1, the gas pressure piston speed and viscous effects of the air and gas will make such an assumption invalid.

The close relationship between the two values suggest, however, that a parallel may be drawn with respect to the use of natural gas in that the sizes of the gas check holes could similarly be in the same proportion to the size of the air port for the stoichiometric air/fuel ratio of natural gas. A ratio of 9.5 : 1 was, therefore, chosen and calculations made to determine the size of holes necessary to achieve this proportion. Brass plugs were inserted to blank off the existing holes and then drilled out to the smaller size calculated, ie. 0.1185 inch, a number 31 drill giving the required size. It may be pointed out at this stage that increasing the size of these holes by just one drill size (in the order of 0.0025 inches) will decrease the air/fuel ratio by 0.5 : 1 illustrating the sensitivity of these holes to alterations.

With this modification, it now became possible to start the engine with the main cylinder on natural gas and the ignition on town gas with the working supply pressure set at 3 inches water gauge.

Two observations were made at this point which determined the course of subsequent investigations:

1) The cranking speed necessary in order to produce a start was high and only just about attainable by hand.

2) During the first ten minutes after starting the engine, it would appear from an observation of the pecker acting on the gas admission valve, that two or three ignitions would sometimes be missed before a firing stroke resulted. As the engine warmed up these irregularities were seen to diminish.

An attempt was made first to rectify the latter. It was felt that these irregularities, if eliminated, would improve the starting difficulties.

<u>Adjustments made with engine running</u>

Tests were carried out in order to determine the most satisfactory gas pressure, which would give the best and most even engine performance by adjusting the governor situated before the antifluctuator valve. When the operating pressure was 1½ inches water gauge, the engine began to slow in speed, eventually stopping due to lack of gas. At 6.0 inches pressure the engine ceased to fire, this time presumably from too much gas. During these tests, the gas cock on the engine was fully open.

The limits of operating pressure were thus obtained. The governor pressure was then set to 5 inches, since at this higher pressure the irregularities referred to above were virtually eliminated when the engine was warmed, only one firing stroke being sufficient to cause the engine to make 10 to 12 revolutions before the pecker, controlled by the governor could again operate the gas valve. By varying the setting of the main gas cock positioned near the engine, it now became possible to reduce the engine speed to a 'tick-over'. These adjustments however did little to improve the difficulty experienced in starting and efforts were now directed toward this end.

<u>Gas requirements during starting</u>

The immense effort required at the flywheel to obtain the cranking speed necessary to produce a atart was clearly unacceptable, but it was this fact which suggested that an investigation into the engine requirements as regards air and gas and the conditions that exist during starting, would be desirable.

When the piston speed is low such as occurs during starting, the volume of air drawn into the cylinder is reduced, the gas supply, however, is at a pressure above that of the atmosphere and consequently at these low engine speeds, there is every possibility that a mixture - grossly over-rich in gas - will enter the cylinder. The narrow flammability limits of natural gas are thereby soon exceeded making combustion impossible. Continued attempts at starting under these conditions result in an accumulation of an unburnable mixture within the cylinder, making the possibility of start even more remote and produce an ever worsening situation.

Hydrogen based town gas on the other hand, having much wider flammability limits, is much more tolerant to such conditions and this fact, together with its ability to ignite more readily, makes the possibility of a start much more certain.

From these considerations, therefore, it would appear that when natural gas is used the gas pressure during starting needs to be reduced, which will in turn reduce the quantity entering the engine.

Various methods of doing this were tried, all of which to a greater or lesser extent produced an immediate improvement in starting. Before the three most suitable methods found are described, however, it is worth noting at this stage that the tests carried out to improve the starting showed the extreme sensitivity of the settings required to give a suitable gas/air mixture for the engine to ignite at these low speeds and there is little doubt that a failure to provide for these sensitive conditions will cause starting by hand cranking to be of the utmost difficulty, if not impossible.

Methods of reducing gas pressure for starting

With the restriction to the gas supply now in the slide valve, a more effective control of the gas could be made with the gas cock situated near the engine. It was found, for instance, that the limits - too much or too little gas - were within its range of adjustment, that is, the cock was required to be somewhat less than fully open for normal running (otherwise the engine would stop because of too much gas) and when opened slightly, the engine could be made to run at a very slow speed. The difference between these two settings was indeed small and quite unlike that experienced when running on town gas and illustrates how easily the flammability limits of natural gas may be exceeded.

The three most suitable methods found best for starting, any of which can be adopted, are now described:

1) Turn on the isolating valve supplying the anti-fluctuator until the bag is filled - turn off the valve. Open the gas cock on the engine to full and crank the engine. A point will be reached when the gas pressure and air supply are compatible with the engine speed, the engine will then fire after which the valve must be opened a slight amount immediately to allow the engine speed to increase.

2) With the isolating valve fully open, the gas cock on the engine is adjusted beginning at the closed position until one is obtained at which the en-

gine will fire. After starting the cock must be opened to permit full speed.

3) A by-pass supply system can be arranged incorporating a zero-governor and small reservoir as shown in Figure 4.

The relative merits of each method are as follows:

The first has the advantage of simplicity, but has a tendency to be inconsistent. It relies upon a gradual fall of pressure in the system and when just above that of the atmosphere, the engine will fire. On odd occasions, once having fired, the engine would be unable to obtain gas quickly enough from the main cock and would come to a stop. The method is largely successful however.

The second method is simple and effective but necessitates very careful positioning of the gas cock in order to produce a start. If a faster speed is required after starting then this setting is destroyed when the valve is opened. To use this method, therefore, requires some means of accurately obtaining the best position of the valve for starting.

The third method, although requiring additional pipework is the best solution. The small reservoir is required to be situated as close to the engine as possible and in the order of 1 cubic foot volume (see Figure 4).

A further method which was found to be effective and used on this engine consists of a combination of the second and third methods, but without the small reservoir and zero governor.

The gas cock on the engine is locked in the starting position and the fine-control valve (Figure 4) turned off. The engine is rotated and upon starting, this valve is turned on. The main gas cock can therefore be left in the position found to be most suitable for starting and the gas supply for normal running is by the second valve.

The necessity for the foregoing considerations was proved by the fact that as a result of the tests carried out to improve the startability, the engine will start quite readily after about two revolutions of the flywheel, requiring only a moderate force, even when starting from cold.

If the engine had not run for several days, it was found advisable to rid the air that accumulates in the gas system before attempts are made to start the engine. This can be done by allowing gas to flow through the system for a few seconds, after which the engine must be rotated with the gas turned off to clear the cylinder. The chosen starting procedure can then be adopted.

The conclusions reached as a result of the modifications made and tests carried out to this engine are as follows:

1) When natural gas is supplied to the engine it is necessary to restrict the amount drawn in per cycle to about a half that of town gas.

2) The means of restriction should be placed so as not to create a large volume upstream of it in which gas may accumulate before passing into the engine cylinder. The most satisfactory method on this engine was obtained by reducing the size of the gas check holes in the slide valve.

3) A valve of the adjustable type, placed in the gas pipe is not by itself entirely satisfactory as a means of restriction, since

   (i) it is unlikely to fulfil the requirement stated in (2) and

   (ii) it does not conveniently provide for the different conditions that have been found to exist during starting and those present when running at speed.

4) Because of the narrow flammability limits of natural gas, it is necessary to devise some means whereby the gas pressure during starting is near to that of the atmosphere to ensure that the engine cylinder does not become over-filled with gas making combustion impossible. Several methods by which this may be achieved are described in the section - 'Gas requirements during starting'.

5) It was not found possible with this engine to run the flame ignition system satisfactorily on natural gas. This is due to the failure of the flame within the igniting port to remain stable and burn within this port as it was carried over within the slide valve. Contributory factors to this effect are the presence of burnt products from the previous cycle and the convected current of air passing through the port, which although necessary, lifts the flame away from its point of origin. Efforts are to continue, however, with the aim of making ignition possible using natural gas and it is felt this may be achieved by reducing the size of the hole through which the gas for ignition enters the igniting port.

6) Provided that the recommendations for starting are adhered to, the engine will start readily from cold and its performance for demonstration purposes is quite satisfactory.

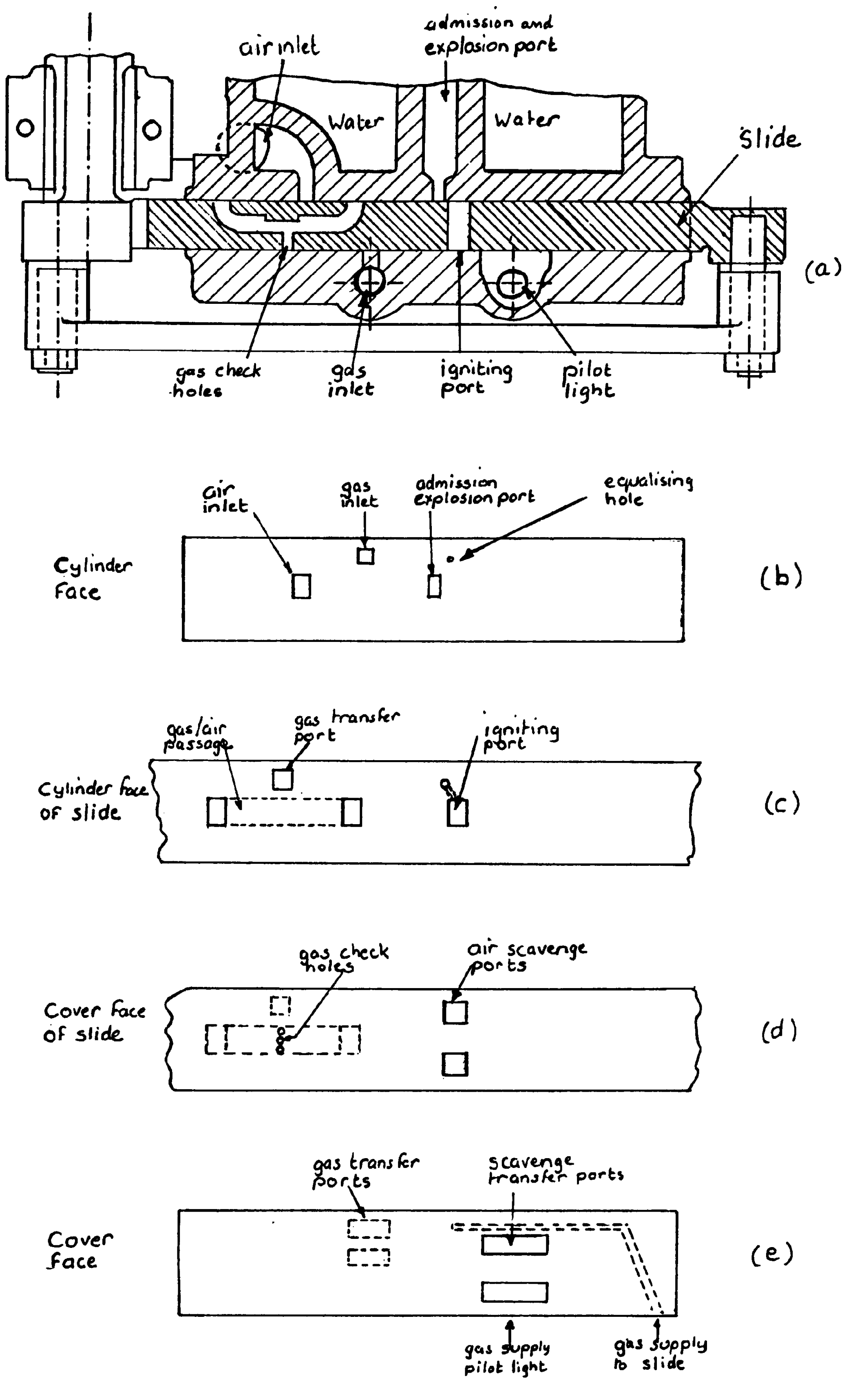


FIG. 2 SLIDE VALVE DETAILS

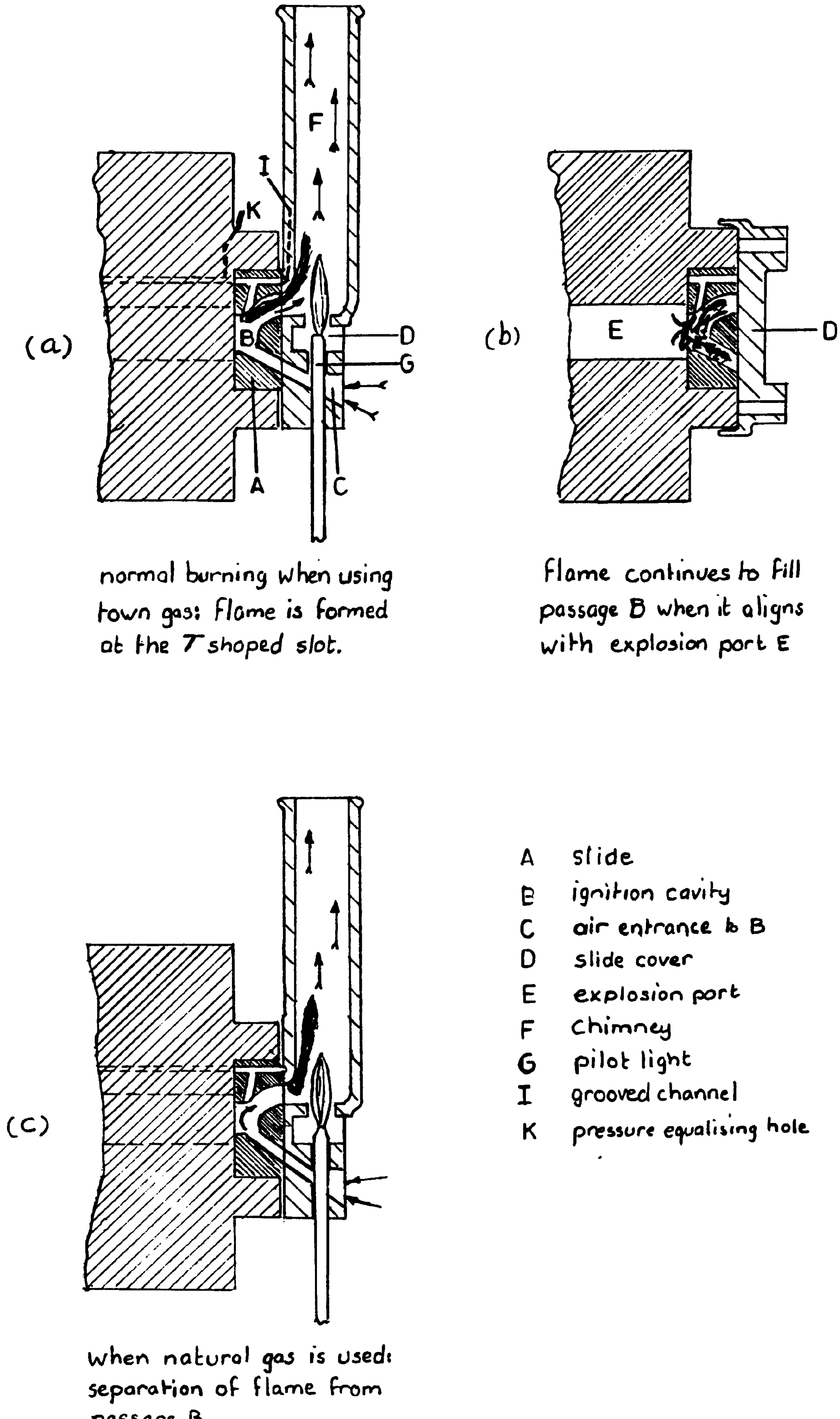


FIG. 3. IGNITION FLAME WITH TOWN AND NATURAL GAS

The Robinson Engine

Engine details

Single cylinder 4 stroke	
Bore diameter	3 inch
Stroke	3 inches
Power rating	0.75 bhp
Speed	600 rev/min
Compression ratio	5 : 1
Speed control	No governor fitted
Ignition	Hot tube untimed. Heated externally
Flywheel diameter	18 inches
Valves	Combined air/gas flap valve Exhaust - poppet valve
Manufactured by	A. E. & H. Robinson, Manchester, c. 1900
Town gas consumption	2o ft^3/hr at 600 rev/min

Valve timing

The combined air and gas valve is a flap valve held on its seat by a light spring (Figure 6) and is opened during the inlet stroke by the excess of atmospheric pressure over that in the cylinder.

The ignition is untimed (many hot tube ignition devices of this type were fitted with a timing valve which would admit a fresh charge into the hot tube at a pre-determined point in the stroke).

The exhaust valve is operated by an eccentric which can be adjusted to vary the opening and closing angles. In

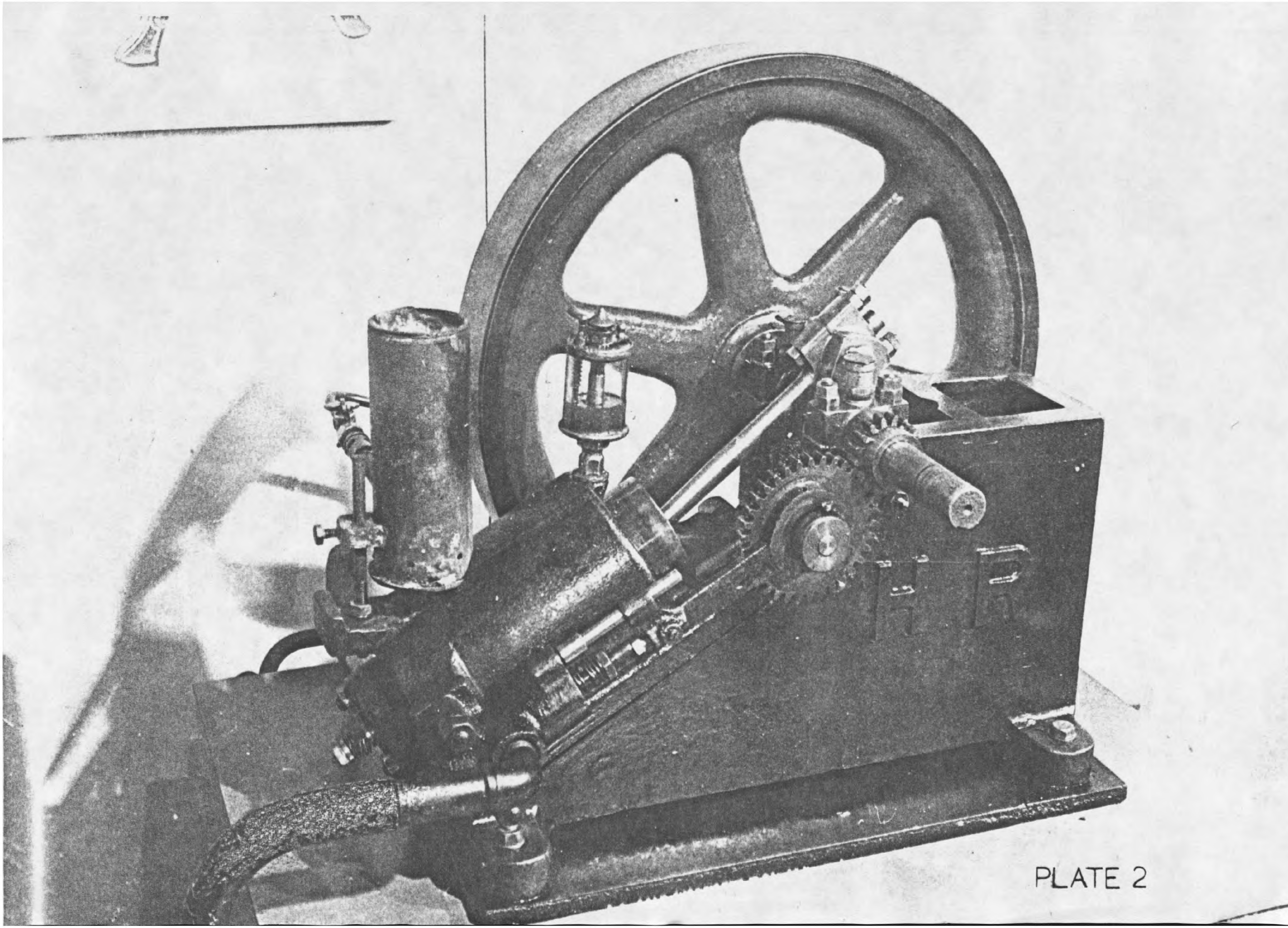


PLATE 2

this case the valve opened 45^o before outer (or bottom) dead centre and closed 5^o after inner dead centre.

The ignition tube and burner assembly

The ignition tube consists of a 6 inch length of wrought iron tube $\frac{3}{8}$ ins diameter, which is screwed into the combustion space of the cylinder. It is surrounded by an outer tube 2 inches diameter, which should be lined internally with a refractory material such as asbestos. An external burner is attached to this outer tube, which serves to heat the tube to a bright red heat.

Ignition occurs when the fresh charge is forced up the heated tube by the piston as the compression stroke. The timing of ignition may be varied therefore by raising or lowering the burner, the further away the heated position is from the base, the later will occur the ignition.

With this type of ignition, the following factors affect the timing at which this occurs:

1) The length of the tube
2) Dimensions of the passage leading to the tube and also of the tube itself
3) The degree of compression of the mixture before ignition
4) The temperature of the tube
5) The position of the heated portion of the tube
6) The speed of the engine
7) The air/fuel ratio of the mixture
8) The location of the tube within the combustion space
9) The condition of the outer and inner surfaces of the tube

This method of ignition became popular from about 1888. It superseded the flame ignition methods and was used on automobiles up to about 1905, in this case the tubes being made of porcelain.

When a timing valve is fitted, ignitions are more regular, the Robinson engine having no such device, exhibits occasional irregularities in firing. The overall performance, however, achieved with the re-designed burner and tube is highly satisfactory. It can be started by a flick of the flywheel and will race at very high speed, unless the gas supply is controlled.

The combined gas and air admission valve

This is a very simple arrangement (see Figure 6) and consists of a block of cast iron, in which seven holes, each 3/16 inch diameter are drilled through which air is admitted; a further hole also 3/16 inch diameter is drilled half way into the block (from the cylinder side) which communicates only to the gas pipe. Provided, therefore, that the gas supply pressure is equal to that of the atmosphere, the air to gas ratio will be 7 : 1. Since a slight gas pressure is necessary, however, it is most probable that the working ratio is about 6.5 : 1 - too rich a mixture for natural gas to burn.

Gas supply system

The gas supply system required for this small engine (Figure 5) was considerably simpler than the Otto-Crossley engine, since no dual system was necessary.

To replace the anti-fluctuator valve which was not available, a flexible bladder was placed between the governor and the engine, providing the reservoir from which the engine could draw gas. When the engine was running, the bladder was only partially inflated. For starting purposes, it was necessary to open the valve slightly, after which if more speed was required, it could be opened more fully. A supply pressure of 2-3 inches water gauge was found to be quite suitable for both starting and running.

First experimental attempts by the N.W.G.B.

The Industrial Development Centre of North West Gas, Stretford, Manchester had, at some time previously, carried out some tests on this engine and had succeeded in producing a burner arrangement for use with town gas and also in getting the engine to start and run satisfactorily using this fuel. Several attempts were made, using this burner arrangement, to run the engine on natural gas, but were unsuccessful, even when a change-over from town gas to natural gas was made with the engine running.

Modifications to the admission valve

The air/gas ratio of 7 : 1 being too rich a mixture when natural gas is used, is required to be increased to nearer the stoichiometric value of 10 : 1. This was achieved by re-calculating the respective gas and air ports, the calculations made being as follows:

Combined area of 7 holes at 3/16 inch diameter = 0.19328 ins^2

Choosing a mixture ratio of 11 : 1 the new area of gas hole required = $\frac{0.19328}{11}$

= 0.01757 ins^2

A drill size of No. 24 will be found to give the required diameter. The modification was effected by sealing the gas hole with a brass plug and then drilling out with the chosen drill size.

By using a propane burner to heat up the tube, the engine now started on natural gas. The heated portion was about 2¼ inches from the base. The propane burner, although providing a temperature of tube which was more than sufficient to ignite natural gas, was noisy and clearly unsatisfactory for demonstration purposes. The problem remaining now was to design a burner and tube assembly that would satisfactorily produce ignition of natural gas.

Burner requirements

The temperature at which a mixture of methane and air will spontaneously ignite is given in Table II as 704°C. After making due allowance for temperature fall across the tube thickness, radiation losses and the cooling effect of the fresh charge entering the tube, an estimate of the tube temperature required in the outer face would be 900°C - 950°C. This is about the limit that can be achieved by a well designed burner and choice of jet when using natural gas. Preventing undue heat losses is, therefore, essential and is best done by lining the outer tube on the inside with asbestos. This tube was made from a piece of wrought iron pipe $2\frac{1}{4}$ inches diameter and 5 inches long. The base was sealed (apart from the hole necessary to pass over the ignition tube) and six holes each $\frac{1}{8}$ inch diameter were drilled around the circumference at the base to assist the air supply for the flame.

The best jet giving the highest temperature of tube (measured by placing a thermocouple inside the tube) was found to be a size 75 Amal jet, so placed that it provided a mixing length of 4 inches in the supply pipe which then entered the base of the outer tube (see Figure 7). With a gas pressure of 6 inches water gauge to the burner, the above arrangement enabled a temperature of 850°C to be attained on the inner face of the ignition tube.

The author is indebted to the Industrial Development Centre of North West Gas for their assistance in the experiments carried out to obtain a satisfactory burner arrangement.

<u>Tests with the new burner and ignition tube</u>

After setting the height of the burner to that when the propane was used and allowing about ten minutes for it to become thoroughly heated the engine was started. The running on this occasion, however, was uneven and the speed much reduced compared to previous tests with the propane burner heating the tube. Lowering the burner produced a slight improvement in running, but was not entirely satisfactory. A shorter ignition tube of 3 inches was then made from a piece of stainless steel and fitted; the former burner height being retained. The engine now started readily and picked up speed rapidly. Lowering the burner to about 1 inch from the base produced a further slight improvement in running and with these adjustments, it became possible to start the engine - after a 10 minute warm-up period for the tube - merely by flicking the flywheel by hand.

It was clear from this result that the previous tube being twice the length of the new one, acted on the fresh charge by cooling it, producing weak ignitions. The use of stainless steel eliminates the scaling that occurs when wrought iron is used.

As a result of the tests carried out with the burner, the following facts emerged:

1) The wall thickness of the ignition tube must not be excessive as to cause a high temperature fall.

2) The diameter of the ignition tube passage affects the velocity with which the flame front of the ignited gases within the tube strikes the main charge, ie. the flame front of the ignited mixture within the tube will progress into the main cylinder charge only if its velocity is greater than that of the unburnt mixture entering from the cylinder (see Figure 1).

Bearing in mind the slow flame speed of natural gas, it will be appreciated that a satisfactory combination of length and diameter of ignition tube is essential, as a rough guide to length of ignition tube, it should be such that when heated, the whole length (with the exception of about $\frac{1}{2}$ inch near the base) should glow a bright red to orange colour. By so doing, the fresh charge on entering the ignition tube will be progressively increased in temperature and ignition will be more certain. With a long tube, the burner is only able to produce a localised 'hot spot', the temperature of which is insufficient to ignite natural gas. Furthermore, the unburnt charge as it enters the tube will be cooled after contacting the hot spot. Ignitions in this case will be irregular and weak.

As a result of the modifications to the admission valve, and the newly designed burner and ignition tube, the engine could easily be started by hand turning the flywheel to give highly satisfactory running.

Before experiments on this engine were concluded, one final test was made to see if the engine would start when the brass sleeve, which restricted the gas supply in the admission valve, was removed.

In spite of strenuous efforts on the flywheel, however, nothing more than an occasional weak firing resulted. Upon replacing the sleeve, the engine started instantly.

The following conclusions are made with regard to the Robinson engine:

1) A restriction to the gas supply which will give an air/fuel ratio of about 11 : 1 calculated on the respective port areas is required being most effectively situated in the admission valve block.

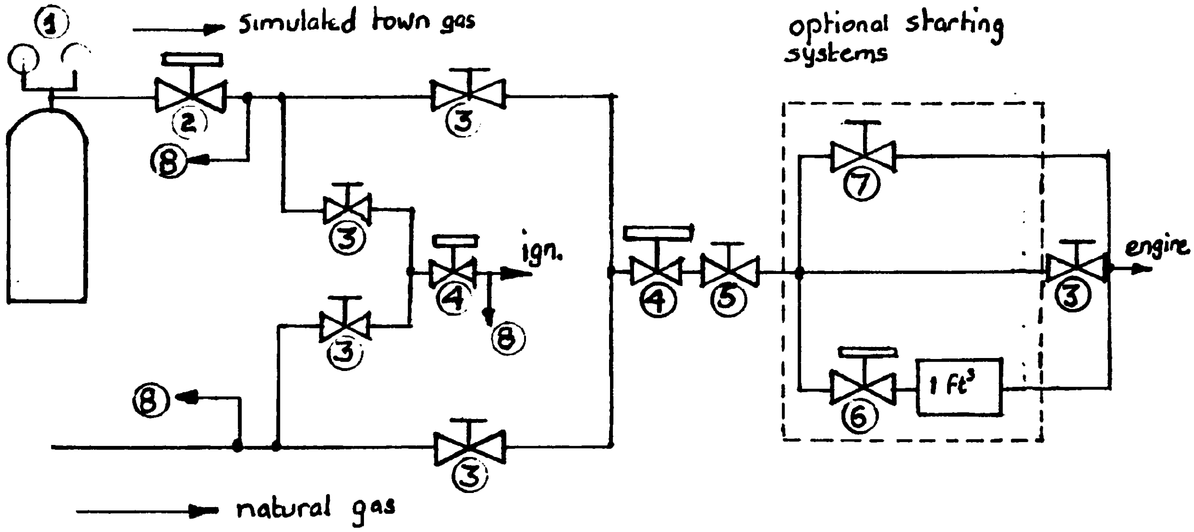
2) The ignition tube is required to be no longer than 3 inches, $\frac{3}{8}$ inch diameter and of wall thickness 3/32 inch. If the material used is stainless steel, the scaling will be virtually eliminated.

3) To obtain the high temperature necessary for the ignition of natural gas, all undue heat loss must be prevented by insulating the outer tube

and reducing cold air draught.

4) A smaller size jet than that required for town gas will be required for the burner. In this case a size 75 Amal jet used with a mixing length of 4 ins. The gas supply pressure for this purpose was 6 inches water gauge.

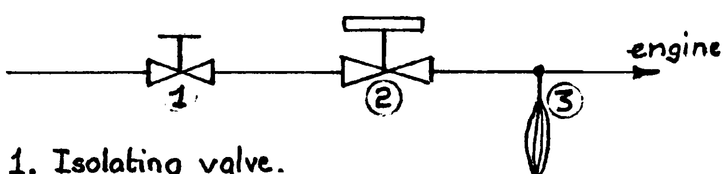
5) After allowing a warm-up period for the ignition tube of about ten minutes, the engine could be easily started by hand, flicking the flywheel about two revolutions. The speed had then to be restrained by reducing the gas supply.



1. High pressure regulating set.
2. High pressure governor. (15 lbf/ins² inlet, 13 ins W.G. max. outlet)
3. Isolating valve.
4. Pressure governor. (type Jeavons J.10.)
5. Anti-fluctuator. (flexible container)
6. Zero governor. (type Jeavons J.18.)
7. Fine control valve.
8. Tappings for vertical engine.

Minimum size of all fittings ½ inch.

FIG.4. DUAL GAS SUPPLY SYSTEM FOR THE CROSSLEY HORIZONTAL AND VERTICAL ENGINES



1. Isolating valve.
2. Pressure governor. (type Jeavons J.10.)
3. Flexible bladder.

FIG.5. GAS SUPPLY SYSTEM FOR THE ROBINSON ENGINE

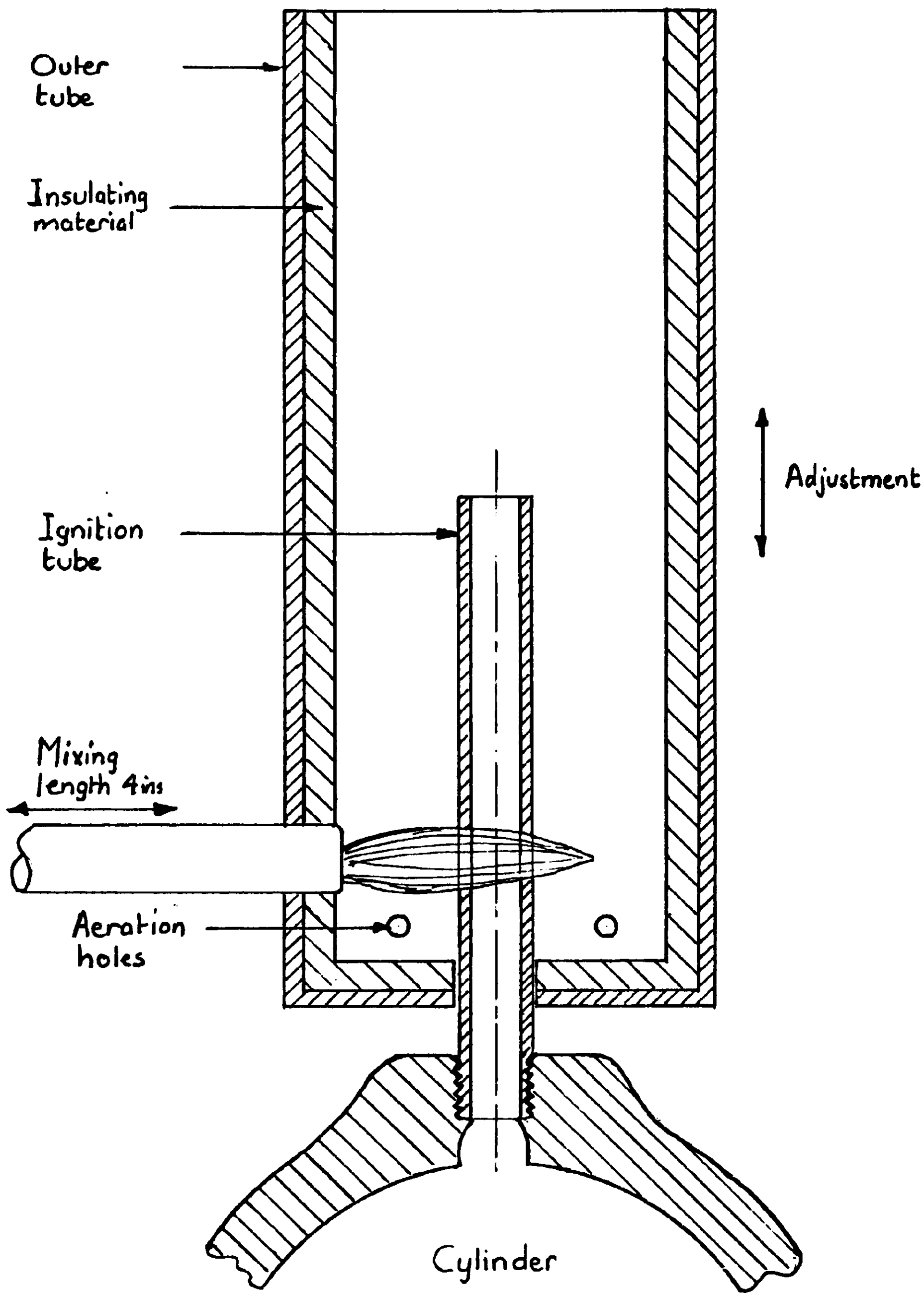


FIG.6 IGNITION TUBE AND BURNER DETAILS. ROBINSON ENGINE

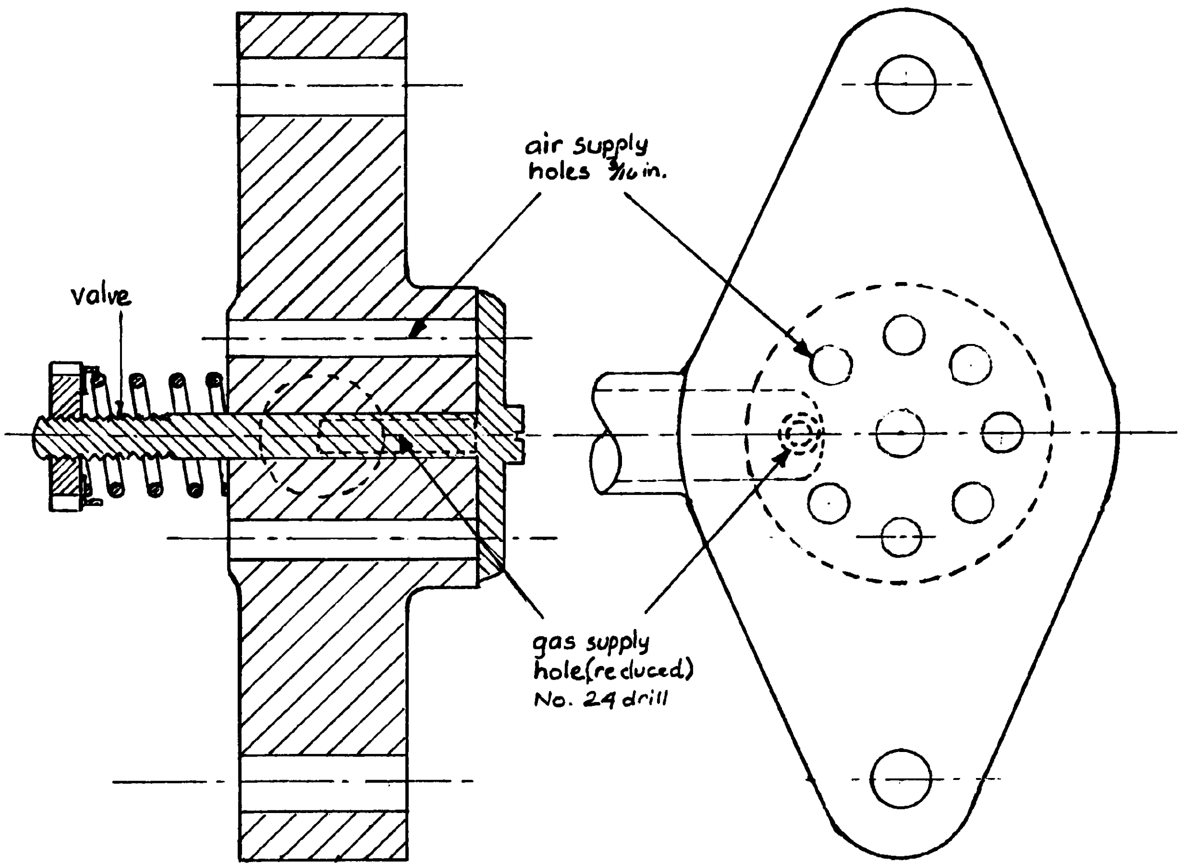


FIG. 7 GAS/AIR ADMISSION VALVE.
ROBINSON ENGINE

The Otto-Langen vertical atmospheric engine

Engine details

Cylinder bore diameter	9 inches
Maximum rack travel	3 ft 4 inches
Maximum number of ignitions per minute	30
Diameter of flywheels	4 ft 0 inches
Mode of ignition	Flame and slide valve
Normal fuel	Town's gas
Brake horse power	1
Exhaust valve	Non-return in exhaust pipe
Governing	Centrifugal
Manufacturers	Crossley Brothers, Manchester
Year of manufacture	c. 1875
Town gas consumption	44 ft^3/bhp/hour

The principle on which this engine operates is quite unlike the two previous engines described in that it does not employ compression of the charge (reference 5). The main characteristic of the engine is the 'free piston' ie. it is not attached to a crankshaft by a connecting rod, consequently, when the explosion of the charge occurs in the cylinder, full expansion is permitted by allowing the piston to ascend to its maximum capacity determined by the explosive force exerted upon it. The engine displayed in the Museum is a much improved version of the original Otto and Langen engine, which was considered to be extremely noisy when first exhibited in Paris in 1867. The firm of Crossley Brothers was largely responsible for the improvements.

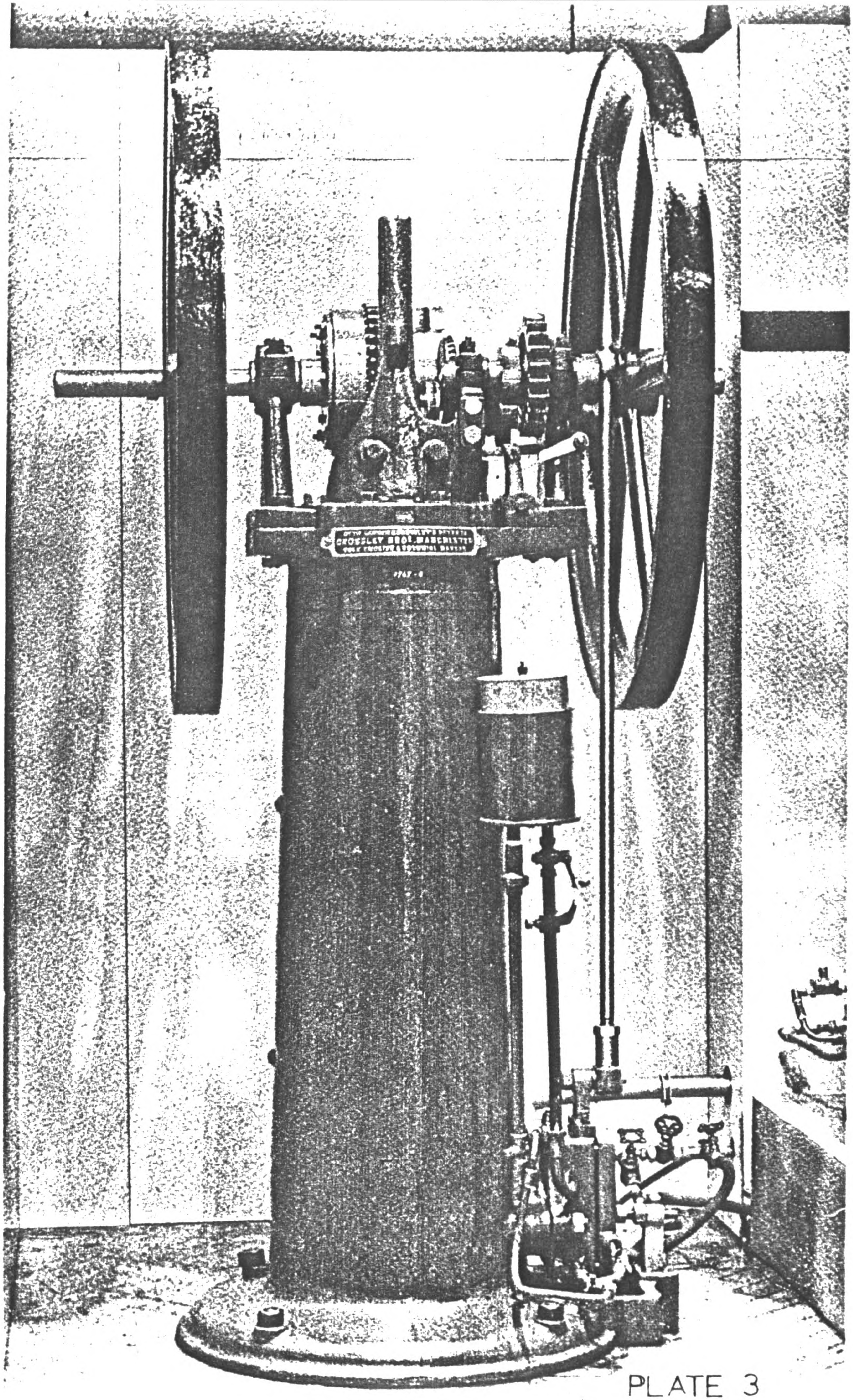


PLATE 3

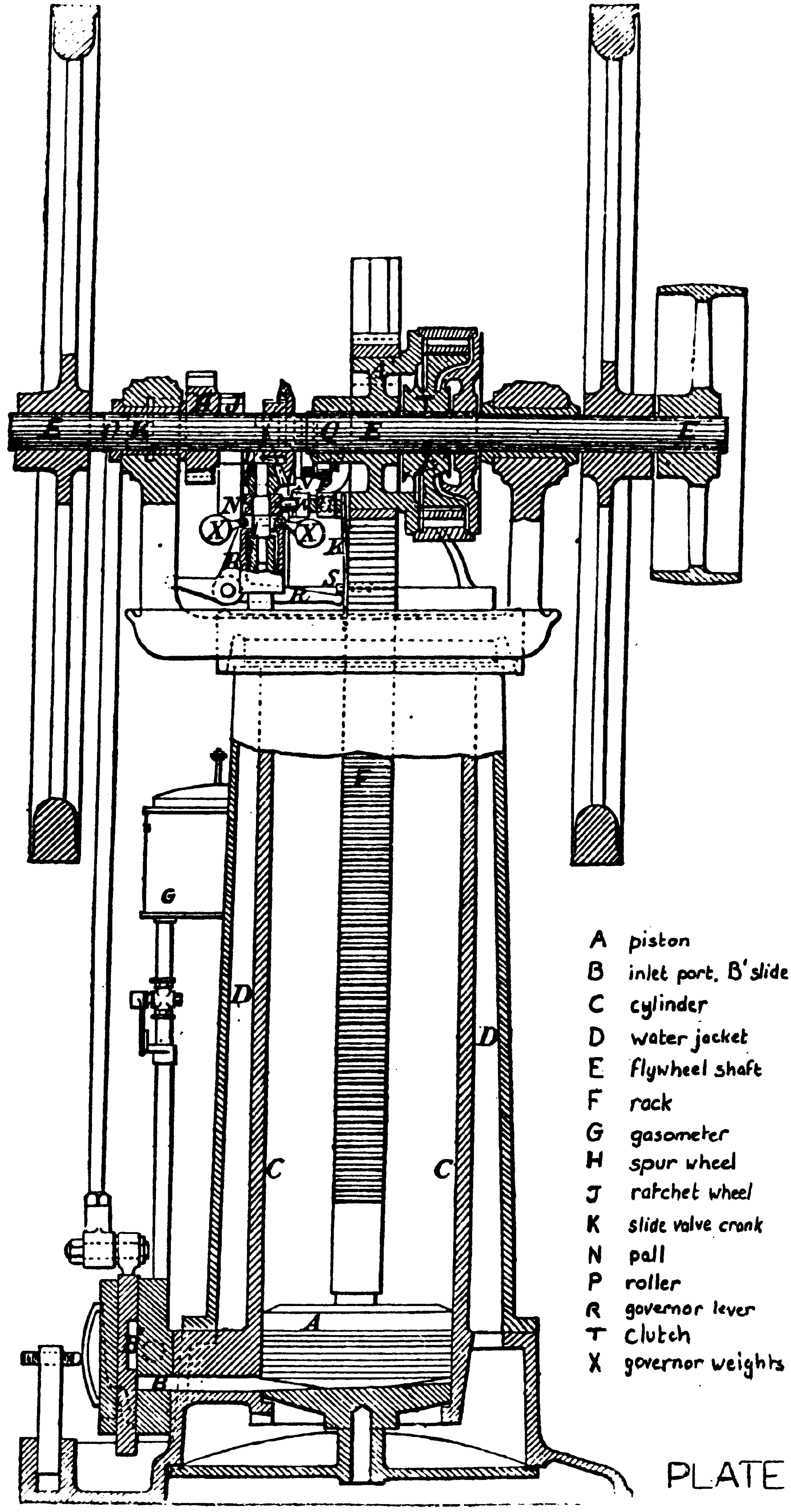

A piston
B inlet port, B' slide
C cylinder
D water jacket
E flywheel shaft
F rack
G gasometer
H spur wheel
J ratchet wheel
K slide valve crank
N pall
P roller
R governor lever
T clutch
X governor weights
E
E
E
G
D
D
C
C
A
F
X
X
B

PLATE 4

Description of operation

Referring to the sectional drawing (Plate 4), the vertical cylinder which is open to the atmosphere at the top, is surrounded by a water jacket and contained in the cylinder is the piston which weighs about 112 lb to which is attached the toothed rack. This rack is in constant mesh with a spur wheel, which is mounted on the flywheel shaft, but is not connected to the shaft except through the intervention of a clutch. It is this clutch arrangement which allows the free ascent of the piston - the rack turning the spur wheel quite freely in the opposite direction to that of the flywheel shaft - whilst the piston is on its descent, however, the clutch comes into operation, the spur-wheel, clutch and flywheel shaft rotating as one unit. It is the downward motion of the piston, therefore, that executes the working stroke. The length of the rack is about twice the circumference of the spur-wheel.

A second gear on the flywheel shaft meshes with another on a counter-shaft, along which the mechanism for controlling the slide-valve, the centrifugal governor and the raising of the piston is placed.

Cycle of operations

The piston is first raised about 4 inches of its stroke by the action of the counter-shaft when the flywheels are rotated thus allowing a charge of gas and air to be drawn in beneath the piston. Next, the mixture is ignited by a pocket of gas contained in the slide which is lit by a pilot light situated in the slide cover; upon ignition of the main cylinder charge, the piston shoots up with great force, the rapid expansion, together with the cooling effect of the cylinder walls, creates a pressure lower than that of the external atmosphere within the cylinder. When the piston is at its maximum height, the excess of atmospheric pressure over the cylinder pressure together with the gravitational effect acts on the upper side of the piston, causing it to descend.

The exhaust products are pushed out through the non-return exhaust valve by the descending piston as it nears the bottom of its stroke.

When the speed becomes excessive, the centrifugal governor actuates a lever, which in turn releases a ratchet and pawl arrangement fixed to the side of the countershaft gear-wheel; by so doing the latter is then able to rotate freely without driving the counter-shaft, the piston is not raised and the slide valve is not moved to allow a fresh charge to enter until the speed falls once more.

Operation of the slide valve

Since this engine does not employ compression of the charge before ignition, the configuration and operation of the slide valve is simpler - but nontheless ingenious - than that used on the Otto-Crossley horizontal engine.

To obtain a clear description of its working, a perspex model was made and the positions and sizes of the various ports etc. marked on Figure 8a shows the position and shapes of the ports and passages on the outer side of the cylinder face. Figure 8b is the slide, the dotted lines representing the passages machined on its inner face. Figure 8c is the outer cover, which is held in position by 4 dowels. A seal is obtained by a threaded bolt which is adjusted to act on a semi-elliptical piece of spring steel, the end of which contact the outer cover. The position of the slide shown in Figure 8d is that which it occupies at the start of a cycle.

When the flywheel shaft is rotated, it causes the piston to be raised about 1/11 of its full stroke - about 4 inches and the slide descends, finally occupying the position shown in Figure 8d. Before it reaches this lowest position, however, at about half way, the communication from the cylinder to the exhaust port is made complete by the passage C, the burnt products from the previous cycle are therefore expelled.

In the lowest position, Figure 8d, it will be seen that passage A now allows gas to flow to passage B, mixing with the air in the latter and then passing into the port P, which communicates with the base of the cylinder. Meanwhile, the gas in the igniting port I has been ignited and a pocket of burning gas is now contained there. The slide now rises until the igniting port aligns with port P, igniting the new charge present there and hence bringing about the explosion which thrusts up the piston.

A puzzling aspect concerning the purpose of the shallow passage S, which connects the two ports P and E, was revealed by the model of the slide valve. In order to rid the cylinder of burnt gases prior to the new cycle, the exhaust port is positioned slightly higher than the inlet port P, so that the descending slide will connect the exhaust port and port E first. By so doing, however, the piston as it descends will seal off port E preventing the exit of the exhaust gases remaining in the cylinder. They would also be compressed preventing the full descent of the piston in the cylinder and being trapped therein would dilute the new charge - perhaps even prevent the full quantity being drawn in.

The passage S prevents this situation from happening by allowing the last portion of exhaust gas to pass along it from the port P to the port E and exit via the passage C and exhaust port.

Gas supply system

Experiments with this engine involved the use of both simulated town gas and natural gas with means of effecting a changeover. Since the dual system shown in Figure 4 devised for the horizontal engine was conveniently placed to serve the vertical engine also, it was only necessary to make simple tappings and place a further governor in the line to reduce the gas pressure below that which was found suitable for the horizontal engine.

The reservoir which acts as the antifluctuation device is shown in Figure 9 and is similar in principle to the gasometer, ie. a loose fitting inverted container which is raised and lowered by the gas contained beneath it: a seal is provided by a quantity of water in the base. By this method, the pressure of the gas supplying the engine is kept reasonably constant at about 1 inch water gauge.

The device was not used, however, it being replaced by a flexible bladder which was found to be more tolerant of the pressure changes in the gas system resulting from the experiments. The two open ends were simply joined and a tapping inserted to which was attached the bladder.

Air/gas ratio

References made to various articles and periodicals appertaining to this engine revealed wide variations in the estimates of the proportions of gas and air admitted into the cylinder. Thus, in a paper read before the members of the Institute of Mechanical Engineers in 1875 (Reference 3) Mr. F. W. Crossley stated that calculations to obtain the efficiency of this engine has been based on an explosive mixture consisting of 1 volume of gas to 6½ volumes of air, whereas experiments have shown that the proportions were 1 : 8. In the English Mechanic (Reference 4) a correspondent stated that 'he had before him a prospectus of the patentees stating that 1 volume of gas was mixed with 9 volumes of air'. Tests carried out by M. Tresca of the Conservatoire des Arts et Metiers in Paris and reported in the I. Mech. E. paper (Reference 3) states that '1 volume of gas with 27 volumes of air, subsequently increasing to 54 volumes of air' was used.

The latter can clearly be dismissed as incorrect and unpractical. Experiments carried out on explosive mixtures using town's gas by Dugald Clerk (Reference 1) beginning in 1883 the results of which were read to the Institute of Civil Engineers in 1884 by Professor Fleeming Jenkins (Reference 2) and also later experiments made by Clerk in 1885 (Reference 1), which were published in 1886 indicated that the maximum air/gas ratio that was capable of any useful effect to an engine was 1 volume of gas to 15 volumes of air with a ratio of 1 volume of gas to 6 of air giving maximum pressure.

Measurements of the air and gas ports of this engine showed that they were in proportions 1 : 4.05 gas to air. Clearly, therefore, no satisfactory conclusion could be reached as to what proportions the engine actually used although the available evidence would indicate that a ratio of something like 1 : 8 or 9 was probable, if this was so, then these figures lie just within the flammability limits of natural gas and it should therefore be possible to run the engine using natural gas. It was, therefore, decided that an attempt to run the engine on natural gas should be made without any modifications by first starting it on simulated town gas and then changing over to natural gas, in that way a more effective control of the quantity of gas admitted could be exercised. Simulated town gas was used on the ignition.

The change over was achieved in a remarkably smooth manner, the only adjustment found necessary to keep the engine running was that the gas cock regulating the flow into the engine was required to be slightly reduced, indicating perhaps that the mixture was slightly over rich in gas. The working gas pressure was set to 2 inches water gauge.

Starting tests - flame adjustments

With the engine in the unmodified state, starting proved to be a more difficult operation when natural gas was used. The method found best consisted of first imparting a reasonable momentum to the flywheel shaft. When this is done, the gas cock is turned on and the engine subsequently fires. On some occasions, however, a delay occurs between the moment the gas is turned on and the first ignition and, judging by the force of the next explosion, allows an accumulation of a highly explosive charge in the cylinder. When town gas is used for starting, it occurs almost instantly the gas is turned on, making the risk of such an accumulation of gas much less.

When attempts were made with the ignition on natural gas, similar difficulties to those experienced with the horizontal engine were experienced, although to a lesser extent, in that the ignition flame was frequently extinguished when the slide valve descended (due to unburned gas in the slide pocket igniting on contact with the pilot light). Adjustments to the coarse valve supplying gas to the slide produced only marginal improvement and the uninterrupted performance that results when town gas is used on the ignition could not be achieved.

From the results of these tests, it would appear that the quantity of natural gas being supplied needs to be reduced so that in the event of non-ignition during starting, the accumulation of a very explosive charge within the cylinder will be avoided. This is best achieved by blanking off at least one of the five gas check holes in the slide.

The conclusions resulting from the tests carried out on this engine are as follows:

1) With modifications consisting only of those to reduce the gas supply pressure, the engine can be run on natural gas, its being necessary to reduce slightly the quantity supplied by means of the main cock situated close to the slide valve.

2) With the ignition system on natural gas, there is a tendency for the pilot light to be extinguished at infrequent intervals; this is caused by an excessive quantity of gas which is present in the slide. It is possible that this may be rectified by using a valve with much finer control than the present one.

3) In the majority of cases, a satisfactory start can be made using natural gas, occasionally, however, if the first firing stroke occurs somewhat late, a highly volatile charge accumulates in the cylinder resulting in an alarming explosion on the subsequent firing stroke. This to some extent can be overcome by very careful control of the gas valve when starting. A more satisfactory method, however, is to reduce the gas supply to the engine by blanking off one of the gas check holes in the slide. It is intended that this will be done, but is not considered urgent since the procedures outlined above for starting and running are satisfactory.

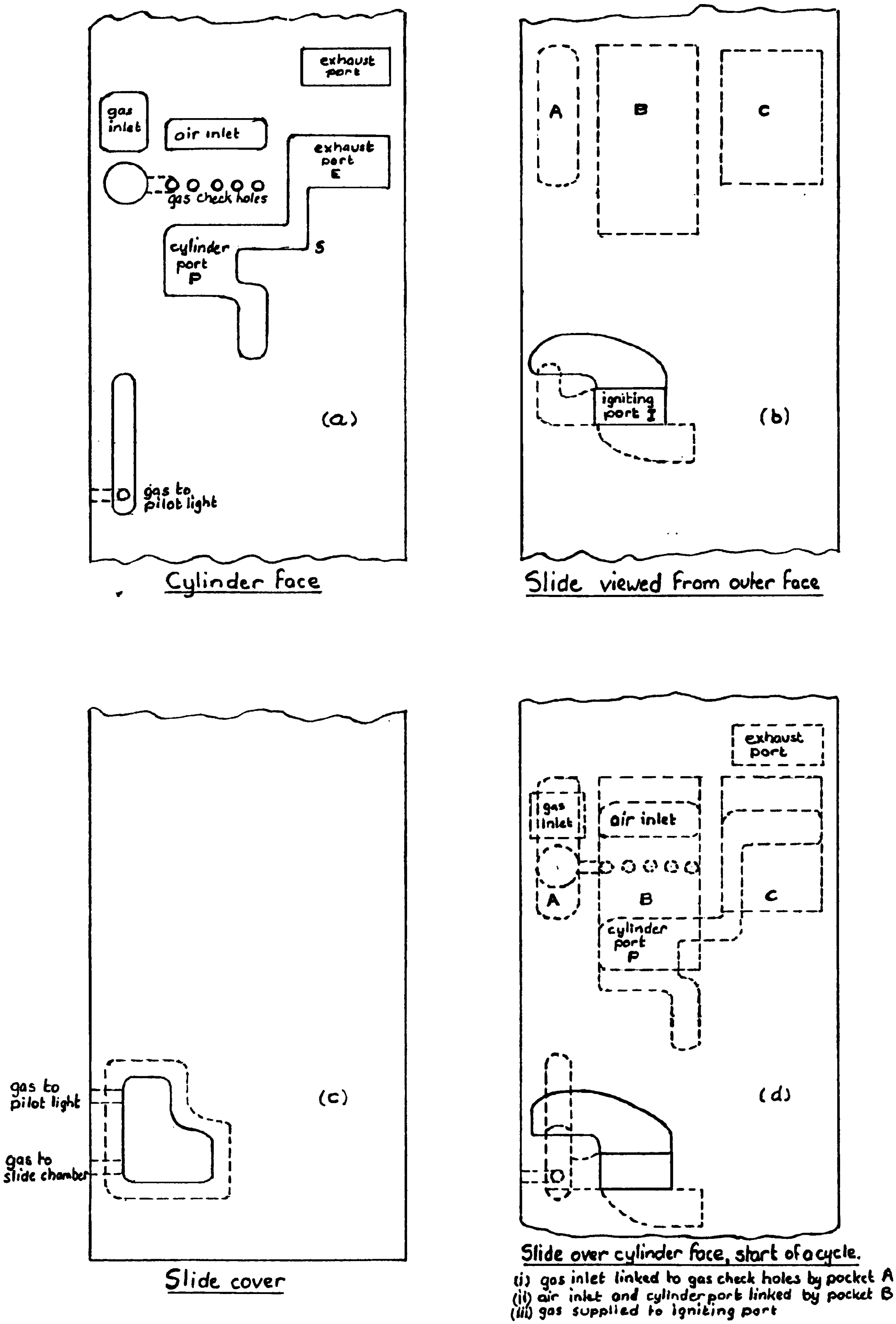
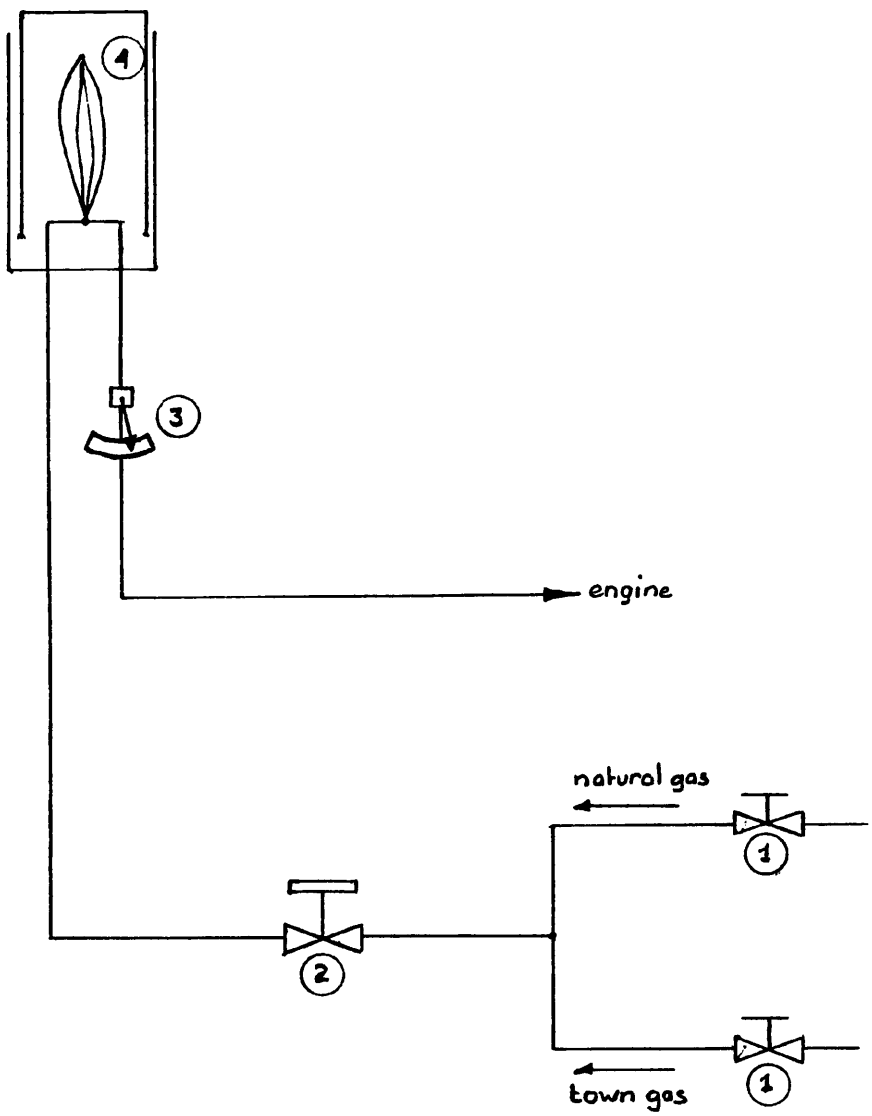


FIG.8 SLIDE VALVE DETAILS OTTO-LANGEN



1. Isolating valve
2. Jeavons J.17 governor
3. Main gas cock
4. Gasometer containing bladder

FIG.9 GAS SYSTEM OTTO-LANGEN ENGINE

General comments

The work carried out on these three old engines, which has now enabled them to run on natural gas, has proved an interesting and worthwhile exercise.

In the case of the horizontal and vertical engines, it has allowed a full appreciation of the working of the slide valve and flame ignition characteristics which previously was largely a matter of conjecture and has revealed some of the problems with which the early pioneers of gas engines had to cope in their attempts to produce a satisfactory method of ignition which was certainly high on the list. The design and timing details of the slide valve must have been what in modern day terms would be called a 'draughtsman's nightmare' and one can but have profound respect for the originators in bringing it to a successful working form - despite its shortcomings - to give reliable service until about 1888, when this method of ignition was eventually abandoned in favour of the hot tube.

The fact that these engines can be made to run on a variety of fuels is a further tribute to the ingenuity of these 19th Century engineers.

Since each of the three engines has a distinct mode of operation, the horizontal Crossley employing compression with a slide valve and flame ignition, the Robinson engine also using compression but with hot-tube ignition and the Otto-Langen Atmospheric engine using 'free expansion' with a slide valve and flame ignition of a different principle from the horizontal engine, the problems encountered during the experiments were, in the main, separate and distinct. Those of the horizontal Crossley engine for instance evolved largely in getting the ignition flame to carry out within the slide, obtaining a suitable gas pressure for starting and running and providing a satisfactory method of restricting the gas supply.

The work on the Robinson engine was largely concerned with providing a suitable burner and ignition tube as well as a suitably placed restriction, whilst in the atmospheric engine - the least troublesome of all - only a slight modification to the slide valve is required.

By far the greatest amount of the work was involved with the Crossley horizontal engine, this proving contrary to an initial assessment which was made of the kind of problems likely to be encountered in which it was believed that the Robinson engine would be the most troublesome. This belief stemmed from the knowledge that attempts by the Industrial Development Centre of North West Gas and other Institutions possessing engines of this type (there are a surprising number still in existence) who had encountered difficulties. In many cases, the ignition tube had been removed and electric ignition substituted in its place. In the event, however, of conversion of the hot-tube ignition Robinson engine was relatively straight-forward.

Judging from recent communications received by the author, it would seem that spark ignition - either magneto or induction coil - the problems of conversion are much less and of a more simple nature. Several factors may contribute to this. The electric spark is a high energy source and easily capable of igniting a combustible mixture of natural gas and air; the engines to which magnetos are fitted will date from about 1905 at the earliest by which time vast improvements had been made in respect of design; compression ratios had increased from about 2 to 1 in 1880 to about 6 to 1; lift valves of the mushroom type had now become standard practice and the design of ports and combustion chambers reflected the knowledge gained from experiments and researches that took place in the latter 1880's and during the 1890's. Engines were also of much larger size and power output and piston speeds were greater. The main considerations in a conversion of such engines is that the ignition timing is advanced about 6^o to 8^o to counteract the slower flame speed of natural gas and a restriction to the gas supply is made by either reducing the port area or reducing the lift of the gas admission valve.

Finally, it is hoped that this report may be of some value to those institutions (Museums, Colleges, etc) who have had or are having difficulties with engines which previously were running satisfactorily using town gas. At some future date, however, it is intended that the work described in this report will form a technical appendage to research work which is currently being carried out. If, therefore, it is desired to communicate or copy out any part of the work contained herein, it would be appreciated if notification of such intention was given to the author.

References

1) Clerk, D. The Gas Petrol and Oil Engine 1910 Vol I p. 138 and p. 143

2) Jenkin, F. 'Gas and Caloric Engines' A paper read by Professor Jenkins before the Institute of Civil Engineers 1883-4.

3) Crossley, F. W. 'On Otto and Langen's Atmospheric Gas Engine and some Other Gas Engines'. A paper read by Francis W. Crossley before the Institute of Mechanical Engineers 1875

4) The English Mechanic (1874) Vol 18 p. 191

5) Engineering Vol. 20 Dec. 1875 p. 514 'Otto & Langen's Gas Engine'.

6) The Industrial Development Centre, North West Gas, Stretford, Manchester.

APPENDIX TWO

The various agreements between N. A. Otto and Co. of Cologne; Langen, Otto and Roosen of Cologne and Messrs Simon and Crossley of Nottingham and Manchester respectively. These agreements consist of:

1) That between Louis Simon and Son of Nottingham and N. A. Otto and Company of Cologne - 3 December 1868:

   This is the first agreement related to gas engines that was ever made between German and English firms. It describes, quite explicitly, how Simons were appointed agents only to receive and sell engines from Germany; also that they were obliged to find a manufacturer in Great Britain after they (Simon's) had demonstrated an engine in London.

2) That between Crossley Brothers and Langen, Otto and Roosen - 20 August 1869:

   The bid to find a manufacturer had obviously materialised. The Crossley Brothers of Manchester had become involved and this agreement outlines the arrangements that were made which would enable them to manufacture the Otto-Langen Atmospheric Engine in Great Britain, should they so desire. They were allowed to sell engines, however, only to Simons, who would then market them.

3) That between L. Simon and Son and Langen, Otto and Roosen - 25 October 1869:

After testing an engine sent over from Germany, Crossleys decided to become manufacturers. This new situation had an effect upon the existing arrangements between Simon's and Langen, Otto and Roosen. This agreement, therefore, authorises Simons to be the sole sales agent for Great Britain and Ireland, The Colonies excepted. Engines were now to be received from Crossleys. Clause II describes an arrangement by which the sales activities would go to Crossleys 'three months after seventy-five engines had been sold'.

4) That between Crossley Brothers and Langen, Otto and Roosen - 15 June 1870:

The Crossley Brothers became the sole sales agents and manufacturers of atmospheric gas engines from the date given above. Note Clause 13, which provides an option for Langen, Otto and Roosen to obtain yet another manufacturer in Great Britain, if they felt the need.

The letter given at the end of this appendix describes a private arrangement that was made between the Crossley Brothers and Simons, overcoming certain delays in payments that were due to Crossleys. It will be seen, in fact, that Crossleys became sub-agents to Simons.

AGREEMENT BETWEEN LOUIS SIMON AND SON OF NOTTINGHAM, AND N.A.OTTO AND CO. OF COLOGNE

3 DECEMBER 1868

We = N.A.Otto & Co., You = L.Simon and Son

Clause 1

We hereby authorise you to be responsible for the sales of our Atmospheric Gas Engines in Gt. Britain and Ireland.

Clause 2

In Manchester and surroundings, our old friends, Messrs Roosen and Cornelsen (from Jan 1 1869, N.F.Cornelsen) of 22a South King St, Manchester, shall safeguard our interests for all engines sold in that district, the commission to be split in half for each of you.

Clause 3

You, in conjunction with us, are the buyer and are responsible for accounts and payments.

Clause 4

We will ship the ordered engines direct to the customer, the account to be sent to you. The following prices will be charged from the factory in Cologne. (without packing).

¼hp. with governor 250 Talers. Packing, 5 Talers

½hp, with governor 400 Talers. Packing, 8 Talers

½hp, with governor 375 Talers. Packing, 8 Talers

1hp, with governor 515 Talers. Packing, 12 Talers

2hp, with governor 640 Talers. Packing, 15 Talers

* Taler - a German monetary unit used up to 1891, equal to three gold marks.

These prices include the complete engine and cooling tank, a flexible bladder, 3 gas cocks, fittings and complete set of spanners. Not included are pipes to connect the tank and engine with gas and water.

Clause 5

It is up to you to increase the price of the 2hp engine to that of the Hugon of the same output, in which case, half of this increase is for you and half for us.

Clause 6

It is up to you to offer these engines to the public at a price greater than that already stated which will include freight and packing charges from Cologne to a British Port. You must then inform us of these prices.

Clause 7

We will give you a commission of 10% on all engines you sell in England, Scotland and Ireland.

Clause 8

We will charge you the nett price for the engines, to be paid two months after receipt of the account. We will send you with the account, a Bill of Exchange which you will sign and return immediately. We are willing to accept a cheque from you at the date of expiration which you will forward to N.F.S.Cornelsen in Manchester.

Clause 9

You promise to improve sales activities in the United Kingdom with all your power, by travelling and other suitable means, without asking for costs or travel expenses.

Clause 10

For the cost of adverts in suitable papers and journals, you will pay 1/3 and we will pay the rest. For the cost of printing prospectuses, manuals and all other printed materials, N.A.Otto and Co., will pay the first £15 sterling, any costs exceeding this amount to be paid by you.

Clause 11

You will attempt to obtain from customers, references which you will then send to us. We, in return, will send you ours. Such references will be printed from time to time.

Clause 12

You agree not to sell any gas engines other than those concerned in this agreement, nor to support their sales.

Clause 13

You agree not to produce our engines yourself without our permission, nor to let them be produced by others but to buy them only from us or from someone duly authorised by us.

Clause 14

We deliver to London a half-horsepower engine where you will install it to drive your bronzing machine so that potential customers can see the engine working. You will pay the cost of transporting this engine. We will retain ownership of it and reserve the right to decide on its sale, depending on whether or not a certain number of engines are sold in London (which will serve as references) or the engines should be produced in your country and no longer shipped over.

Clause 15

Should we feel you are not as sufficiently active in promoting sales as one would normally expect of an agent, we reserve the right to cancel this agreement.

Clause 16

If, as a result of the demonstration of this engine to the public, it should prove acceptable, you will attempt to find someone who will either buy the invention or produce the engine against a royalty, in and for Gt.Britain and Ireland or, a certain part of it, in which case, three months period of notice must be given to cancel this agreement with you. Should the engines be produced by someone for only a part of the United Kingdom, you will continue as agent for the remainder and we will continue to supply you our engines. In any case we promise you that we will safeguard your sales activities and will attempt to obtain an arrangement which will enable you to continue as sole sales agent. Should it transpire that you sell the invention, we will pay you a commission of 15% of the money received, but should you succeed in finding someone who will build the engine in London against a royalty, you will receive a commission of 20% of the royalty. This commission of 15% or 20% respectively, will be divided between you and Herr Cornelsen in a manner yet to be agreed.

Clause 17

You will arrange for a special record of sales to be kept in a proper manner, this record to be available for inspection by us at any time.

Signed. N.A.Otto & Co.

AGREEMENT BETWEEN MESSRS. CROSSLEY BROS. OF MANCHESTER AND MESSRS. LANGEN, OTTO AND ROOSEN OF COLOGNE

20 AUGUST 1869

Clause 16 of the December 1868 agreement between Simon's of Nottingham and N.A.Otto, in which Simon's (and perhaps Roosen and Cornelsen also), were under obligation to find a manufacturer had obviously materialised. Discussions with Crossley Bros had apparently taken place and this agreement describes how Crossley's were given the opportunity of deciding whether or not they would become a manufacturer of Atmospheric Gas Engines for the firm of Langen, Otto and Roosen.

Evidence exists in the archives of Klöckner-Humboldt-Deutz that Langen had communicated with Crossleys by a letter, dated 16 June 1869, but no record of this letter can be found.

Clause 1

Langen, Otto and Roosen will send one atmospheric engine to Crossley Bros. of Manchester in order that Crossley's may examine it and test it. This engine to be sold within one month to the German firm's customer, Mr.Sydney Smith of Manchester. After the examination and sale, Crossley's to decide whether or not to enter into a Contract and to become a manufacturer (but not to sell direct to the public) with a view at some future date, to becoming an agent for sales in the United Kingdom, excluding the British Colonies.

Clause 2

In the event of a positive decision by Crossley Bros. to enter into a Contract, Langen, Otto and Roosen will send them a complete collection of drawings for all four sizes of engines; ¼hp; ½hp; 1hp and 2hp in order that Crossley Bros should work from the drawings to build the engines. The cost of the drawings to be £30 if tracings and £10 if blueprints.

Clause 3

Crossley Bros. to pay £50 in advance when signing the contract. After 75 engines have been sold in the U.K. Crossley Bros. were to continue building engines for Langen, Otto and Roosen, for a period of three months. Langen, Otto and Roosen to pay Crossley's the full list price of such engines less 17½% for the first 50 engines and less 20% for subsequent ones.

Clause 4

The prices of the engines which may only be changed by agreement between the two parties concerned is to be:- £42 for ¼hp. £60 for ½hp. £80 for 1hp. £110 for 2hp.

Clause 5

At the end of the three month period (Clause 3), Langen, Otto and Roosen would engage Crossley Bros. as the only agent and Manufacturer of Atmospheric Gas Engines for the United Kingdom and Ireland, excluding the British Colonies. Crossley Bros. to pay a License fee of 7½% of the list price up to 50 engines and 10% for all subsequent engines.

Clause 6

Crossley Bros. are obliged not to produce, or sell, any other engines except those of the Otto and Langen Patent.

Clause 7

Crossley Bros. will manufacture and sell these engines only for the United Kingdom and not for any other country.

Clause 8

All engines produced under this contract must display in a prominent position a name plate which says

LANGEN AND OTTO PATENT

and the serial number of the engine. No number must be taken more than once and all engines which are produced and sold must be recorded in a book, which, at all times shall be available for inspection by Langen, Otto and Roosen or their appointed agent.

Clause 9

License payments to be paid every third month. In the case of the engines produced for Langen, Otto and Roosen and which are sold by them, the license fee to be paid monthly.

Clause 10

After acquiring sales rights, all costs incurred with respect to advertising, printing and announcements etc, by Crossley Bros. to be paid by them.

Clause 11

Crossley Bros. are required to produce engines strictly to the drawings. This applies to the measurements as well as the materials used. Any modifications made to the engine should be agreed on a written basis (the latter to be treated liberally).

Clause 12

During the period the contract is in force, any improvements or ideas by either party should be freely exchanged. In such cases, no extra license fees would be incurred.

Clause 13

Crossley Bros. to agree to make such arrangements that would enable them to manufacture 25 engines in the first year, and in subsequent years, 50 engines per year if required. On failure to comply with these numbers, Langen, Otto and Roosen would then be free to appoint another manufacturer in the United Kingdom and the agreement hitherto described would be cancelled. On the other hand, in the event of compliance, the terms so far described, shall be valid as long as the patent is in force.

Clause 14

In the event of the patent of Otto and Langen infringing that of any other that may anywhere exist, whereupon Crossley Bros. may be called upon to pay a penalty, the said Crossley Bros. would be compensated by Langen,Otto and Roosen for any inconvenience resulting therefrom.

Signed. Crossley Bros of Manchester.

AGREEMENT BETWEEN LOUIS SIMON AND SON OF NOTTINGHAM

AND LANGEN, OTTO AND ROOSEN OF COLOGNE

25 OCTOBER 1869

This agreement is a direct result of clause 16 of the December 1868 agreement between Simon's and N.A.Otto & Co., having been implemented. Crossley Bros. had obviously decided to become manufacturers (see agreement 20 Aug. 1869) and consequently, a new arrangement was necessary between Simon's and the newly founded firm of Langen, Otto and Roosen.

Under the terms of their first agreement with Simon's, (13 Dec 1868) N.A.Otto and Co were pledged to safeguard the interests of Simon's in the event of a manufacturer being found. Hence, this rather complex new agreement which permitted Simon's to sell engines but not manufacture them, and Crossley's to manufacture them but sell them only to Simon's.

We = Simon and Son | You = Langen, Otto and Roosen

Clause 1

You authorise us to be the sole sales agent for engines, produced by Crossley Bros. of Manchester, in Gt. Britain and Ireland, The British Colonies excepted.

Clause 2

We, in conjunction with you are the buyers and are responsible for the accounts; to see that the customer receives the bill and that you receive the money.

Clause 3

As your agent, we will charge the customer the following prices which can be changed only with the agreement of you and Messrs Crossley Bros. From the factory, delivered in Manchester (packing extra)
¼hp £42; ½hp £60; 1hp £80; 2hp £110.

Clause 4

We receive a commission of 10% of list price for the first 75 engines.

Clause 5

We will obtain the cash from the customer, deduct our commission and on your behalf, forward the balance to Messrs Crossley Bros. In the cases where no cash is paid, a Bill of Exchange will be accepted from the customer, this will then be forwarded to you with our endorsement. For the purpose of calculating interest, the period will be two months from the date of the account.

Clause 6

We promise to improve sales activities of your engine in the United Kingdom with all our power by travelling and other suitable means. All travel expenses and other costs to be borne by us.

Clause 7

For the cost of adverts in suitable papers and journals, we will pay 1/3 of the cost and you the remainder. For the printing of prospectuses, manuals and other printed materials, you will pay £15 should such costs exceed £15, we will pay the balance.

Clause 8

We will obtain from customers, references regarding engines sold to them and will forward them to you. You will send us the references you have obtained.

Clause 9

We agree to sell only engines concerned with this agreement and to the sales of gas engines other than these, we will give no support.

Clause 10

We agree not to produce your gas engines ourselves nor to, let them be produced by anyone else other than an authorised company and to obtain them only from such a company.

Clause 11

Three months after 75 (seventy-five) engines have been sold (having been produced according to your patent as registered in the United Kingdom) the sole sales activities will then go to Messrs Crossley Bros of Manchester and we will have no claim upon you in respect of any engines sold. In this event, we will form an arrangement with Crossley's and receive a 15% Commission on the royalty you receive from Crossley's. In return, we are obliged to safeguard your interests in respect of Crossley's.

Clause 12

We will keep a record of sales in a proper manner which at all times will be available for inspection by you.

Clause 13

Should you feel that we are not as sufficiently active in the sales of your engine as you would normally expect of an agent, you reserve the right to cancel this agreement. In the event of differences arising, we agree to subject ourselves to an examination of your Court and in such a case, we would choose a solicitor in Cologne.

Signed. Louis Simon & Son, Nottingham.

CONTRACT BETWEEN MESSRS. CROSSLEY BROS. OF MANCHESTER AND MESSRS LANGEN, OTTO AND ROOSEN OF DEUTZ, COLOGNE

15 JUNE 1870

This contract is signed by Langen, Otto and Roosen and dated three days after a similar contract of 12 June 1870 which is signed by Crossley Bros.

This earlier contract is described as "between Langen, Otto and Roosen and Crossley Bros." An explanation of this is that in communicating with each other, the clauses, first drawn up by Langen, Otto and Roosen on the 12 June and then signed by Crossley Bros, were repeated in extense by the latter on the 15 June and then signed by Langen,Otto and Roosen.

Clause 1

Langen,Otto and Roosen authorises Crossley Bros. of Manchester to be their sole manufacturer and sales agent for their guaranteed Atmospheric gas engines for Great Britain and Ireland, excluding the British Colonies.

Clause 2

Crossley Bros to pay a provision fee to Langen,Otto and Roosen of 10% of the list price and in addition 2½% for the first 50 engines.

Clause 3

Prices of engines which are to be agreed by both parties are:-
£42 - ¼hp. £60 - ½hp. £80 - 1hp. £100 - 2hp. These prices do not include packing and transportation.

Clause 4

Crossley Bros. are to produce and sell these engines only in Great Britain and Ireland and not in any other country. Neither in the British Colonies.

Clause 5

Crossley Bros. are obliged to manufacture and sell no other gas engines in the United Kingdom than those of Langen, Otto and Roosen.

Clause 6

All engines built under the terms of this contract must have displayed in a prominent place a nameplate which says

LANGEN AND OTTO PATENT

and the serial number of the engine. No number is to be used twice and all engines produced are to be recorded in a special book which should be available at any time to Langen, Otto and Roosen or any person appointed by them.

Clause 7

Crossley Bros. are to supply Messrs Simon & Son of Nottingham on the account of Langen, Otto and Roosen 3 - ½hp engines and 2 - 1hp engines. These to be paid for by a reduction of the provision to be paid to Langen, Otto and Roosen. Such provision to be paid quarterly by Bankers Order.

Clause 8

All costs incurred due to advertising, printing, etc, including transportation of engines sold, to be paid by Crossley Bros.

Clause 9

Crossley Bros. are obliged to produce engines exactly to the drawings and measurements and materials as supplied and directed by Langen, Otto and Roosen, and no modifications or improvements are to be made without permission of Langen, Otto and Roosen, (the latter to be exercised in a liberal manner).

Clause 10

Improvements by either party effected while the contract is in force may be patented in Gt. Britain and Ireland by the inventor: it being left to the discretion of either party as to whether or not they make use of such improvements. In the event of their being used, no payment or provision will be made. In all other countries except Gt. Britain and Ireland, all such improvements may only be patented by Langen, Otto and Roosen.

Clause 11

Crossley Bros. are obliged to produce and sell, 25 engines in the first year from the First of July 1870 onwards, 25 engines in the first year and 50 engines in each of the following years. Failure to comply with this will enable Langen, Otto and Roosen to cancel the contract and be free to appoint another manufacturer to produce their engines. In this event, Crossley Bros. would no longer be liable in any way to Langen, Otto and Roosen.

Clause 12

In the event of the Patent of Otto and Langen infringing that of any other that may anywhere exist, whereupon Crossley Bros. may be called upon to pay a penalty, the said Crossley Bros. would be compensated by Langen, Otto and Roosen for any inconvenience.

Clause 13

Should Langen, Otto and Roosen have the opportunity to find persons to form a new company and build their engines in the United Kingdom, Crossley Bros. would be obliged to give such a new company every assistance in their own interest. Also, Crossley Bros. should form an arrangement with the new company, whereby Crossley's would eventually undertake the full sales activities of the engines. Crossley's should arrange to supply the new company with engines at a special price which should be a matter of agreement.

Clause 14

This contract supersedes the contract or agreements hitherto in force between Crossley Bros. and Langen, Otto and Roosen.

Signed Langen, Otto and Roosen.

Letter from Crossley Bros. of Manchester, to Messrs Simon and Son of Nottingham

Dated Oct, 27, 1869

This letter indicates that verbal consultation between Crossley's and Simon's had taken place, with a view to allowing Crossley's to become a sub-agent of Simon's and hence sell engines, which previously only Simon was allowed to do.

The need for this provision appears to have been necessary since, in a letter dated Sept 22, 1869 written by Crossley Bros. to Langen, Otto and Roosen, Crossley's complained that they were entirely in the hands of someone over whom they had no control, particularly with respect to the money due to them resulting from engines sold by Simon.

> "Referring to our conversation and your letter, we now write to you, substantially confirming our verbal agreement:-
>
> 1st. It relates only to those cases in which we sell engines for you - having nothing to do with what will no doubt be the chief part of our business during your agency, namely, selling engines to Messrs Langen, Otto and Roosen to be again sold through you.
>
> 2nd. When we ourselves sell engines as your sub-agents, we must receive from you before delivery of engines, an invoice of same, directing the purchaser, to settle the amount with us. (15% of which we pay to you).
>
> 3rd. You alone can invoice the engines, but when we are the sellers, the invoice will extend to the price of the engines only (which of course is already fixed by the list prices). Packing, and other extras if supplied, will be invoiced by us.
>
> 4th. When we act as your sub-agents we shall receive half your commission, or 5% on the list price, for which, since we agree to divide the responsibility of the sales with you, always, however, notifying you of the persons dealt with so that should you discredit them, we must either take the whole responsibility or decline the order.
>
> 5th. So long as we remain your sub-agents, we agree to pay one half of your share of the Manchester advertisements. Our name appearing with yours.
>
> 6th. This agreement will terminate three months after 75 engines have been sold in the United Kingdom or previously, at the option of either party to it or, (say) one month after notice being given in writing by one at the known address of the other.

Referring to clause 2. Our agreement with Cologne is to pay only 7½% royalty on the first 50 engines, and as we have paid (as per agreement) a certain amount of this in advance, we shall at first have only to credit you with your own commission on the sales, namely 5%.

We hardly think it worthwhile to alter the list price to Hugon's but will mention it in our next to Cologne and now hope we shall be able to do some good business together.

Requesting you to acknowledge this letter, repeating the clauses in extense.

We are Gentlemen, yours faithfully,

Signed Crossley Bros.

APPENDIX THREE

A reproduction of testimonials of users of Crossley Gas Engines in various branches of industry between the years 1877 and 1887

CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

20,000. 5.88.

THE "OTTO" GAS ENGINE

OVER 27,000 DELIVERED.

List of Awards

1885—Society of Arts Inventions Exhibition, London—GOLD MEDAL.
1881—Adelaide International Exhibition, Adelaide—GOLD MEDAL.
1884—Crystal Palace International Exhibition, London—GOLD MEDAL.
1881—Melbourne International Exhibition, Melbourne—GOLD MEDAL.
1885—International Inventions Exhibition, London—GOLD MEDAL.
1884—International Health Exhibition, London—GOLD MEDAL.
1880—Wirral and Birkenhead Agricultural Society's Exhibition, Liverpool—GOLD MEDAL.
1882—Bradford Fine Art and Industrial Exhibition, Bradford—GOLD MEDAL.
1882—New Zealand International Exhibition, Christchurch—GOLD MEDAL.
1881-2-5—Wirral and Birkenhead Agricultural Society's Show, Liverpool—SILVER MEDAL.
1879-81—Manchester, Liverpool and North Lancashire Agricultural Show, Manchester—SILVER MEDAL.
1879—Nottingham Gas Exhibition, Nottingham—SILVER MEDAL.
1877—South Shields Gas Exhibition, South Shields—SILVER MEDAL.
1882—Naval Architectural Appliances, etc., Exhibition, Tynemouth—SILVER MEDAL.
1884—Forrestry Exhibition, Edinburgh—SILVER MEDAL.
1885—Mining Exhibition, Glasgow—SILVER MEDAL.
1880—Northumberland Agricultural Society Exhibition, Newcastle—SILVER MEDAL.
1886—Liverpool International Exhibition, Liverpool—SILVER MEDAL.
1882—Peterborough Industrial and Fine Art Exhibition, Peterborough—SILVER MEDAL.
1879—Yorkshire Fine Art and Industrial Exhibition, Bradford—BRONZE MEDAL.
1883—Cork Industrial Exhibition, Cork—BRONZE MEDAL.
1881—Brighton Health Congress Exhibition, Brighton—BRONZE MEDAL.
1879—Sydney International Exhibition, Sydney (Special First)—BRONZE MEDAL.
1886—Colonial and Indian International Exhibition, London—BRONZE MEDAL.
1879—Teplitz Gewerbe & Industrie Ausstellung—GOLDENE MEDAILLE.
1879—Prag Industrie Ausstellung des Gewerbevereins—SILBERNE MEDAILLE.
1877—Linz Gewerbe & Industrie Ausstellung—EHRENPREIS I GROSSE SILBERNE EHRENMEDAILLE.
1880—Graz Landesausstellung—EHREN DIPLOM (Höchter Preis).
1882—Triest Esposizone Industriale Aust. Hung.—EHREN DIPLOM (Höchster Preis).
1883—Wien Internationale Electrische Ausstellung—AUSDRUCK DER ALLERHÖCHSTEN ZUFRIEDENHEIT SI MAJESTÄT DES KAISERS VON OESTERREICH.
1884—Turin Esposizone d' Elettricita—AUSZEICHNENDE ERWÄHNUNG.
1880—New York American Institute—MEDAL OF SUPERIORITY (Bronze).
1880—Cincinnati Industrial Exposition Ohio Mechanics' Institute—SILVER MEDAL.
1884—San Francisco Industrial Exhibition Mechanics' Institute—SILVER MEDAL.
1884-5—New Orleans—The World's Industrial and Cotton Centennial Exhibition—GOLD MEDAL.
1881-5—New York American Institute—MEDAL OF SUPERIORITY (Bronze).
1879—Berlin—SILBERNE MEDAILLE, Papier-Ausstellung.
1878—Erfurt—GOLDENE MEDAILLE, Gewerbe-Ausstellung.
1879—Berlin—SILBERNE MEDAILLE, Mullerei-Ausstellung.
1879—Nürnberg—SILBERNE MEDAILLE.
1879—Prag—GOLDENE MEDAILLE.
1880—Düsseldorf—GOLDEN STAATS MEDAILLE, Gewerbe-Ausstellung.
1881—Paris—GOLDENE MEDAILLE, Electricitats-Ausstellung.
1881—Frankfurt—A. M. GOLDENE MEDAILLE.
1881—Altona—GOLDENE MEDAILLE.
1881—Braunschweig—SILBERNE MEDAILLE.
1882—Magdeburg—SILBERNE MEDAILLE.
1885—Antwerpen—EHREN DIPLOM, Welt-Ausstellung.
1886—Stockholm—SILBERNE MEDAILLE, Industrie Ausstellung.
1886—Altenburg—SILBERNE MEDAILLE, Gewerbe-Ausstellung.
1879—Arnheim—GOLDEN MEDAILLE.
1883-4—Amsterdam—GOLDENE MEDAILLE.
1884—Middelburg—GOLDENE MEDAILLE.
1885—Gorlitz—GOLDENE MEDAILLE.
1885—Dütinchem—ERSTER PREIS.
1885—Königsberg—SILBERNE EHRENMÜNZ.
1885—Odense—SILBERNE MEDAILLE.
1879—Cherbourg—Exposition Artistque & Industrielle—RAPPEL DE MÉDAILLE D'OR.
1879—Paris Exposition Internationale des Sciences Appliquées à l'Industrie—MÉDAILLE D'OR.
1880—Mans Exposition Industrielle—MÉDAILLE D'OR
1881—Epinal Exposition Industrielle—DIPLÔME D'HONNEUR.
1881—Tours Exposition de Tours—MÉDAILLE D'OR.
1881—Versailles Concours Régional de Versailles—MÉDAILLE D'OR.
1885—Paris Exposition de Meunerie et de Boulangerie—MÉDAILLE D'OR.
1882—Nantes Exposition Industrielle—MÉDAILLE D'OR.
1882—Bordeaux—MÉDAILLE D'OR.
1882—Niort—MÉDAILLE D'OR.
1883—Foix Exposition Industrielle—MÉDAILLE D'OR ET DIPLÔME D' HONNEUR.
1883—Troyes Exposition Industrielle—MÉDAILLE D'OR.
1883—Blois Exposition Industrielle—MÉDAILLE D'OR ET DIPLÔME D' HONNEUR.
1884—Nice Exposition Internationale—MÉDAILLE D'OR.
1885—Paris Exposition du Travail à Paris—DIPLÔME D' HONNEUR.
1886—Paris—EXPOSITION DES ARTS INDUSTRIELS.
1886—Nantes & Marseille Expositions—DIPLÔME D' HONNEUR.
1887—Saltaire Exhibition—GOLD MEDAL.
1887—Newcastle Exhibition—SILVER MEDAL, Highest Award.

CROSSLEY BROS. LIMITED, Engineers, Openshaw, MANCHESTER.

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CROSSLEY'S "OTTO" GAS ENGINE

INVENTIONS EXHIBITION, LONDON, 1885.

GOLD MEDAL BY EXHIBITION COMMITTEE.

ALSO.

Special Award of Gold Medal by the Royal Society of Arts.

LONDON
24, POULTRY, E.C.

NEWCASTLE-ON-TYNE
4, GRAINGER-ST. WEST

GLASGOW
19, RENFIELD-ST.

CROSSLEY BROS. LIMITED

OPENSHAW

MANCHESTER

PRICE LIST of CROSSLEY'S "OTTO" Gas Engine.

(AT WORKS, OPENSHAW.)

SINGLE CYLINDER HORIZONTAL ENGINES.

Page of Catalogue	Nominal HP.	Approx. Indicated HP.	Price Without Water Vessel.	Price with Water Vessel.		Overall Dimensions (of Engine only).				Approx. Nett Weight of Engine.		Approx. Weight Packed Complete.		Standard Size of Pulley.		Size of Fly Wheel.		
			£	£	s.	Length. ft.	in.	Breadth. ft.	in.	C.	Q.	C.	Q.	Diam. in.	Wide. in.	Diameter. ft.	in.	Wide. in.
6	*½	2	60	61	10	6	0	3	7	13	0	16	1	10	5	3	6	2¾
6	1	2¾	80	82	10	7	5	4	1	19	1	23	3	12	6	4	0	4¾
7	2	4	120	123	0	8	3	4	7½	29	1	34	0	17	6	4	6	3¾
7	3	6	155	158	0	8	10	4	6¼	36	0	40	3	20	7	5	0	3½
8,17,18	4	8	170	174	0	8	6	4	3	36	0	40	0	20	7	5	0	4⅝
7	6	12	195	200	0	10	1¼	6	6½	59	2	65	3	24	10	5	6	5⅝
8,17,18	7	14	210	215	0	9	11	5	0	58	0	64	3	24	10	5	6	5⅝
7	8	15	225	231	0	10	1½	7	5¼	62	0	68	1	27	12	5	6	6½
8,17,18	9	18	250	256	0	10	0	5	3	65	0	71	0	27	12	5	6	6¼
7, 19	12	25	300	310	0	10	4	7	4	91	2	98	1	36	12	5	6	6
9	14	33	330	Special Price to suit position.		10	9	7	0	125	0	133	0	48	14	5	6	6½
10	16	40	350			11	8	7	9¼	144	0	152	2	54	18	5	10	6
11	20	50	380			12	0	8	2	155	0	163	2	54	18	5	10	9

The speed of above sizes is 160 revolutions per minute, except the 1-HP. and ½-HP., which run at 180 revolutions.

* SPECIAL NOTE.—This Engine should really be called a 1-HP. nominal, as the power was recently doubled.

The 12-HP., 14-HP., 16-HP., and 20-HP. Engines are fitted with two Fly Wheels.

DOUBLE CYLINDER HORIZONTAL ENGINES.

Page of Catalogue	Nominal HP.	Approx. Indicated HP.	Price Without Water Vessels.	Price with Water Vessel.		Overall Dimensions (of Engine only).				Approx. Nett Weight of Engine.		Approx. Weight Packed Complete.		Standard Size of Pulley.		Size of Fly Wheel.		
			£	£	s.	Length. ft.	in.	Breadth. ft.	in.	C.	Q.	C.	Q.	Diam. in.	Wide. in.	Diameter. ft.	in.	Wide. in.
12	4	16	240	248	0	8	6½	6	3	69	2	75	3	24	10	5	2	7¼
12	6	24	330	340	0	10	6	6	4¼	103	0	114	0	36	12	5	8	6½
not shown	16	80	600	Special		...		...		...		...		...	...	...		...
,,	20	100	680			...		...		...		...		...	...	...		...

The speed of above sizes is 160 revolutions per minute.

SINGLE CYLINDER VERTICAL ENGINES.

Page of Catalogue	Nominal HP.	Approx. Indicated HP.	Price Without Water Vessel.	Price with Water Vessels.		Overall Dimensions (of Engine only).				Approx. Nett Weight of Engine.		Approx. Weight Packed Complete.		Standard Size of Pulley.		Size of Fly Wheel.		
			£	£	s.	Height. ft.	in.	Breadth. ft.	in.	C.	Q.	C.	Q.	Diam. in.	Wide. in.	Diameter. ft.	in.	Wide. in.
5	Domestic.	¾	32	33	0	3	2	2	3	6	0	7	0	5	4	2	2½	3½
13, 14, 15, 16	5-MP.	1	45	46	0	4	8	3-sq.		9	0	12	2	10	5	3	0	3¾
,,	½-HP.	2	55	56	10	4	8	3	0	12	0	14	0	10	5	3	0	3⅝
,,	1½ ,,	3	90	93	0	5	10	4	0	17	0	20	0	17	6	4	0	4½
,,	3-HP.	6	130	133	0	...		...		...		...		...	...	...		...
,,	5 ,,	9	170	175	0	7	3¼	3	10	30	0	34	0	24	10	5	0	4⅝

The speed of the 5-HP., 3-HP. and 1½-HP. Engines is 160 revolutions per minute; of the 5-MAN and ½-HP. 180 revolutions; of the Domestic 250 to 300 revolutions.

Standard Driving Pulley, one spare Piston Ring, and one spare Spring sent out with each Engine FREE. One spare set of Slide Valves is also sent with all sizes except the 5-Man and Domestic.

CROSSLEY'S PATENT "ELECTRIC LIGHT" GOVERNOR FITTED TO ENGINES WHEN REQUIRED

CROSSLEY'S PATENT CAST IRON GAS BAG SUPPLIED WITH ALL ENGINES.

Special quotations for larger sizes; also for Engines combined with Pumps, Refrigerators, Ventilating Fans, Dynamos, and other Machinery.

PRICES and TERMS on application for CASH, or on the DEFERRED PAYMENT SYSTEM.

Selection of Testimonials

FROM USERS OF

THE "OTTO" GAS ENGINE

FOR DRIVING

ENGINEERS' TOOLS

(ONLY).

16-HP. *Manchester Works, Ledsam Street, Birmingham, July 24th*, 1883.

Messrs. Crossley Brothers Limited.

Dear Sirs,—In answer to yours of 23rd instant, your 16-HP. Engine continues to give us every satisfaction. We have now had it at work for a little over two years, and are so well pleased with the result that we shall never think of having a steam engine again. This Engine drives about forty Lathes, eight Planing Machines, five Shaping Machines, five Drilling Machines, three Boring Machines, and about thirteen other Engineers' Tools. Yours truly,

JAMES ARCHDALE & CO.

16-HP. *Middleton Ship Yard, West Hartlepool, February 6th*, 1884.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—In reply to your telegram received this afternoon, we find it difficult to compare the cost of Gas Engine with the cost of steam, as the pair of boilers we displaced provided steam for two Steam Hammers; their steam pipes were also in connection with the other nest of boilers.

In the original pair of boilers we burnt about 1½ tons of coal per day, at 9/- per ton=13/6, and we are now burning about 5,100 feet of gas per day, costing 12/9. The boilers, of course, took the whole time of one man; in fact, he usually had about 7½ days in every pay. The 16-HP. Gas Engine does not cost more than one day in the week (say 5/-), and the cost of water, wheeling away of ashes, is in favour of Gas Engine.

We are, yours truly,

pp. EDWARD WITHY & CO.

(Signed) T. H. WARWICK.

12-HP. *Alfreton Iron Works, Derbyshire, May 2nd*, 1882.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to yours of the 30th ult., we have pleasure in stating that the 12-HP. "OTTO" Gas Engine supplied by you is working very satisfactorily. The Engine is now driving a large Planing Machine, one Double-action Hydraulic Pump, and a large Pipe Cutting Machine. We intend shortly to apply several other machines, &c., and have no doubt it will perform equally well up to specified power.

Yours truly,

JAMES CLARKE & CO.

8-HP. 145, *Thornton Road, Bradford, May 4th*, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—My 8-HP. Gas Engine runs 54 hours every week. I have Root's Blower for Cupola, said to take 4-HP. to drive it. I have a Sand Grinding Mill, pair of Emery Wheels for fettling, 24 inch diameter, 2 in. broad, running 850 revolutions per minute; large Lathe for turning brass circles; Face Plate, 4 ft. 6 in. diameter; one 7-ft. Screw Cutting Lathe, and one Hand-turning Lathe for brass boring; Cleaning Machine and Cutting Machine for brass nuts. It runs them all. I have had no trouble with it yet—not a stoppage of any kind. Our gas is 3/- per 1,000; the cost has been 12/- per week. I am well satisfied. If you have any inquiries for others in this neighbourhood, you are at liberty to send any one to see it any day. So far as I am able to judge, the Engine is capable of doing a lot more work yet. I am, yours respectfully,

JOHN RADFORD.

8-HP. *All Saints' Iron Works, Bristol, May 2nd*, 1881.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—Replying to your note of April 30th, we have pleasure in stating that the 8-HP. "OTTO" Gas Engine supplied to us, June, 1879, and which has been running from 54 to 70 hours per week, still continues to work satisfactorily. It at present drives blast for six Forges, one large and one small Punching and Shearing Machines, five Lathes, four Drilling Machines, Polishing Buffs, Emery Wheels, &c.

We are, yours truly,

ALF. GARDINER & SONS.

(This firm have since put in a larger Engine.) *per* W. M.

8-HP. 34, *St. Mary Street, Cardiff, and at* 132, *High Street, Merthyr Tydvil, August 30th*, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to yours of the 26th instant, the 8-HP. "OTTO" Silent Gas Engine you supplied us in March last gives the fullest satisfaction, and is at present working—

One 12-in. Centre Screw-cutting, Sliding, and Surfacing Lathe.
One 8-in. " " " " "
One Double-geared Drilling Machine.
One Slotting Machine.
One Milling Machine.
One Pattern Maker's Lathe.
One Grindstone. (54-in. drain.)
One 6-Fire Fan for Smithy.

And, in addition, one of our patent "Self-sustaining" Hoists for one ton.

The cost is under 18/- per week, including gas, attendance, and oil. We have every reason to be pleased that we adopted it instead of steam.

Yours truly,

THOS. THOMAS & SON.

8-HP. *New Bailey Street, Salford, Manchester, July 24th,* 1883.

Messrs. Crossley Brothers Limited.

Dear Sirs,—In reference to yours of yesterday, we have now had an 8-HP. "OTTO" Gas Engine running continually during the past five years (and frequently on night-work as well). We are perfectly satisfied with its working and the power given out, and have proved it to be cheaper to us than steam, being also cleaner, requiring less room, and *very little* attention. It drives daily over twenty-four machines, tools, &c.

Yours truly,

J. CARTER & CO.

7-HP. *Ward Road Brass Works, Dundee, September 16th,* 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The size of our "OTTO" Engine is 7-HP., and the Machines driven are :—Nine Lathes, Polishing Machine, Shaping Machine, Buffing Machine, Eclipse Emery Grinding and Sawing Machine, Valve Boring and Screwing Machine, Grindstone, and Circular Saw. The approximate cost of gas per week is 16/- The Engine works very well, giving us every satisfaction, and, in our estimation, is capable of driving almost double the amount of machinery it is now driving.

Yours truly,

HUNTER & GRAHAM.

p. A. GRAHAM.

6-HP. *Pitfield Wharf, Waterloo Bridge, London, September 8th,* 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The Gas Engine (6-HP.) which you supplied to us is used for sawing and engineers' and smiths' shop, driving the following machines :—

Two Lathes.
Three Drilling Machines.
One Screwing Machine.
One Punching and Shearing Machine.
One Emery Grinder.
One Grindstone.
One 16-in. Blast Fan.
One Circular Saw Bench, 30 in.
One Band Saw.

Although they are not all in use at one time, as a rule we find the Engine quite capable of doing the work, giving no trouble except a good cleaning once a week. Takes a man about 1½ hours a week and plenty of good oil. We find average cost of gas 5d. per hour, which, in London, is less than one labourer's wages. Result most satisfactory. Shall be glad to show anyone the Engine who wishes to see its working.

Yours faithfully,

Pro HALL, BEDELL & CO.

W. P. HEATH.

6-HP. *Lower Hurst Street, East Birmingham, April 27th,* 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to yours of the 26th instant, the 6-HP. Gas Engine, No. 5390, is used in my works, and works four Lathes, Planing Machine, Shaping Machine, Drilling Machine, and Slack's Emery Wheel, &c., with the greatest ease, and will work more machinery if wanted. I am very pleased with it, and shall be glad to recommend it to my customers, and anyone requiring an efficient, clean, and economical Engine,

I remain, Gentlemen,

Yours respectfully,

EDWARD S. BOND.

6-HP. 64, *Spittal Hill, Sheffield, May 9th,* 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—Yours of the 6th instant just to hand. The Engine I have got is your nominal 6-HP., No. 5772. I was very well satisfied with the one I took out, but I am quite as well satisfied with this one; really I am delighted with it; and anyone applying to you for one, anywhere in our neighbourhood, I shall be pleased to show and explain anything they want to know, as you know many people wonder whether they will do the work, being strange to them. You are quite at liberty to give the 2-HP. and the 6-HP. Engines that I have well tried every praise before the public. The 6-HP., now at work while I write, is driving two 11-inch Lathes, two Drilling Machines, one Planing Machine, one 8-in. Slotting Machine, and Grinding Stone and Shafting. Yours truly,

RICHARD TOWNSEND.

4-HP. 34A, *King Street, Tradeston, Glasgow, September 16th,* 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 4-HP. "OTTO" Engine drives the following Machines :—One 10-in. Self-acting Lathe, five 7-in. Brassfounders' Lathes, one Nibbling Machine, one Circular Saw (12-in.) and Buff, and one Grindstone. The approximate cost of gas is about 7/- per week of fifty-four hours. We are highly pleased with the Engine. For finish and efficiency, it gives entire satisfaction. We consider it a formidable rival to the steam engine, and shall have pleasure in recommending it to our friends.

Yours respectfully,

RONALD & McROBIE.

4-HP. *Dorking Foundry and Iron Works, 62, West Street, Dorking, Sept. 2nd,* 1887.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your inquiry respecting our 4-HP. Gas Engine, we have worked it sixteen months, and it has given great satisfaction, both as regards the saving and the work done. It drives one large and one small Lathe, Drilling Machine, and one Set of Fans to blast furnace. Yours truly,

STONE & TURNER.

3½-HP. *Netherthorpe Street, Sheffield, August 27th,* 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—As you are aware, I have been using your Engines for over nine years, and this 3½-HP. Engine is the third I have had from you, and it gives me every satisfaction, working, as it does, 12 or 13 different tools, in the shape of Lathe, Shears, Punching Machine, Stamps, Grinding Stone, &c. I am, Gentlemen, yours truly,

ROBERT WATTS.

3½-HP. 79, *and* 79*a*, *Rosoman Street, Clerkenwell, and* 6, *Templeton Road, Finsbury Park, N., London, May 11th,* 1883.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—I have great pleasure in saying the 3½-HP. Gas Engine supplied by you works in all respects to my entire satisfaction. The work it has to do is to drive a large Planing Machine, 6 ft. by 3 ft., Fan for four fires, Grindstone, large Drilling Machine, small Drilling Machine, Circular Saw Bench, three Lathes, and will do a great deal more if required. It goes the whole day long, with about ten minutes' attention.

Yours respectfully,

THOS. H. HEWITT.

P.S.—I am about to put a 10-in. Screw Cutting Lathe and Slotting Machine in addition.

3½-HP. *45, Tabernacle Street, Finsbury, London, E.C., August 23rd, 1887.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—We have much pleasure in stating that the 3½-HP. Engine we had from you for own use here works admirably, and without fault, driving all our machinery easily, which now consists of some ten Lathes, Planing Machine, &c., but we rarely are running all at the same time. However, we have no fault to find.

We are, dear Sirs,
Yours faithfully
For ALFRED SLATTER & COMPANY LIMITED,
FRANK DAY, *Secretary.*

3½-HP. *Holmfirth, April 23rd, 1883.*

Messrs. Crossley Brothers, Engineers, Manchester.

Gentlemen,—"OTTO" No. 5338, 3½-HP. The Engine we got from you was to turn one of Lloyd's patent Fans, 30 in. diameter, 12 in. outlet, and it does the work quite easy.

We remain, yours respectfully,
J. & J. N. LEYBIN.

2-HP. *Ditching Rise Telegraph Manufactory, Brighton, December 27th, 1879.*

Gentlemen,—I enclose cheque for small account. I may say how very satisfied I am with the 2-HP. Engine you supplied July, 1879; we have no trouble with it. We clean out the slide valve and passages every week—the piston and cylinder seldom require cleaning. We run 54 hours per week. My gas bill for the last quarter was 11,000 feet, at 3/6, and allowing for another 1,000 feet for the slide light, amounts to £2 2s., or 6½d. per day. I have carefully reckoned the cost of oil, labour, &c., and put it at 1s. per day for all expenses. The Engine drives about 160 feet Main Shafting, one 8-in. Lathe, four 5-in. Lathes, one 4½-in. Lathe, one 3-in. Lathe, two Drilling Machines, two Grindstones, and one Circular Saw. As we seldom have all running at once, we seldom require to use the weight on the governors. It has cost nothing for repairs.

Yours truly,
M. VOLK, *Torpedo Engineer.*
(Has also a 12-HP. and ½-HP. Engine for other purposes).

2-HP. *Spalding, July 2nd, 1884.*

Messrs. Crossley Brothers.

Gentlemen,—In reply to your enquiry of 26th, the 2-HP. Gas Engine you supplied me with last December is used by myself. You may also be glad to know that it drives the following Shafting and Machinery both satisfactorily and economically, viz: some 70 ft. of 1¾-in. Main Shafting, thirteen Counter Shafts, five 6-in. to 8-in. Lathes, one heavy 11-in. Gap Lathe, 6 ft. 6 in. by a 2 ft. 6 in. Planing Machine, 8-in. Geared Shaper, one strong Double-geared Pillar Drill, one small Drill, Boring and Facing Machine, Geared Milling Machine, Wood Turning Lathe, Emery Wheels, &c. I am putting down another 9 in. by 18 ft. Lathe, and Boring Machine, expecting it will drive them also. I thought you would be surprised to hear of so small an Engine driving so much machinery.

Yours faithfully,
H. B. MASSEY.

1-HP. *Victoria Foundry, Alton, Hants, Oct. 13th, 1880.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to yours this day, I beg to say the 1 horse Gas Engine I erected does more than it was thought to do, and works well. It drives a line of 3¼-in. Shafting, 30 ft. long, one Lathe, one Paint Mill, one Band Saw, one Drilling Machine, without finding hardly a check. Any further information I shall be pleased to give. The cost of working is something like a penny per hour for gas, and can be seen at any time at work, on application.

I am, yours respectfully,
JOHN B. BLAKE.

½-HP. *R. E. Office, Chatham, August 23rd, 1887.*

Messrs. Crossley Brothers Limited, Manchester.

The Engine you refer to is giving every satisfaction. It is working a Turning Lathe and Burnishing Lathe in Armourer's shop, H.M. Gun Wharf.

H. W. FORTESCUE CHAPMAN, *Capt.*,
D.O., R.E.

½-HP. *Angus's Coach Works, Newcastle-upon-Tyne, September 16th, 1887.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—We bought one of your 2-HP. Gas Engines in 1875. It has driven a Fan Blast for ten fires satisfactorily, and is still at work.

We got one of your ½-HP. Engines in the beginning of this year. It drives two light Drilling Machines, and a Grindstone for sharpening tools. We find it exceedingly useful and convenient. Gas for the two Engines costs us about 1½d. per hour. The net price of our gas is 1/11 per 1,000 feet.

Yours truly,
HENRY ANGUS & CO.

½-HP. *78, Cross Lane, Great Horton, September 16th, 1887.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—My ½-HP. Engine drives the following:—One Slide Lathe, 12-ft. gautre; one Hand Lathe, 8-ft. gautre; one Upright Drill, ordinary size; one Patent Blacksmith's Blower, No. 3: one Grindstone; and Counter-Shafting for each article (16 ft. of 2-in. Shafting). The approximate cost of gas per week is 2/10, and we run fifty-five hours per week. I am pleased to say the Engine does its work remarkably well, and it gives me great satisfaction.

Yours truly,
JOSHUA WADE.

5-MP. (Vert.) *Belinda Street, Hunslet, Leeds, September 16th, 1887.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—Our 5-MP. Vertical "OTTO" Engine drives the following machines:—Small Planing Machine, 6-in. Self-acting Lathe, 4½-in. Self-acting Lathe, 3-in. Self-acting Lathe, Small Drilling Machine, Wheel Cutting Machine, and Grindstones. The approximate cost of gas per hour is ⅜d. We consider this by far the best little Engine in the market for small power. We have had it working now two years without the slightest trouble, and have no reason to think but it will continue to do so. We can highly recommend it to users of small power.

Yours, &c.,
B. W. CLEGG & SON.

5-MP. *Howick House, Preston, Aug. 23rd, 1887.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 5-MP. Gas Engine you supplied me with "turns" my private workshop, and does this very well. I am quite satisfied with it. It gives no trouble.

Yours truly,
EDWIN G. WRIGLEY.

Testimonials from Users of the "OTTO" Engines, for every other class of work, can be had on application.

LIST OF USERS

For Driving ENGINEERS' TOOLS (only).

	HP.	
Aberdeen	½	William Jackson, Beechgrove-terrace.
Alfreton	12	James Clarke & Co., Alfreton Ironworks. (*See Test.*)
Alton	1	John B. Blake, Victoria Foundry. (*See Test.*)
Anstruther	2	James Anderson, Smith.
Ashton	½	George Lowe, 73, Wigan Road.
Barnsley	3½	Hutchison Bros.
Barrow-in-Furness	12	Barrow Ship Building Company (also a 7-HP. for their Pattern Shop).
Batley	3½	Dewsbury & Batley Tram Co.
Bedford	12	J. & F. Howard.
Belfast	12	William Ewart & Son, Bradford Street.
,,	6	John Hall, Queen Street.
,,	6	R. Crawford, Afred Street.
,,	3½	McLachlan & Ross, Abercorn Basin.
,,	3½	A. & W. Godwin, Queen Street.
,,	3½	J. & J. Scott, Upper Church Lane.
,,	3½	R. Patterson & Son, High Street.
,,	3½	J. Shaw, Mount Pollinger.
,,	½	J. Pettigrew, High Street.
,,	½	J. M. Graves, Fall Mills.
Bingley	8	R. Ainsworth & Co., River Street.
Birmingham	16	J. Archdale & Co., Ledsam Street. (*See Test*).
,,	16	R. Heaton & Sons, The Mint.
,,	16	W. Eades, Son & Co., Montgomery Street.
,,	16	John Yates & Son, Rocky Lane, Aston.
,,	16	John Yates & Son, Rocky Lane, Aston.
,,	16	D. F. Taylor & Co., George Street.
,,	16	J. C. Onions Limited, Bradford Street.
,,	16	W. & T. Avery, Ryders Green, Oldbury.
,,	16	Patent Nut and Bolt Company, Smethwick.
,,	16	Argosy Fine Casting Co., Tenant Street.
,,	16	W. Bown, 308, Summer Lane.
,,	16	Patent Nut and Bolt Company, Smethwick.
,,	14	Webley & Co., Weaman Street.
,,	12	Birmingham Corporation.
,,	12	Wright & Harrington, Bradford Street.
,,	12	G. Hughes, St. Stephen Street.
,,	12	G. Hughes, St. Stephen Street.
,,	12	G. Hughes, St. Stephen Street.
,,	12	G. Hughes, St. Stephen Street.
,,	12	W. & T. Avery, Digbeth.
,,	12	Smallwood & Co. Leopold Street.
,,	12	English Watch Company, Vyse Street.
,,	9	Webley & Co., Weaman Street.
,,	8	Lovedee & Co., Charlotte Street.
,,	8	John Wright & Co., Essex Works, Broad Street.
,,	8	Jones & Co., Cecil Street.
,,	8	James Tombs, Bedstead Works, William Edward St.
,,	8	F. A. Ludlow, Andover Street.
,,	8	John Bent & Son, Bell Barn Road.
,,	6	E. S. Bond, Lower Hurst Street. (*See Test.*)
,,	6	Wright & Fletcher, Lower Hospital Street.
,,	6	C. Trueman, Steelhouse Lane.
,,	6	Thomas Parkes, Broad Street.
,,	3½	Rice & Co., Sherlock Street.
Birmingham	3½	John Wright & Co., Essex Works, Broad Street.
,,	3½	W. Pitt, John Bright Street.
,,	3½	George Kendrick, 26, Rea Street.
,,	3½	F. T. Martino, Erdington.
,,	3½	A. J. Ward, 233, Bradford Street.
,,	3½	Redman & Son, Edmund Street.
,,	3½	Monton & Brettell, Tower Road, Aston, Gun Manufacturers.
,,	2	W. Hallet, 9, Carver Street.
,,	2	W. G. Garnett, 211, Bradford Street.
,,	1	George Burt, 10, Great Charles Street.
,,	1	Wheeler & Son, Oldbury.
,,	1	F. Kitson, 113, Broad Street.
,,	½	T. W. Crees, King Edward Road.
,,	.5-HP.	Perkins & Powell, 3, Bartholomew Row.
Blackburn	2	Seed & Son.
,,	2	J. Baldwin, 46, Church Street.
,,	½	Gas Company.
Blythswood	12	Sir Arch. Campbell, Bart. (Also used for Electric Lighting.)
Bolton	1	Town Hall. (Engineers' Department.)
,,	½	W. Banks, 32, Corporation Street.
Bradford	8	Cockshott & Jowett, Thornton Road (late T. Radford). (Root's Blower and other machinery.)
,,	8	E. Stansfield, 219, Leeds Road.
,,	8	R. Pease, Little Horton Lane.
,,	8	S. Wood & Co., Portland Street.
,,	4	— Holroyd, Bottomley Street, Manchester Road.
,,	2	R Pickles & Co., 82, Laurel Street.
,,	½	J. Wade, Great Horton. (Lathe, Blower and Grindstone.)
,,	½	Joseph Wood.
Brighton	2	Magnus Volk. (*See Test.*)
Bristol	8	Bristol Gas Company.
,,	6 (Twin)	A. Gardiner & Sons, Nelson Street. (*See Test.*)
,,	3½	Smith & Son, Drawbridge.
,,	2	Jones & Co., Bridge Street.
Burnley	3½	W. Barker, Elm Street, Burnley Lane
,,	3½	L. Atkinson, Old Hall Street.
,,	½	J. Shackleton, 33, Berkeley Street.
,,	½	Henry E. Kear.
Bury St. Edmunds	1	Robert Boby, St. Andrew's Works.
Calne	½	Mondell & Woodward, Engineers.
Cambridge	7	Professor Stuart, University.
,,	3½	Scientific Instrument Company.
Cardiff	16	Wallsend Pontoon Company Limited. (Driving several large Lathes, Drilling Machines, overhead Traveller, Smithy Fan, &c.)
,,	16	Wallsend Pontoon Company Limited. (Driving Plant for making Pontoons.)
,,	16	Solomon Andrews & Son. (Driving Smithy Fan, Fan, Drilling Machines, &c.)
,,	8	Thomas Thomas & Sons. (Driving Lathes, Drilling Machines, Smithy Fan, Hoist, Slotting and Milling Machines, Emery Wheel and Work-Working Machines.)

HP.

CARDIFF ...... 3½ Spiller & Co. Limited. (Driving several Lathes, Drilling, and other Machine Tools.)
CARLISLE...... 1 Carr & Co., Victoria Warehouse.
" ...... 1 Pickering & Crighton, 74, London Road.
CHATHAM .... ½ Captain H. W. Chapman, Royal Engineers.
" .... 1½ (Vert.) Louis Brennan, New Torpedo Works.
CHELTENHAM 6 Gas Company.
CHESTERFIELD 2 Grassmore Colliery Company, near Chesterfield.
CHESTER..... 3½ Gas Works.
" ...... ½ (Vert.) Box & Sons, 46, Frodsham Street.
CLAYTON, *near Bradford*.... 3½ Wilman Brothers.
CLECKHEATON 3½ W. Blackburn & Co.
CLITHEROE.... 2 Ellis, Bank & Son, Waterloo Road.
COVENTRY .... 8 Hillman, Herbert & Cooper.
" .... 1 F. L. Gillot, Whitely Villa.
CREWE........16 L. & N. W. Railway Company. [And several smaller sizes of Engines.]
DONCASTER .. 1 Henry Whiteley, 10, Market Place.
DORKING...... 4 Stone & Turner, Engineers.
DUBLIN ...... 8 J. Edmundson & Co., Capel Street.
" ...... 6 Tramway Company, Inchicore Works.
" ...... 6 James Roberts, Francis Street.
" ...... 3½ Great Southern and Western Railway, Inchicore.
" ...... 3½ Chancellor & Co., Fleet Street.
" ...... 2 Gregg, Mooney & Co., Great Brunswick Street.
" ...... 2 W. Carson & Son, Bachelors' Walk.
" ...... 2 Cornelius Bull, 16, Upper Gloucester Street.
" ...... 2 J. H. Webb & Co., Corn Market.
" ...... 2 Benjamin Williams, Palmerston Place.
" ...... ½ — Robinson, Sackville Street.
DUNDEE ...... 7 Hunter & Graham.
" ...... 6 College (Mechanical School).
" ...... 4 Robertson & Oncar, Wallace Foundry.
EALING DEAN . ½ W. Tomkins, 1, Bedford Villas.
EDINBURGH ..16 W. & B. Cowan, Buccleuch Works. (Rolling Mill.)
" .. 8 J. Greig, Jun. & Co., Regent Works, Regent Road.
" .. 7 F. Dickson, Dakfield Foundry, 26, Frederick Street. (Rort's Blower.)
" .. 6 William Bryden & Son, 55, George Street.
" .. 4 A. Usher & Co., St. Leonard's, Edinburgh.
" .. 3½ J. & G. Cox, Gorgie Mills. (Patent Sand Blast.)
" .. 3½ W. Barton & Sons, Forrest Road.
" .. 3½ Museum of Science and Art (Professor Archer).
" .. 2 James Law, Viewforth Park.
" .. 2 J. Dickson & Son, 63, Princes Street.
" .. 1 A. Young, 60, Forrest Road. (Surgical Instruments.)
" .. 1 J. Ritchie & Son, 25, Leith Street.
" .. ½ Gas Company.
" .. ½ J. E. & S. Richardson, 52, George Street, Bicycle Manufacturers.
" .. ½ D. Glen, 8, Greenside Place.
" ..5-MP. H. Hilliard & Son, 7, Nicholson Street. (Surgical Instruments.)
" ..5-MP. William Robertson, 28, Rankeillor Street.
" ..5-MP. J. Gardner, 32, Forrest Road.
ELLSECAR .... ½ Earl Fitzwilliam, Mineral Office.
EXETER ...... 6 (Twin) Downe & Baker.
" ...... ½ E. C. Brand, Cathedral Yard.
FARNWORTH .. 3½ Barnes & Co. Limited.
FROME ....12 W. H. Singer, Art Metal Works.
GATESHEAD-ON-TYNE ......12 Clark, Chapman & Co.
" ......12 Clark, Chapman & Co.

HP.

GATESHEAD-ON-TYNE ...... 8 Clark, Chapman & Co.
" ...... 3½ Tramways Depôt, Sunderland Road.
GLASGOW...... 8 Clyde Shipping Co., Carlton Place, Bridge Street.
" ...... 8 R. Greenlees & Co., 32, East Howard Street.
" ...... 6 William Harvie & Co., 220, Broomielaw.
" ...... 4 Ronald & McRobie, 34, King Street, S S.
" ...... 3½ T. Buchan & Sons, 249, Argyle Street.
" ...... 3½ H. Buchan, 52, Oswald Street.
" ...... 3½ G. & W. Dollar, 137, High Street.
" ...... 2 J. Murray, 8, Brown Street.
" ...... 2 T. Coulter, Barrowfield Works, French Street.
" ...... 2 A. & J. Gilchrist, 25, Eglinton Street.
" ...... 1 J. D. Dougal, 23, Gordon Street.
" ...... 1 James Reid & Co , Napiershall Street.
" ...... ½ Melbourne & Nutter, 134, Renfield Street.
" ...... ½ R. & A. Main, Ropework Lane.
" ...... ½ R. E. Collins, West Balgray, Hillhead.
" ...... ½ R. C. Murray & Co., 7, Carlton Court, Bridge Street.
" ...... ½ W. Horton, 11, Exchange Square.
" ...... ½ Robert Scott, 182, Trongate.
" ...... ½ P. Henderson, Royal Arcade.
" ...... ½ J. R. Brotchie, 25, Eglinton Street.
" ...... ½ R. S. Crawford & Co., 3, Gibson Street.
" ......5-MP. Crossley Brothers Limited. (Planing Machine and Emery Wheel.)
GOMERSAL .... 1 B. Craven.
GRANTHAM.... 4 A. & J. Shaw.
HALIFAX .... 8 Henry Edmonds & Son, Silver Street. (*See Test.*)
" .... 8 Thomas Pulman, Bolt and Screw Manufacturer.
" .... 8 Charles Cain, Son, & Greenwood.
" .... 3½ George Birch, Church Street.
HALSTEAD .... 3½ Portway & Son, Iron Founders.
HARROW ...... 2 Cogswell and Harrison.
HECKMONDWIKE........ 3½ R. France, Regent Street.
" .. ½ Dutton Brothers, Greenside. (8-in. Centre Lathe, Drill and Grindstone.)
HITCHIN ...... 3½ Gathward & Son.
HOLLINWOOD .. 4 Alex. Thompson, Tin Works.
" .. 2 J. & R. Lees.
HOLMFIRTH .. 3½ J. & J. N. Leybin.
HUDDERSFIELD 14 W. Mitchell, 14A, Greenhead Road.
" .. 1 J. Golden, Cross Church Street.
HULL .... 8 J. Holmes, Neptune Street.
" .... 6 Pickering & Haldane, St. Andrew's Dock.
" .... 3½ Vulcan Iron Works Company.
" .... 2 J. Wood, Albert Dock.
" .... ½ J. Grime & Co., Prospect Street.
HUNSLET......5-MP. W. B. Clegg, Belinda Street.
HYDE .... 8 Maiden & Co.
" .... 8 F. E. Forbes, Clarendon Place.
IPSWICH ..... 1 Warner & Son, Engineers.
JARROW ...... 7 C. M. Palmer & Co.
KEIGHLEY .... 3½ W. Wells, Brassfounder.
KENDAL ...... 2 Gilbert Gilkes & Co., Canal Ironworks.
KILMARNOCK ..5-MP. L. B. Russell, 67, Portland Street.
LANCASTER ..5-MP. Fenton & Co., Ironmongers.
LANDPORT .... 8 H. & W. Davies, Pye Street, Commercial Road.
LEITH .... 3½ Edinburgh and Leith Gas Company.
" .... ½ J. & W. Kirkwood, Galvanised Iron Bath Makers.
LEEDS .... 8 Charles Wilson, Gas Stove Maker, Carlton Works, Woodhouse Lane.
" .... 8 G. Bray & Co., Blackman Lane, Gas Burner Manufacturers.

	HP.	
LEEDS	8	L. Pool & Son, Sweet Street.
„	8	Charles Wilson & Sons. (Engineers' Tools.)
„	8	Luke Pool & Sons, Holbeck. (Screwing and Turning.)
„	6	J. T. Nelson, Crown Point Road.
„	6	John Nelson, Crown Point Foundry. (Engineers' Tools.)
„	3½	George Bray & Co. (Brass finishing Lathe for Gas Burner making.)
„	3½	G. Bray & Co., Blackman Lane, Gas Burner Manufacturers.
„	2	Kitson & Co., Airedale Foundry.
„	2	Chadwick, Smith & Co., Dewsbury Road.
„	2	Edward James, Sewing Machine Maker, Swan Street. (Engineer's Tools.)
„	2	Chadwick, Smith & Co. (Brass finishing Lathes.)
„	1	S. Dixon & Son. (Brass finishing Lathes.)
„	1	S. Dixon & Son, Swinegate.
„	½	Hammond, Bending & Co., Butt's Court. (Engraving Tools.)
LEEK	5-MP.	Thomas Ryder, 35, King Street.
LEICESTER	3½	Thomas Gadd, Engineer.
„	1	W. Chamberlain, Wigston Magna.
„	½	J. T. Gent & Co., Farraday Works, King Richard Road.
„	½	J. J. Vaughan, Silver Street.
LIVERPOOL	8	R. Singlehurst & Co., 11, Red Cross Street.
„	8	F. Braby & Co., Hatton Garden.
„	8	Bennett Brothers, Victoria Street.
„	3½	John Jones & Co., St. George's Engine Works
„	2	W. & J. Ellison, 55, Paradise Street.
„	1	Thomas Cheshire & Co., Johnson Street, Dale Street.
„	1	Liverpool Fire Brigade, Hatton Garden.
„	½	Holmes & Vaudrey, 1, Crosshall Street.
LONDON	14	Emanuel and Sons, Marylebone Lane, W.
„	12	Hughes & Kimber, West Harding Street, E.C.
„	12	Polytechnic Institution, Regent Street, W.
„	12	Francis & Co., York Road, King's Cross.
„	12	Davies & Timmins, Bowling Green Lane.
„	12	Davies and Timmins, Bowling Green Lane, E.C.
„	12	Francis & Co., York Street, King's Cross.
„	8	Phœnix Gas Company, Vauxhall.
„	8	Maxim Weston Electric Light Company Limited, 27, Bankside, S.E.
„	8	Commercial Gas Company, Stepney, E.
„	8	W. Barnes & Son, Christopher Works, Charlton Street, Euston Road, N.W.
„	8	Pilsen Joel Electric Light Company Limited, Malden Crescent, Kentish Town, N.W.
„	8	Waterlow & Sons Limited, Finsbury.
„	8	Waterlow & Sons Limited, Finsbury.
„	8	W. M. Still & Co., Charles Street, Hatton Gardens.
„	7	J. J. Hicks, 8, Hatton Garden, E.C.
„	7	Linley & Biggs, Mount Row, East Road, E.C.
„	7	A. Thrower, Portland Works, Soho.
„	7	W. Heath, 21, Bride Lane, Fleet Street, E.C.
„	7	J. F. Lovelock, Homburg Street, London Fields.
„	6	H. H. Matthews, 22, Charterhouse Square, E.C.
„	6	W. R. Sykes, Barrington Road, Brixton.
„	6	J. Benson & Co., Ludgate Hill, E.C.
„	6	Lloyd & Davies, 42, Great Guildford St, Southwark.
„	6	Hall, Bedall & Co., Pitfield Wharf, Waterloo Bridge. (*See Test.*)
LONDON	6	Emmerson, Walker & Co., Horseferry Road, Stepney.
„	6	Hutchinson & Co., Fann Street, E.C.
„	6	J. Nixon., jun., St. John's Square Passage, Red Lion Street, Clerkenwell.
„	6	Patent Metal Die Company, Addington Street Westminster, S.W.
„	6	Wenham Patent Gas Lamp Company, Black Horse Yard, Rathbone Place.
„	6	South London Tram Co., Queen's Road, Battersea.
„	6	Self-opening Tin Box Co., York Road, King's Cross.
„	6	E. Fenton, 72, Bishopsgate Street, E.C.
„	6	Peal & Co., 487, Oxford Street, W.
„	6	— Elesley, 32, Great Portland Street. W.
„	4	Elliott Brothers, 102, St. Martin's Lane, W.C.
„	4	J. Smith & Son, 60, Gifford St., Caledonian Rd., N.
„	4	A. Lee, 98, King's Road, Camden Road. (Engineer's Tools and Dynamo.)
„	3½	H. B. Merton, Esq., 3, Palace Houses, Bayswater. (Lathes and Dynamo.)
„	3½	E. Edwards, 10, Wilderness Row, Goswell Road.
„	3½	R. J. Miller, 4, Upper Baker Street.
„	3½	D. Napier & Sons, Vine Street, York Rd., Lambeth.
„	3½	Richmond & Co., Kirkby Street, Hatton Garden.
„	3½	J. Lee, 47, Cowcross Street, E.C.
„	3½	H. Schmidt, 9, Charlotte Mews, Fitzroy Square.
„	3½	F. Knoeferl, 100, Bolsover Street.
„	3½	J. Brown & Co., Upper Thames Street, S.E.
„	3½	Maw, Son & Thomson, Aldersgate Street.
„	3½	E. H. Bennett, Artichoke Hill, St. George's, E.
„	3½	Hunter & English, Bow, E.
„	3½	Aublet & Co., 38, Spital Square, Bishopsgate, E.C.
„	3½	Wilson Engineering Company, Pear Tree Street, Caswell Road.
„	3½	T. H. Hewitt, 79, Rosamon Street, Clerkenwell. (*See Test.*)
„	3½	Mr. Culver, Spencer Works, Clerkenwell Road.
„	3½	Burdick & Co., East Ferry Road, Millwall.
„	3½	S. Godden, 43, Upper George Street, Bryanston Square.
„	3½	Morris' Aiming and Sighting Company, 7 and 9, St. Bride Street, Ludgate Circus, E.C.
„	3½	J. W. Ladd & Co., 116, Queen Victoria Street, E.C.
„	3½	Burdick & Cook, East Ferry Road, Millwall.
„	3½	Brown & Englefield, 112, St. Gaffron Hill.
„	3½	Sampson & Goddens, 43, Upper George Street.
„	3½	A. Slatter & Co. Limited, 45, Tabernacle Street, E.C.
„	2	Wade & Dagley, 8, Townsend Road, St. John's Wood, N.W.
„	2	Indian Office, South Kensington.
„	2	Knight & Cottrill, 9, St. Bride's Avenue.
„	2	W. Graham & Sons, Trig Lane, Upper Thames St.
„	2	Metropolitan Board of Works, Deptford Pumping Station, Greenwich.
„	2	*Pall Mall Gazette* Mechanics' Shop.
„	2	J. Fry, 42, Stephen Street, Lisson Grove.
„	2	J. Stannah, Southwark Bridge Road.
„	2	Mr. Dowling, 24, Australian Avenue.
„	2	F. Ullmer, Cross Street, Farringdon Road.
„	2	Lewis & Lewis, Cambridge Heath Road.
„	2	London, Brighton, and South Coast Railway, New Cross.
„	2	Dyson & Co., 60, Pitfield Street, Hoxton.

	HP.	
LONDON	2	W. F. Stanley, 4 and 5, Great Tunstill, W.C.
"	2 (Vert.)	H. B. Merton, 3, Palace Houses, Bayswater.
"	2	A. S. Scott, 21, Bush Lane, E.C.
"	2	J. G. Frei, 94, St. John's Road, Clerkenwell.
"	2	Matthews & Tilcock, Mill Mount Works.
"	2	Dyson & Co., 60, Pitfield Street, Hoxton, N.
"	2	W. F. Stanley, 4 and 5, Great Tunstile, E.C.
"	2	John Ayres, 64, Collier Street, King's Cross.
"	2	W. Nunn & Co., 204, St. George's Street, E.
"	2	S. Gerish, Buttesland Street, East Road, N.
"	1½ (Vert.)	G. Dovey, 25, Albert Terrace, New Church Road, Camberwell, S.E.
"	1	South Metropolitan Gas Company, Old Kent Road.
"	1	— Wood, 3, Gun Square, Houndsditch.
"	1	H. Bamford, White Lion Street.
"	1	H. B. Merton, 3, Westbourne Crescent.
"	1	Mr. Franklin, New North Road.
"	1	Richard Fox, 2, Queen Street, Clerkenwell.
"	1	W. F. Shephard, 13, St. Peter Street, Hackney Road.
"	1	Rich Brothers, 42, Grange Road, Bermondsey.
"	1	Crossley Brothers Limited, 24, Poultry, E.C.
"	1	E. Herisse, 1, Shacklewell Lane, Dalston, N.
"	½	G. Humphreys, Engineer, Sevenoaks.
"	½	J. W. King, 21, Richmond Villas, Sevensister's Road, N.
"	½	Cogswell & Harrison, 226, Strand, W.C.
"	½	William Dawes, Saw Maker, 22, Goldsmith Row, Hackney Road, E.
"	½	Rich Brothers, 42, Grange Road, Bermondsey.
"	½	E. S. Potter, 37, Queen's Gate Gardens, S.W.
"	½	The European Lock Company Limited, 69, Coleman Street.
"	½	Cagswell & Harrison, Harrow Road.
"	½	C. Walker, 4, Canal Road, King's Cross.
"	½	Arnold & Sons, 35, West Smithfield, E.C.
"	½	J. Ayres, 13, Winchester Street, Pentonville Hill, N.
"	5-MP.	J. Mayes, 55, Red Lion Street, E.C.
"	5-MP.	— Archbold, Esq., "Libiola," Shortlands, Kent. (Lathe in Amateur Workshop.)
LURGAN	2	W. H. Boyce, 65, Union Street.
LUTON	½ (Vert.)	J. Delger, Engineer.
MAIDSTONE....	3½	J. Barcham Green, Hayle Paper Mills.
"	3½	Drake & Muirhead.
"	3½	Gas Company.
MANCHESTER..	16	Crossley Brothers Limited, Openshaw. (Drilling Machines, Slotting Machines, small Planing Machines, Lathes, &c., &c.
" ..	16	(bracketed with the above)
" ..	16	Crossley Brothers Limited. (Lathes, &c., for Brass Work.)
" ..	16	Crossley Brothers Limited. (Heavy Tool Shop.)
" ..	16	Crossley Bros. Limited (Foundry Cranes and Blower.)
" ..	16	(bracketed with the above)
" ..	14	Naysmith, Wilson & Co.
" ..	12	Crossley Brothers Limited. (With Pumps combined for Accumulators.)
" ..	12	Crossley Brothers Limited. (Pattern Shop.)
" ..	6 (Twin)	Crossley Brothers Limited. (Smithy Fires and Electric Lights to offices.
" ..	12	Smith & Coventry, Salford. (Tools; auxiliary to Steam Engine.)
" ..	8	J. Carter & Co., New Bailey Street. *(See Test.)*
" ..	8	W. Birch, Broughton Lane.
" ..	8	Hans Renolds, Brook Street.
MANCHESTER..	8	Technical School.
" ..	8	S. Marsden & Sons, London Road.
" ..	8	Joseph Lea, Dyche Street, Shudehill.
" ..	7	Claviger Cycle Company, St. Mary Street.
" ..	6	Manchester Water Meter Company.
" ..	4	Claviger Cycle Company, St. Mary Street.
" ..	4	S. D. McKellan, 3, Chapman Street, Hulme. (Scientific Instrument Maker.)
" ..	3½	Gresham & Craven.
" ..	3½	G. H. Slack, Victoria Street, Ford Street.
" ..	3½	Ed. Wood, Red Bank.
" ..	3½	Theo. Clark, 180, Stockport Road.
" ..	2	Baxendale and Co., Miller Street.
" ..	2	J. J. Royle, 27, West King Street. (Tools.)
" ..	2	Claviger Cycle Company, St. Mary Street.
" ..	½	F. C. Olney, 312, Stretford Road. (Machine Tools.)
" ..	½	John Wall, 147, Broad Street, Pendleton. (Tools.)
" ..	½	J. S. Haworth, 24, Brazennose St. (Machine Tools.)
" ..	½	J. Casartelli, Clarence Street, Cheetham. (Scientific Instrument Maker.)
" ..	½ (Vert.)	Thomas Brown, Clowes Street, Chapel Street, Salford.
" ..	½ (Vert.)	Storey & Sons, Salford. (Smithy Fan.)
" ..	5-MP.	George Cussons, Teneriffe Street, Broughton. (Scientific Instrument Maker.)
MIDDLESBORO'.	3½	Dorman, Long & Co., Iron Manufacturers. (Testing Machine.)
" ..	3½	— Caswell, Esq., Engineer.
MONKSWEARMOUTH	2	H. Allison, Clock House.
NEWARK	2	Thorpe & Co.
"	5-MP.	James Trickett.
NEWCASTLE-ON-TYNE..	16	Wigham, Richardson & Co.
" ..	16	Swan & Hunter, Ship Builders.
" ..	16	Sir W. G. Armstrong & Co. Limited.
" ..	16	Sir W. G. Armstrong & Co. Limited.
" ..	16	Sir W. G. Armstrong & Co. Limited.
" ..	16	Sir W. G. Armstrong & Co. Limited.
" ..	8	Dinning & Cook, Ironfounders.
" ..	6	R. & W. Hawthorn, Forth Banks.
" ..	6	Magnus Mail, Brass and Copper Works, Hudson St.
" ..	4 (Twin)	Newcastle Machinist Company, Darncrook.
" ..	3½	Ernest Scott & Co., Close Works.
" ..	3½	J. Ridley & Co., 25, Newgate Street.
" ..	½	Combination Metallic Packing Co., Corporation Quay, Hillgate.
NEWCASTLE (Staff.)	1	J. Baildon & Co., Ironmongers.
NEWMARKET ..	6	David Edwards.
NORTHAMPTON	3½	Gas Light Company.
NORWICH......	1	Stevens & Clarke, Engineers.
"	2	Fox & Son, Ironmongers.
"	2	J. R. Pearson, Cutler
NOTTINGHAM..	3½	E. B. Cox, Lace Machine Manufacturer.
OLDHAM	12	— Toole, Ironfounder, &c.
"	12	G. Orme & Co., Meter Manufacturers.
"	3½	Asa Lees and Co. (Driving Fan)
"	3½	Squire Taylor, Moss Street.
"	½	George Orme & Co. (Meter Works.)
PAIGNTON	2	McCormack & Co.
PERTH	1	George Valentine, 77, High Street.
PETERBOROUGH	½	T. W. English, Cemetery Road.

	HP.	
Portsmouth ..	6	— Crompton, Albion Wharf.
,, ..	½	H. Tipping & Co.
Preston	5-MP.	E. G. Wrigley, Howick House.
Queensbury ..	5-MP.	M. Stocks, High Street.
Rochdale	½	James Taylor, 13, Back Drake Street.
Rochester ..	3½	Gas Company.
Ross	½	W. Blake.
Rye Bridge ..	6	James Oakes & Co.
Ramsbottom..	½	R. Nuttall & Co.
Salford	½	(Vert.) Thomas Brown, Brassfounder, Clowes Street.
Saltaire	½	G. W. Phillipson. (For Driving small Lathe and Grindstone.)
Shawforth ..	3½	Joshua Hoyle & Son, Freehold Mill.
Sheffield	16	Vickers & Co., River Don Works.
,, ..	6	Richard Townsend, 40, Spital Hill. *(See Test.)*
,, ..	6	R. Watts, Netherthorpe Street.. *(See Test.)*
,, ..	6	Davy Brothers, Engineers, Park Iron Works.
,, ..	6	Leadbetter & Scott.
,, ..	3½	J. Watts, Lambert Street, Westbar.
,, ..	3½	John Wilson, Sycamore Street.
,, ..	2	Sheffield Steam Hauling Company.
,, ..	2	J. Jennings, Eyre Street.
,, ..	2	William Walker, Noggutt Lane.
,, ..	2	Leadbetter & Scott.
,, ..	2	Lee & Lambert.
,, ..	1	H. Shaw & Sons, 47, Monmouth Street.
St. Helens ..	6	Nuttall & Co. *(See Test.)*
Skipton	3½	Hanby Brothers, Ironfounders.
Smethwick ..	16	Patent Nut and Bolt Company.
Southport ..	½	T. Ormston, Blundell Street.
,, ..	½	White & Riley, 21, East Bank Street.
Southsea	½	Portsmouth Water Works, Brunswick Road.
South Shields	2	G. S. Grey, 91, West Holborn.
Spalding	2	H. B. Massey. *(See Test.)*
Stacksteads	½	J. Astley, Ironmonger.
Staveley	9	Staveley Coal and Iron Company.
Stockton-on-Tees	16	R. Rogers & Co. Engineers.
,, ...	8	Pearse & Co., Shipbuilders.
,, ...	2	G. H. Smile, Carr Street.
,, ...	½	George Benson, 51, Matilda Street, Norton Road.
Sunderland ..	16	Short Brothers, Shipbuilders, Pallion.
,, ..	8	Sunderland Industrial School.
,, ..	2	J. Marshall, Brass and Copper Works.
,, ..	2	Henry Allison, Sheepfolds.
,, ..	1	James Morton, Borough Road.
,, ..	½	(Vert.) Gill Brothers, Tweed Street.
,, ..	½	R. Mills, 10, Ann Street.
,, ..	½	W. Fowler, Millfield.
,, ..	½	Marriott, Bolt & Co., 15, Backholmeside.
Swanage	8	H. Ramsay, Millwright.
Swansea......	½	Antoine Brossard, 33, Underhill Street.
Taunton	6	C. Allen & Son, Tone Bridge Foundry.
Wainfleet ..	2	Arthur H. Rose.
Wallsend	16	Tyne Pontoon Company, Dry Docks.
Walsall......	8	Fairbanks, Lavender & Co., Eldon Street.
Waltham Abbey	8	H.M. Gunpowder Factory.
Wellington..	3½	Bishop Brothers.
West Hartlepool..	16	E. Whithy & Co.
Wirksworth (Derby)	½	(Vert.) C. J. C. Prescot, Engineer.
Wolverhampton....	8	George Price, Cleveland Street, Safe Manufacturer.
,, ...	3½	Harrington & Co., Bicycle Manufacturers, Stewart Street.
,, ...	3½	Ready & Son, Bilston Street.
Worcester ...	1	Gas Light Company.
Worksop......	3½	H. P. Forrest, Market Place

List of Users of the "OTTO" Engines, for every other class of work, can be had on application.

Cuthbertson & Black, *Printers*, 1, Minshull Street, Manchester.

List of a Few Users

OF

CROSSLEY'S "OTTO" GAS ENGINE

FOR DRIVING

BRASS FINISHING, POLISHING, AND CUTLERS' MACHINERY

(ONLY.)

	HP.	
Aberdeen	½	(Vert.) G. Littlejohn & Co., Saddlers, 16, Back Wynd.
Belfast	8	John Hall, Queen Street.
"	7	McLachlan & Ross, Abercorn Basin.
"	3½	R. Patterson & Sons, Ironmongers.
"	3½	A. & W. Goddwin, Queen Street.
"	3½	Steel & Sons, Royal Avenue.
"	½	J. Pettigrew, Granville Buildings, High Street.
Birmingham ..	16	W. Brown, 308, Summer Lane.
" ..	16	Joseph Gilbert, Bissell Street.
" ..	16	G. Moore, Priory Works, Aston.
" ..	16	John Yates & Co., Rocky Lane, Aston. (Cutlery.)
" ..	16	John Yates & Co., Rocky Lane, Aston. (Cutlery.)
" ..	16	Snell & Prideaux, Ernest Street.
" ..	16	F. Robinson, Scotland Street.
" ..	16	J. Herbert, Dean Street.
" ..	16	A. W. Wills & Son, Park Mills, Nechells.
" ..	16	T. Moore, London Works, Aston.
" ..	14	Webley & Son, Weaman Street.
" ..	14	H. P. Tay, Leopold Street.
" ..	12	Partridge & Son, New Bond Street.
" ..	12	Wills Brothers, Rea Street.
" ..	12	A. Moore, Viaduct Works, Aston.
" ..	12	E. Ford & Co., Bath Street.
" ..	12	Wright & Harrington, Ryland Street.
" ..	12	J. Barwell, Great Hampton Street.
" ..	12	Sherwood & Sons, Regent Works.
" ..	12	J. & D. Smallwood, Leopold Street.
" ..	12	J. Wright & Co., Ignis Works, Oxford Street.
" ..	12	Showell & Sons, Lower Lovday Street.
" ..	12	Lawton & Son, Harford Street.
" ..	9	Webley & Son, Weaman Street.
" ..	9	Salkeld & Son, Smallbrook Street.
" ..	8	J. & D. Smallwood, Leopold Street.
" ..	8	J. Lawton & Son, 31, Horford Street.
" ..	8	W. L. Barber & Co., Cardigan Street.
" ..	8	L. Taylor & Co., 146, Lionel Street.
" ..	8	J. Carlyle, Constitution Hill.
" ..	8	Gibson & Birch, Brassfounders, Cheapside.
" ..	8	C. B. Partridge, New Bond Street.
" ..	8	Charles Brown, Park Street.
" ..	8	Hughes & Sons, Brassfounders, Woodcock Street.
" ..	8	S. W. Smith & Co., Cambridge Street.
" ..	8	T. Read & Co., Devonshire Street, Lodge Road.
" ..	8	Barnes & Son, Broad Street.
" ..	8	S. Hall & Sons, 15, Wrottesley Street.
" ..	8	J. Rawlinson, Leopold Street.
Birmingham ..	8	Townsend & Thompson, Ernest Street.
" ..	8	C. Winn & Co., Wood Street.
" ..	8	J. E. Hartley, St. Paul's Square.
" ..	8	Newman & Son, Hospital Street.
" ..	8	Pemberton & Son, Livery Street.
" ..	8	Mason & Co., Dale End.
" ..	7	A. J. Smith, Jeweller, 46, Frederick Street.
" ..	6	Saunders & Son, Bordesley Street.
" ..	6	E. Webb, William Street, Lozells.
" ..	6	J. C. Hudson, 39, William Street, Islington.
" ..	6	E. Horton, 239, Bradford Street.
" ..	6	Butler & Sons, Aston Road.
" ..	6	James & Co., Irving Street.
" ..	6	M. E. Eaves, Holland Street.
" ..	6	Tonks & Co., Moseley Street.
" ..	6	Phillip & Son, Cecil Street.
" ..	6	Marrian & Co., Great Hampton Street.
" ..	6	W. James, 201, Broad Street.
" ..	6	Wright & Fletcher, Lower Hospital Street.
" ..	6	Hinks & Sons, Great Hampton Street.
" ..	6	Thomas Read & Co., Devonshire Street.
" ..	6	Harris & Parr, Cardigan Street.
" ..	6	Isaac Whitehouse, 106, Aston Road.
" ..	6	T. Saunders, St. Mary's Street, Ladywood.
" ..	6	B. S. Rounds, 9, Northampton Street.
" ..	6	Nash, Bond & Co., Tower Street.
" ..	6	S. Srawley, Hall Street.
" ..	6	Parkins & Pavell, New Bartholomew Street.
" ..	4	Webb & Son, Easington Street.
" ..	3½	J. Clarke, Washington Street.
" ..	3½	Lucas & Son, Little King Street.
" ..	3½	E. Beardmore, 42, Clifford Street, Lozells.
" ..	3½	J. Foley Hall, St. Paul's Square
" ..	3½	A. W. Wills, Park Mills, Nechells.
" ..	3½	Cooper & Co., Lionel Street.
" ..	3½	G. C. Haseler & Co., 19, Vittoria Street.
" ..	3½	Beckett Brothers, Tarford Street.
" ..	3½	F. T. & A. Barrett, 28, Summer Row.
" ..	3½	James Wheeler, 95, Vauxhall Road.
" ..	3½	Rollason, Wood & Co., 52, Tenby Street, N
" ..	3½	William Jones, Cregoe Street.
" ..	3½	Manton & Mole, Warstone Lane.
" ..	3½	John Banks, Northampton Street.
" ..	3½	Hazlewood & Turner, Clifford Street, Wheeler Street.
" ..	3½	Taylor & Street, Newall Street.
" ..	3½	Thomas White, Brearley Street.

	HP.	
Birmingham	3½	C. Twigg, Little Ann Street.
,,	3½	Bevan, Hallam & Co., Mott Street.
,,	3½	W. Smith, Newhall Street.
,,	3½	Johnson & Camman, 33, Powell Street.
,,	3½	Henry Fitter & Sons, Vyse Street, Hilton Street.
,,	3½	E. T. Read & Co., Pritchett Street.
,,	3½	Morton & Brettell, Tower Road, Aston.
,,	3½	Dippee & Son., Frederick Street.
,,	3½	Flint & Son, Vittoria Street.
,,	3½	Emson & Son, Hordrough Street.
,,	2	J. M. Davies, Vyse Street.
,,	2	N. C. Reading & Co., 186, Warstone Lane.
,,	2	Wooley & Barnes, Aston Lane.
,,	2	Porter & Sons, Northampton Street.
,,	2	Marsh & Co., St. Paul's Square.
,,	2	W. Whiston, Great Charles Street.
,,	2	Kynock & Co., Ammunition Works, Witton.
,,	2	Thomas Smith, 42, Frederick Street.
,,	2	Messrs. Keeling, 6, Richard Street.
,,	2	Messrs. Read, Spencer Street.
,,	2	Stanley & Co., 23, Augusta Street.
,,	2	T. Birkett, Whittall Street.
,,	2	B. Round, Northampton Street.
,,	2	Ball Brothers, Regent Parade.
,,	2	Salt & Son, Surgical Instrument Makers, 21, Bull Street.
,,	2	R. & W. McKenzie, Upper Trinity Street.
,,	2	Adams & Sons, Northwood Street.
,,	2	— Burt, Great Charles Street.
,,	2	— Hallett, Carver Street.
,,	1½	(Vert.) J. Butler & Son, 192, Aston Road.
,,	1	H. Hickman, 27, Upper Hockley Street.
,,	1	W. Wilding, 72, Vyse Street.
,,	1	J. Collins & Sons, 47, Frederick Street.
,,	1	George Burt, Great Charles Street.
,,	1	Thomas Whitcomb, 69, Northwood Street.
,,	1	White & Co., 146, Hockley Hill.
,,	1	M. J. Rice & Co., Sherlock Street.
,,	1	M. Davies, 21, Frederick Street.
,,	½	T. Carlyle, Portland Street, Aston.
,,	½	J. Shackleton.
,,	½	J. Morton, New Spring Street.
,,	½	Reynolds Brothers, Vyse Street.
,,	½	J. Manton, Vyse Street.
,,	5-MP.	Parkins & Pavell, New Bartholomew Street.
Bolton	½	A. Hanesworth, Grundy Fold.
Bradford	8	R. Pease, Brass Finisher.
,,	1	B. & A. Butterfield, 7, Tyrol Street. (Cutlery.)
Brighton	2	J. Weller, 30, London Road.
,,	2	James Holsner, Steam Brass Works, Ship Street.
,,	2	H. E. Mitchell, 4, North Road. (Cutlery.)
,,	1	William Artis, 8, Western Road. (Cutlery.)
,,	1	Henry Perry, North Street. (Cutlery.)
,,	½	W. French, 11, Meeting House Lane. (Cutlery.)
Bristol	5-MP.	W. Price, Silversmith, Black Boy Hill.
Burton-on Trent	2	J. J. Smith & Co., Union Street.
Cambridge	½	(Vert.) MacIntosh & Sons, Market Place. (Cutlery.)
Clayton, *near Bradford*	3½	Willman Brothers.
Colchester	1	G. & H. Farmer, 106, High Street. (Cutlery.)
Coventry	3½	J. Harrington & Co., Jordan's Well. Bicycle Springs.
,,	3½	S. Harrington & Co.
Derby	½	J. Eagers, Saddlergate.
Derby	½	J. Stones, Green Lane.
Dublin	12	Jacob & Co., Middle Abbey Street.
,,	8	J. Edmondson & Co., Capel Street.
Dundee	3½	Hunter & Graham, Rattray Street.
East Hartlepool	3½	J. J. Hardy.
Edinburgh	16	W. & B. Cowan, Buccleuch Street.
,,	12	W. H. Singer, Art Metal Works.
,,	6	W. Bryden & Sons, 55, George Street.
,,	3½	A. Gaskirk, Easter Road.
,,	3½	W. Barton & Son, 11, Forrest Road.
,,	2	James Law, 3, Viewforth Park. (Cutlery.)
,,	1	Archibald Young, 61, Forrest Road. (Cutlery.)
,,	½	W. Steedman.
,,	½	(Vert.) — Gardner, 32, Forrest Road.
,,	½	T. E. & R. S. Richardson, 52, George St. (Cutlery.)
,,	5-MP	W. Robertson, 28, Rankeillor Street. Surgical Instruments.
,,	5-MP.	H. Hilliard & Son, 7, Nicholson Street. Surgical Instruments.
Exeter	7	Wippell Brothers & Row.
,,	6	Downe & Baker, South Street.
Frome	12	W. J. Singer.
Glasgow	8	R. Greenlees & Co., Howard Street East.
,,	6	W. Harvie & Co., 220, Broomielaw.
,,	4	Ronald & McRobie, 34A, King Street.
,,	3½	Hugh Buchanan, 52, Oswald Street.
,,	3½	Thomas Buchan & Co., 249, Argyle Street.
,,	2	A. Gilchrist, Eglinton Street.
,,	2	Archibald Hamilton, 34, Anne Street.
,,	1	J. Reid & Co., 107, Napiershall Street.
,,	1	James White, 241, Sauchiehall Street. (Cutlery.)
,,	½	(Vert.) J. R. Brotchie, 25, Eglinton Street.
Grimsby	½	W. S. Mundy, 25, London Street. (Cutlery.)
Halifax	7	H. S. Holdsworth, Victoria Copper Works.
,,	7	Wright, Sutcliffe & Sons, Lion Brass Works.
,,	½	J. Ramsden, Minor Street. (Cutlery.)
,,	½	Whittaker & Son. (Cutlery.)
Harrogate	½	R. Miller. (Cutlery.)
Hereford	½	— Townsend, Esq., Cutlery Works.
Horncastle	½	Rushton & Co., Fountain Works.
,,	½	R. Butcher. (Cutlery.)
Huddersfield	6	Joseph Taylor & Son.
Keighley	8	S. W. Wells, Greengate.
Kilkenny	5-MP.	— Kelly.
King's Lynn	5-MP.	J. Plowright.
Landport	½	W. Fielder & Son, 25, Russell Street. (Cutlery.)
Leeds	20	John Blakey, Lady Lane.
,,	6	Joseph Jackson, Albion Brass Works.
,,	3½	John Hardaker, 1, Grace Street.
,,	2	Chadwick Smith, Dewsbury Road.
,,	1	S. Dixon & Son, Swinegate.
,,	½	James Foster, 7 & 8, Vicar Lane. (Cutlery.)
Leith	½	J. W. Kirkwood
Liverpool	3½	Liverpool Gas Fittings Company, Duke Street.
,,	3½	J. W. Broadbent, 54, Seel Street.
,,	3½	Wilkinson & Co., 23, Crooked Lane, Canning Lane.
,,	½	E. R. Makin & Co., 68, Duke Street.
,,	½	E. R. Makin & Co., 68, Duke Street.
,,	½	(Vert.) T. Hill, Windsor Street.
,,	5-MP.	R. Kelly, Renshaw Street. (Cutlery.)
London	12	Cox, Son & Buckley, Esher Street, Westminster.
,,	8	J. Pitkin, 56, Red Lion St., Clerkenwell. (Cutlery.)
,,	7	T. Hyde, Hatton Garden, E.C.
,,	7	Elkington & Sons, 15, Myddleton St., Clerkenwell.

	HP.	
London	6	J. Benson, Ludgate Hill, E.C.
"	6	J. Nixon, Jun., St. John Square Passage, Clerkenwell.
"	4	R. Harper & Co., 17, Red Lion St., Clerkenwell.
"	4	Elliott Brothers, 112, St. Martin's Lane, W.C.
"	3½	Maw, Son & Thompson, 7-12, Aldersgate St., E.C.
"	3½	W. Long, 49, Banner Street, St. Luke's.
"	3½	M. Watts, 123, Camberwell Road, S.E. (Cutlery.)
"	3½	R. Favell & Co., Bucknall Street, Oxford Street.
"	3½	T. Smith & Co., 10, Percival Street, E.C.
"	3½	T. T. Shirlevant, 19, Farringdon Road, E.C.
"	2	W. H. Harling, Grosvenor Works, Hackney, E.
"	2	A. Copley, 17, Oak Street, Lambeth. (Cutlery.)
"	1	A. S. Lunt, 297, Hackney Road. (Cutlery.)
"	1	Wm. Gilles, High Street, Marylebone. (Cutlery.)
"	1	W. K. & F. Stacey, Newgate Street, E.C. (Cutlery.)
"	1	May & Sons; Victoria Park Road, E.
"	1	Thwaites & Reed, 7, Rosoman Street, Clerkenwell.
"	1	J. Greenwood & Son, Farringdon Rd., Clerkenwell.
"	½	R. Humphries, Seymour Place, Bryanston Square.
"	½	F. Owen, 57, Endell Street, Longacre, W.C.
"	½	C. Jeffries, 102, Praed Street, W.
"	½	Matthews Brothers, 27, Carey Street, Lincoln's Inn.
"	½	T. Parry, Saw Maker. (Cutlery.)
"	½	Charles S. Roy, The Brown Institution, Wandsworth Road. (Cutlery.)
"	½	F. Oxley, 83, Caledonian Road, N.W. (Cutlery.)
"	½	Arnold & Sons, 35, West Smithfield, E.C.
"	½ (Vert.)	F. H. Hallam, Jun., 117, Lisson Grove, N.W.
"	5-MP.	Dr. W. St. George Elliott, 39, Upper Brook Street, W.
"	5-MP.	J. Mayes, 55, Red Lion Street, E.C.
Manchester	12	S. Gratrix, Jun., & Bro., Alport Town.
"	6	Baxendale & Co., Miller Street.
"	4	S. D. McKellen, Spring Gardens, Scientific Instrument Maker.
"	2	Baxendale & Co., Miller Street.
"	2	S. H. Burgess, 46, City Road.
"	1½	G. Stone, Cutler, London Road.
"	1	John Morris, Market Place.
"	½	H. P. Alwyard, Cotham Street, Strangeways.
"	½	J. Casartelli, Scientific Instrument Maker, Cheetham Street. (Cutlery.)
"	½ (Vert.)	T. Brown, Clowes St., Chapel St., Salford.
Middlesboro'.	9	Brown & Son.
"	8	J. Livingstone, Zetland Brass Works.
Monkswearmouth	2	G. Marshall & Co.
Newcastle	1	R. McQueen & Son, 52, Grainger St. (Cutlery.)
"	¾ (Vert.)	Robert Clarke, 31, Mosley Street.
New Charlton (Kent)	2	Troughton & Sims, Mathematical Instrument Makers.
Norwich	2	Fox & Sons, Haymarket. (Cutlery.)
"	2	J. R. Pearson, St. Andrew's Hill. (Cutlery.)
"	½	Branch Timber Hill. (Cutlery.)
"	½	Thirkettle, St. Giles. (Cutlery.)
Nottingham	6	Thomas Gillott, Hockley Mill. (Cutlery.)
"	2	H. Sollavy & Son, 2, Mount Street.
Oldbury	1	Wheeler & Son.
Oldham	3½	Hargreaves & Bardsley.
Perth	1	George Valentine, 77, High Street. (Cutlery.)
Plymouth	3½	J. Woodcock, 28, Russell Street.
"	2	Troope & Monk.
Portsea	½	James Marks, 61, Queen Street. (Cutlery.)
Portsmouth	½	G. Snow, The Hard. (Cutlery.)
"	½	W. Fielder and Son, 75, Russell Street. (Cutlery.)
Preston	1	Hulme & Son, Alfred Street.
Ross	½	W. Blake.
Sheffield	16	Harrison Brothers & Howson, Shoreham Street.
"	16	Chester Brothers, West Street. (Cutlery.)
"	12	J. Gibbins & Son. (Cutlery.)
"	8	Clarke, Shirley & Co., Eyre Lane.
"	8	Joseph Senior, 36, Latimer Street. (Cutlery.)
"	8	Shirley & Co., Eyre Lane. (Cutlery.)
"	8	W. Gregory & Sons, "Otto" Works, Howard St.
"	8	Nicholls & Co., Gibraltar Street. (Cutlery.)
"	6	G. A. Close & Co.
"	6	T. Nixon, Gibraltar Street.
"	6	R. Townsend, Spital Hill.
"	6	R. Townsend, Spital Hill.
"	6	Leadbeater & Scott, St. Mary's Works.
"	6	C. Bonser, Orange Street.
"	6	E. Close, Great Charles Street. (Cutlery.)
"	6	E. Copley, Rockingham Street. (Cutlery.)
"	6	Deakin Brothers, Langsett Road. (Cutlery.)
"	3½	Deakin Brothers, Langsett Road. (Cutlery)
"	3½	Reuben Clarke, Eyre Lane. (Cutlery.)
"	3½	John Watts, Lambert Street, Westbar.
"	3½	John Wilson, Sycamore Street. (Cutlery.)
"	3½	William Laycock, Esq., Portobello.
"	2	Ellis Longley, Snow Lane. (Cutlery.)
"	2	Lee & Lambert, Matilda Street. (Cutlery.)
"	2	W. Walker, Froggatt Lane.
"	2 (Vert.)	Leadbeater & Scott, St. Mary's Works.
"	½	Barnes & Co., Solly Street. (Cutlery.)
"	½	J. Perigo, Rockingham Street. (Cutlery.)
"	5-MP.	J. W. Dawson, 56, London Road.
Southport	5-MP.	R. Wright, 4, Market Street. (Cutlery.)
Sunderland	3½	J. Rowland, Roker Avenue.
"	3½	Doxford Brothers, Shipbuilders.
"	2	J. & W. Glaholm, Bedford Square.
"	1	J. W. Plumbe, Bridge Crescent.
"	¾ (Vert.)	Gill Brothers, Brass Founders, Tweed Street.
"	½	J. J. Wilson, 19, Hudson Road.
Torquay	½	J. W. Mountstephen, 114, Union Street.
Tunbridge Wells	1	Albert Breeds, High Street. (Cutlery.)
Walsall	6	Grosil & Sons, Green Lane.
"	6	J. Shurnock, 57, High Street.
"	6	H. Frost, 35, Fieldgate.
"	3½	Stanley Brothers, Hill Street.
"	3½	H. Frost, 35, Fieldgate.
"	2	Haley & Gameson, 13, Adams Road.
"	2	Fairbanks, Lavender & Co.
"	2	C. Tranford, Caldmore Road.
West Bromwich	8	C. Bunn, Herbert Street.
Wigan	¾ (Vert.)	J. M. Hall, Market Place. (Cutlery.)
"	½ (Vert.)	H. Berry, Millgate. (Cutlery.)
Willenhall	12	G. Dyke & Son, Doctor's Piece.
"	6	John Cluley, Wood Street.
"	1	Hulse & Son, Somerford Place.
Windsor	2 (Vert.)	H.M. Armoury, Windsor Castle.
Wirksworth	½ (Vert.)	J. Prescott, Esq.
Yeovil	1	H. C. Little, Silver Street. (Cutlery.)
York	1	R. Smith & Sons. (Cutlery.)

2,000. 16/11/87. CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

Selection of Testimonials

FROM USERS OF

THE "OTTO" GAS ENGINE

FOR DRIVING

Wood-Working Machinery.

CROSSLEY BROS. LIMITED, Engineers, MANCHESTER.

16-HP. *Southgate Street and Parliament Street, Gloucester, August 7th,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your post card, we are more than pleased with the 16-HP. Engine; in fact, we are not using the 8-HP., but have taken out the piston rod, and use the fly-wheel and pulley as a counter-shaft to drive a Circular Saw on one of the upper floors, so that the new Engine is driving about 90 ft. of Line Shafting and Countershaft, one Carpet-cleaning Machine and Fan, three Circular Saws (one to cut eleven inches), two Variety Machines for planing, moulding, &c., one Double-spindle Shaping Machine, one 24-in. Power Feed Planing Machine, one large Band Saw, one Lathe, one Rod Machine, one Automatic Tool Grinder for 30-in. knives, one large Grindstone, one Fret Sawing Machine, one Drum-Sand Papering Machine and Fan, one Wool-dressing Machine, and Chaff-cutting Machine, and one Rotary Pump. We purpose putting down more machines, as we find, from the quantity of gas consumed, we are not using the Engine up to its full power. Shall be pleased to show our factory to anyone you may send.

Yours faithfully,

MATTHEWS & CO.

16-HP. *London.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We shall have pleasure in allowing you to publish the list of machines our 16-HP. Engine drives.

Yours faithfully,

ALDIN & PLATER.

NOTE.—This Engine is driving :—

One 4-cutter (Worseman) Planing Machine, cuts 9-in. planks both sides and edges.

One General Joiner, takes up to 25 in.	One Fan for four fires.
One Circular Saw, 12-in.	One Trying up Machine.
One Circular Saw, 36-in.	One Deal Frame, six Saws for 12-in.
One Morticing Machine.	One Tenoning Machine.
Two Drills for Iron.	One Iron Punching Machine.

16-HP. *Middleton Ship Yard, West Hartlepool, October 7th,* 1882.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your favour of the 6th inst., we have pleasure in stating that we have used a 16-HP. "Otto" Gas Engine since July 14th. It has never given us any trouble, and we are thoroughly satisfied with it.

Yours truly,

EDWD. WITHY & CO.

16-HP. (Early type.) *Steam Cabinet Works, St. Mary's Street, Ladywood, Birmingham, November 19th,* 1880.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—I have the greatest pleasure in giving you my experience of the Otto and Crossley's Patent Gas Engine (16-HP. nominal, 40-HP. indicated), supplied about four months ago, during which time it has been at work regularly 54 hours per week, continually cutting Timber from 15 in. to 18 in. through it, and at the same driving a lot of other machinery, including Band Saw and smaller Circular Saws.

It has given *every satisfaction*, doing its work *equally to steam*, if not better, as we have the *same speed* from morning to night. It is started quite as easily as a steam engine. *One* man *always* starts it, and the time it takes a week, in attention, is about *three hours*, not more, oiling and cleaning included. The power we take averages about 16-HP., the cost of which is, I find, much *lower than steam*. This you will see by the following comparison :—

	£	s.	d.
Gas Engine working to 16-HP.—Gas (per week of 54 hours)	£1	10	0
Oil and Waste	0	1	6
Man, for Cleaning and Attendance	0	2	0
	£1	13	6
Steam Engine (in best order) working from 8-HP. to 12-HP.—Slack (per week of 54 hours)	£1	4	0
Engine Driver	0	16	0
Oil, &c.	0	1	3
	£2	1	3

This, I think, is enough to satisfy any one. The difference, of course, would be greater compared with a steam engine working at 16-HP. We have also to *add to the cost of steam* the *value* of the *room* taken up by the *boiler, slack, and ashes*, also the expenses of boiler cleaning.

Yours truly,

L. FIELD,
J. E. FIELD.

14-HP. *Church Street, Pendleton, May 14th,* 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—My 14-HP. "Otto" Gas Engine drives the following Machines :—One large Saw Bench to take in 42-in. saw; one ditto for 24-in. saw; one Planing Machine, one Band Saw. The approximate cost of working appears to be about 7½d. per hour, according to the amount of work I put upon the Engine. I have two governor weights, and can reduce the speed or work to full power when my work requires it; but the governor regulates the supply of gas necessary. I am well pleased with the Engine. We can cut 18-in. stuff with the large Saw, and run all the other machines at the same time without the slightest difficulty. I have plenty of power, and intend to put in more machines.

I am, yours truly,

JOHN RAMSBOTTOM.

12-HP.

Margate, March 24th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 12-HP. "Otto" Gas Engine, No. 3396, is used for driving Log Frame, twelve saws, 24-in. cutting; 36-in. Circular Saw; Deal Frame, six saws, 15-in. cutting; large Moulding Machine, 12-in. wide by 3-in. moulding; Band Saw, 3-ft. 6-in. pulleys; General Joiner, Recessing Machine, and Drilling Machine. The Engine will drive Circular Saw, Moulding Machine, Deal Frame, with two saws, cutting 9-in. deep, and Recessing and General Joiner.

Yours, &c.,

PARAMOR & SONS.

12-HP.

36, *Queen Street, London, E.C., November 30th*, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—Our 12-HP. "Otto" Gas Engine drives:—Two General Joiners, two Presses, two Cross Cut Saws, one Rip Saw, one Punch, one Set Rollers, one 2-ft. Blackman Air Propeller, one Rabbetting Bench.

Our engineer gives it great credit for the way that it has done its work the last eighteen months.

Yours faithfully,

(Signed) J. F. FARWIG & CO.

12-HP.

Torquay, February 2nd, 1882.

Messrs. Crossley Brothers Limited, Mancheter.

Gentlemen,—Have cut down a 17-in. yellow pine deal, deep way, on self-acting bench, Swede balk, about 13-in. to 14-in. square, and 11-in. and 12-in. white spruce and red deals, and of course all thicknesses under this; as also in the frame saw, four saws cutting down 19-in. deep. Have often worked both machines together; not noticed any difference in the Engine.

Yours truly,

THOS. S. BAKER.

12-HP.

Lower Addiscombe Road, Croydon, September 9th, 1881.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to your inquiry, with pleasure we inform you that the 12-HP. "Otto" Gas Engine you supplied to us in March last, has given every satisfaction. It is now working Circular Saw Bench, Planing Machine, and Moulding Machine. We think of fitting up a Frame Saw for deepening deals, and consider we have plenty of power to drive the lot in full work without distressing the Engine.

We shall be pleased to show any one the Engine you may send to our works.

Yours faithfully,

PEARSON & MYLES.

12-HP.

40, *South Eaton Place, Eaton Square, S.W., London, March 19th*, 1881.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your inquiry respecting my 12-HP. Gas Engine I had from you about fifteen months ago, I must say I am very well satisfied with it, it having far surpassed my expectations as to the cost of working for gas, oil, and attention. It is now working four Wood-working Machines (including a 36-in. Circular Saw), and I have never had any cause to complain as to the want of power, &c.

Yours truly,

THOMAS HEATH.

12-HP.

Fraser Street, Liverpool, October 5th, 1883.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—I return your post card filled up with number of Gas Engine and Horse Power as requested. The Wood-working Machinery which it drives is the following:—One Circular Saw, 3 ft. diameter, one Grooving and Boring Machine, one Shaping Machine, one four-sided Moulding Machine, one Tenoning Machine.

The Engine has been in work for the last fortnight, doing at times light, and at other times heavy work, and the consumption of gas has been about 1230 feet per day—running ten hours per day. The Circular saw has been cutting logs, oak, and pitchpine 13 inches deep. Though only in use for this short time, I am glad to say it has given me every satisfaction.

I am, dear sir, yours faithfully,

THOMAS HAIGH.

9-HP.

Maidenhead, March 17th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 9-HP. "Otto" Gas Engine, No. 8707, is used for driving one Spindle Moulding Machine, one 3-Cutter Moulding Machine, one Saw Sharpener, and one Saw Bench for 24-in. saw. This Engine cuts through a deal 9-in. deep by 21-ft. long in 55 seconds, with 64 explosions per minute.

Yours, &c.,

COOPER & SONS.

9-HP.

Castle Hill, Maidenhead, July 19th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—Replying to your inquiry respecting the 9-HP. "Otto" Gas Engine you supplied us with in January last, we have much pleasure in saying it gives us every satisfaction. We have now had it constantly working for nearly six months, and find the average daily consumption of gas at about 1,700 feet. We are able to work a Circular Saw Bench; a 20-in. Frame Saw; a smaller Circular Saw Bench, with Band Saw attached for rebating; Grooving and other light work; a small Three-cutter Planing and Moulding Machine (planes up to 18-in. wide); and a Spindle Moulding Machine—all at the same time. The large Circular Saw would be cutting up to 7-in. in depth, and the Frame Saw up to 11-in. in depth; a few inches more or less depth with the Frame Saw makes little difference. We can cut up to 11-in. in depth with the Circular Saw, but find it is much more economical to do all the deep cutting we can with the Frame Saw.

The cost of attendance and cleaning is very trifling. We feel sure that the total cost of working, even with gas at our price (4/6 per 1,000), is less than that for a steam engine of similar power, to say nothing of the greater convenience.

We are not able to give you now exact cost for doing a certain amount of sawing, but will endeavour to do so later on.

Yours truly,

J. K. COOPER & SON.

8-HP.

Brunswick Works, Upper Brook Street, Manchester, March 16th, 1878.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to your inquiry, the 8-HP. Gas Engine far exceeds our expectations. I have a Circular Saw Bench and Planing Machine, and can cut 9-in. deep and plain a board 11-in. wide at the same time. I have now worked the Engine for five months, from 6.30 to 5.30 o'clock. The cost of gas is 4d. per hour. It requires very little attention—merely oiling, &c.—say a man one hour per day. It is a most useful Engine; I can with confidence recommend it to any one requiring power. I shall have pleasure in showing the Engine to any person you may send to my works.

Yours faithfully,

JOHN L. WARD.

P.S.—I have fixed shafting, and purpose ordering another saw bench for the second shop, as the Engine appears to have ample power to drive two saw benches.

8-HP.

South Wimbledon, September 3rd, 1881.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I use the 8-HP. Gas Engine for working one of Messrs. Worssam's General Joiners, and am very pleased with the working of Engine, and it is very quiet in its work, and I can deep 9-in. deals, and plane and mould up to 9 in. wide.

I am yours truly,

E. C. ACKERMANN.

8-HP.

Raleigh Street, Nottingham, July 2nd, 1881.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—The Gas Engine (8-HP.) which you supplied us with is used by us to work one of Worssam & Co.'s General Joinery and Trying-up Machines.

We may say we are thoroughly satisfied with the Engine. It works well, and with care and attention it looks as if it will last for a good many years. The cost to run is about 4½d. to 5d. per hour in gas when working.

Yours respectfully,

WRIGHT & SON.

7-HP.

47, *Goulden Street, and* 50, *Marshall Street, Rochdale Road, Manchester, July 8th,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have much pleasure in stating that the Engine you put down for me gives entire satisfaction. I have no trouble with it whatever. I am also pleased to state, for your information, that the consumption of gas from January to March quarter, working from 6 a.m. to 6 p.m., and two days per week from 6 a.m. till 8 p.m., cost £6 10s. 8d. I can cut 10-in. deep with comparative ease, which is as deep as my bench will allow.

I am, gentlemen, yours, &c.,

L. KAUFMANN, *Cabinet Maker.*

7-HP.

Albert Road, Southsea, May 3rd, 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to yours of the 27th, we shall be pleased to give you a testimonial respecting the 7-HP. "Otto" Gas Engine we purchased of you; and we give you full power to print it in your book, and when finished we should be pleased to have one. We can assure you the above Engine is quite up to our expectations. It drives a Double Frame (one of Messrs. Robinson, of Rochdale) and a Circular Saw Bench (self-feeding). The deepest we have cut by the circular saw is pitch pine 11 in. deep, with ease; but we believe we could cut deeper than that. With the double frame we have cut eight cuts down two 3 in. by 11 in. the deep way at the time, and gone exceedingly well; in fact, the Engine works beautifully. With regard to the consumption of gas, our quarter's account came in last week—namely, £4 7s. 2d., and we have averaged about five hours' work a day during the quarter. Any further information you may require we shall be pleased to send to you.

Yours respectfully,

W. & J. BIGGS.

7-HP.

Henry Square, Ashton-under-Lyne, July 13th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have now had your 7-HP. Gas Engine working eight or nine weeks, and find it very suitable for my trade. We can cut pine deals 12 in. deep; but as to the consumption of gas we have not fairly tested it yet, but I think it must be a great saving over coals. I will write you again when we have given it a fair test as to gas consumption

Yours respectfully.

J. W. WILLIAMSON, *Joiner and Builder.*

7-HP.

181, *York Street, Hulme, May 6th,* 1887.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—I have much pleasure in testifying to the efficient manner in which the 7-HP. Engine (supplied to me by your firm last July) does its work.

It will drive my Circular Saw and Band Saw, also Turning Machine and Boring Machine, all at the same time, if required.

Circular saw cuts, as a rule, not more than 7-in. deep. It might cut deeper than that quite easy, but I have not convenience in the workshop to do so. I find it is much cheaper and easier to work than the steam engine I had before. It consumes about 9/- per week of gas, for about 45 to 47 hours per week; but of course we are not always sawing all that time.

Yours truly,

WM. WILKINSON.

7-HP.

Alfred Street, Huddersfield, April 29th, 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gen lemen,—We are glad to express our entire satisfaction with the 7-HP. Engine you supplied us with some months ago. We often work a Circular Saw, a 26-in. Planing Machine, a Turning Lathe, and a Moulding Machine all at the same time, and have no trouble with it. The cost for gas is nearly 2½d. per hour.

Yours respectfully,

ALFRED TAYLOR & SONS.

6-HP.

Cabinet Works, High Street, Leicester.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—My 6-HP. Engine works very satisfactorily. There is no trouble in starting, and it has now been running seven months, during which time I have required no repairs. It often drives all my plant at once. I run the following machines:—

One 16-in. Circular Saw.
One 30-in. do.
Two Wood Lathes, 8-in. centres.
One Grindstone, 3 ft. by 6 in.
One (Haigh, of Oldham) Deal Frame, 14 ft. by 4 ft.; four cuts 14 in. through.
One Band Saw, 36 in., by Moore, Morton & Varley.
One Planing Machine, 18 in., by Haigh, Oldham.

Yours, &c.,

WESTON BROS.

6-HP.

157, *West George Street, Glasgow, Oct. 18th,* 1880.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In answer to your letter of 11th inst., I have the pleasure to say that the 6-HP. "Otto" Gas Engine supplied me for the Joinery in connection with my property at Downhill, has fully answered the expectations I had been led to form of it. Since it was fairly started it has worked very satisfactorily, driving Circular Saw, Planing Machine, Tenoning Machine, and Band Saw. My manager informs me that he has made a careful calculation of the cost for gas and oil, and that it amounts to 2/6 per day of ten hours up to this date.

I am, dear sirs, yours truly,

T. L. PATERSON.

6-HP.

7, *May Place, Mount Pleasant, Liverpool, December 29th,* 1882.

Messrs Crossley Brothers Limited, Manchester.

Gentlemen,—The 6-HP. Gas Engine you supplied me with at the beginning of the present year is giving me entire satisfaction. It drives a 26-in. Circular Saw, 30-in. Band Saw, Circular Moulding Machine, 3-in. Rounding Head Boring Machine, Fret Saw, and Lathe. It has been running from 7 a.m. to 8 p.m. during the last quarter, and the cost for gas was £6 13s., at 2s. 10d. per thousand feet, the side light extra. I find it to be the best Engine in the market; it is easy to start (a boy can start it), and I find all it wants is to be kept clean. I am much pleased with it, and I will do what I can to recommend them to my friends.

I am, yours respectfully,

F. PARKINSON.

4-HP.

Prussia Street, Oldham Road, Manchester, May 5th, 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—It affords me the greatest pleasure to bear testimony as to the superiority of your new type 4-HP. Gas Engine, one of which I am fortunate enough to possess; and having previously been possessed of a steam engine, I am in a favourable position to compare them, and can honestly say that, for cleanliness and economy, your Engine cannot be surpassed. A boy's wages would cover the total working expenses; and added to this is the total absence of dirt and waste. Instead of wasting time getting up steam as formerly, I can now command power at a moment's notice. It drives Circular Saw, Cutting and Moulding Machine, to my entire satisfaction, and it will give me pleasure if you can use this letter to proclaim its merits to the public. I would not be without one at any consideration.

Yours, &c.,

W. JACKSON, *Moulding Manufacturer.*

4-HP.

St. John's Works, St. John's Lane, Halifax, April 29th, 1887.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to your inquiry respecting the new type 4-HP. "Otto" Gas Engine supplied me in March, 1886, I have great pleasure in saying it has far exceeded our expectations. It will drive an 18-in. Circular Saw, cutting 3-in. planks; a Band Saw, a 12-ft. Face Plate, a 6-ft. Face Plate, and three Lathes at the same time. We work it about 54 hours per week, and the cost of gas, oil, looking after and cleaning, does not exceed 7/-. Altogether, it is a great improvement on the old vertical one we had before.

Yours obediently,

Per JAMES FOSTER,

JAMES FOSTER, Jun.

3½-HP.

18, *Norfolk Street, Liverpool, August 4th,* 1881.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to yours of the 2nd inst., I use the 3½-HP. Engine for Sawing Timber. I can cut up to 7 inches with ease, and 9 inches occasionally, also one of Haigh's, of Oldham, wall spindles. It will plane up to 5 inches. (That is the largest iron I have.) Stick mouldings, tongue and grove stop chafner, and a great variety of other small work.

I will have much pleasure in showing the Engine to any one you may send, and also explain several other things that would be worth knowing for a beginner.

I am, gentlemen,

Yours respectfully,

D. BOWMAN.

3½-HP.

Snowden Street.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 3½-HP. "Otto" Gas Engine, No. 3233, is used for driving one 3-ft. Band Saw, one 24-in. Circular Saw, one Wood-planing Machine, two Wood Lathes, one Grindstone, and one small Circular Saw. Will not drive all at one time; but this is not required.

Yours, &c.,

W. H. WILKINSON.

3½-HP.

Asylum Street, Leicester.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 3½-HP. "Otto" Gas Engine, No. 5547, is used for driving one 18-in. Planing Machine, one Moulding Machine, one 30-in. Circular Saw, and one 24-in. Circular Saw. The Engine will drive Planing Machine and 30-in. Saw, or both together.

Yours, &c.,

KELLETT & SON.

3½-HP.

Northgate Street Works, Ipswich, July 4th, 1881.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to your inquiry of the 16th of June—just to hand—I beg to say that the 3½-HP. "Otto" Gas Engine I had from you on the 24th March, 1880, is used for a 2-ft. 6-in. diameter Saw, which will cut an 11-in. deal. It also works a Band Saw and a small Saw Bench. The cost is 10d. per day for gas and oil, and the Engine gives me every satisfaction.

Yours truly,

R. S. SMITH.

3½-HP.

Shelbon House, Littlehampton, June 21st, 1883.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—"Otto" Gas Engine No. 2344, 3½-HP., is used for driving one 2-ft. Saw Bench, one 16-in. Saw Bench with Band Saw attached to it, one Planing and Morticing Machine, one Turning Lathe, and Pump. Shall have had it four years next August, and during all the time it has given me great satisfaction. It is used by myself.

Yours, &c.,

N. O'REILLY.

3½-HP.

60, *Montrose Street, Glasgow, March 17th,* 1882.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have now been using the 3½-HP. "Otto" Gas Engine for over six months, and must confess it exceeds my most sanguine expectations, both in power and cheapness of working. The entire consumption of gas since I received it, as shown by my meter just now, is 23,700 feet, which, at 3/8 per 1,000, comes to something like £4 7s., or just about the amount I paid per year for *water alone* for my former Steam Engine, which your gas one replaced. With regard to power, I have not been able to reach its limit. I can cross-cut and block out with the band saw blocks of lignum vitæ, six inches in diameter, with the greatest ease, much easier than my former Steam Engine (which was 7½-in. cylinder), with steam at 30 lbs. Altogether, when I take into consideration the saving of space and attention, the freedom from dirt, fire, and explosion—not to speak of the cheaper working—*a Steam Engine in comparison for my purposes would be dear as a gift.*

I am, yours very respectfully,

THOMAS TURNER.

3½-HP.

175, *Westgate, Bradford, August 16th*, 1883.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I am surprised at the work your 3½-HP. Gas Engine will do. We are now running the following machinery:—Two Circular Saws, one 24 in. diameter; two Planing Machines, two Wood-turning Lathes; 36-in. Band Sawing Machine, Morticing Machine, Dowel Making Machine, Saw, and Plain Iron Grinding Machine. We run, as a rule, five at once. You are at liberty to make what use of this you think proper. I remain, yours truly,

W. H. WILKINSON.

3½-HP.

462, *Hackney Road, London, October 9th*, 1878.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 3½-HP. Gas Engine is *still* a wonderful success. With fourteen Lathes for wood turning and a Circular Saw, we have never been able to reach the limit of its power during the eleven months we have had it in use. It costs us about a third of what we used to pay for 5-HP. steam. Yours, &c.,

E. MARKS. (MARKS, SLADE & CO.)

3½-HP.

26, *Meruel Street, Belfast, October 1st*, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have a 3½-HP. "Otto" Gas Engine, and a few weeks since was driving one of Messrs. Robinson's Deal Frames, cutting four deep in 13-in. deals; Circular Saw, cross-cutting 4-in. and 3-in. ash, and a Drilling Machine at one time, and looked as if it would have done more.

Yours truly,

SAMUEL SHAW.

1-HP.

75, *Roman Road, Victoria Park, London, E., October 25th*, 1878.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—It is with great pleasure I send my opinion of your 1-HP. Gas Engine. I am working one Saw Bench of Marshall's make, and use a 9-in. Saw, ⅛ in. thick, with 1-in. teeth, with which I can cut 4 deep, without the slightest impression upon the Engine. I can cut 2½-in. yellow deals with ease, and not any appearance of stopping the Engine. I have a Grindstone at work at the same time. I have had about a hundred people to look at it. I think you will get an order from one or two. It is quite a surprise to all, and especially to Engineers who understand sawing. I quite believe it is capable of doing more than double the work I have given it to do. I shall have great pleasure in showing it to anyone you may send. If this testimonial is any use, please use it.

I am, dear Sirs, yours truly,

L. ADAMS, JUNR.

½-HP.

Fine Art Gallery, 28, *Diamond Street, Aberdeen, Oct. 9th*, 1882.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have now had the ½-HP. "Otto" Gas Engine in work for four months. It pleases me very much, working a 14-in. Circular Saw, cutting a 2-in. oak. I observed I cut up 65 superficial feet with 100 feet of gas. This, I think, is good work, and gives me satisfaction.

Yours truly,

JOHN KESSEN.

½-HP.

Stacksteads, June 21st, 1883.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The "Otto" Gas Engine No. 6099, ½-HP., is used for turning *an* 8-*in. Slide Lathe* which does general jobbing for machines and quarrying purposes, also for *Turning Wringing Machine Rollers*, and I may add that it gives entire satisfaction, doing its work quite easy.

Yours, &c.,

J. ASTLEY.

½-HP.

239, *Lord Street, and* 26, *Stanley Street, Southport, July 9th*, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have used one of your improved ½-HP. Gas Engines, for eighteen months, and was in great doubt as to its having power enough before setting it; but, so far, it has done all we want, and is far superior to a small combined steam engine and boiler I used to have, as it requires hardly any attention, and will always work up to its full power. I run a 6-in. Circular Saw with it, and can cut 5-in. oak, walnut, or mahogany—not very fast, perhaps, that thickness, but clean and true; and by turning the wood over have cut 8 in. It also runs a Band Saw, and cuts 6 in. easy. One great advantage it has over a steam engine in my case is, that we don't require it running all day as a rule, but just run it a few hours or minutes as required. As to the gas consumed, I can hardly say exactly, as the supply to the slide lights comes from the shop meter, but I think it will not exceed 1d. per hour. I was shown how to clean and regulate it the first week I had it, and have managed it myself ever since.

P.S.—I work with it besides the Circular and Band Saw, a Fret Saw that will cut to 4-in., and a 6-in. Lathe; but we could not use all four together.

I am, gentlemen, yours truly,

J. M. FAWKE.

5-MP.

Church Street, Crook, July 23rd, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to yours of the 21st, the Engine I received from you is giving me every satisfaction so far. I am very pleased with its performance; it is driving 18-in. Circular Saw. I can cut up 4-in. Mouldings with ease; of course I have countershaft. I do not think it would do this direct. I have just examined gas meter and find I have used 1,600 feet. I have built small room round Engine, and have it under lock and key. Should any one in this district wish to see one of your Engines, at work, you are at liberty to give them my address; I shall be pleased to show them. I have not kept account of hours worked, but I do not think it has cost much more than a halfpenny per hour for gas. I will keep account for a short time and let you know result.

I remain, yours truly,

B. W. BIRD.

STONE WORKING.

12-HP.

29, *Park Street, Plymouth, October 7th*, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—Yours at hand, and we at once say we have pleasure in stating that the Engine is and has been all you stated. We have one Saw Bed (circular), one Planing Machine, and one Sanding Bed; besides the Chaff Cutter and Corn Crusher for Stables. We think the Engine would work more than as much again.

Our consumption of gas would be about 100 feet per hour.

You may remember we had a very small weight made for the governors; this we still continue to use. You can, therefore, be best judge how much more could be added.

In conclusion, we may say that the Engine continues to give us the greatest satisfaction, and should have great pleasure in showing the working to any of your clients.

We can hardly say the approximate quantity of work done per day, as we are so often forced to be changing.

One man does all the starting.

We are, yours truly,

HENRY EDE & SON.

8-HP.

11, *Iron Gate Wharf Road, Paddington*,
October 7th, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have had one of your "Otto" 8-HP. Gas Engines at work for several years driving one Stone Saw Frame, one 9-ft. Rubbing Bed, one Chaff Cutting Machine, and one 1-ton Hoisting Gear—the latter two only occasionally—and has given me every satisfaction.

One year's cost of gas, &c., for the above was as under :—

275,000 feet at 3/2 per 1,000	£43	10	10
Use of meters	2	0	0
Oil	9	0	0
	£54	10	10

Yours truly,
EDWIN TILDESLEY.

8-HP.

Carshalton Steam Marble Works, Carshalton, Surrey,
October 7th, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to your letter of yesterday, I have much pleasure in stating that I am still well satisfied with my Gas Engine, it continues to work hard and gives us no trouble. It drives the following machines :—

One Rubbing Bed, 8-ft. 6-in. diameter, well loaded, very often with heavy stonework and marble.

One 10-ft. Single Rip, taking about 85 strokes per minute.

One Gritting or Grounding Machine for marble or slate, about 85 strokes per minute.

One Polishing Machine for marble, driving a block 2-ft. 6-in. by 6-in. about 85 strokes per minute.

One Small Lathe for polishing buttons, knobs, and small columns.

The Engine works all those at a time, nearly every day (10 hours), at a cost of about 7/6 for gas, at 4/6 per thousand.

I have also a Circular Saw, with which we cut deals, &c., this we drive alone.

I shall be glad to give you any further information I can, and may add that your client need have no hesitation in going in for one of your Engines if he wants one for this kind of work.

Yours truly,
ROBERT G. HOW.

6-HP.

Earl Street, Hastings, October 8th, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your inquiries of the 5th inst., we beg to inform you that we use our 6-HP. "Otto" Gas Engine to drive the following machines;—(1) One 6-ft. Mortar Mill; (2) One Disintegrator, by Wilson, of Exeter (size for 6-HP. Engine); (3) Small Lime-Sifting Machine; the latter being worked at the same time with either of the others.

As we do not work our Gas Engine continuously, and sometimes for only two or three hours per day, it is difficult to approximate the work done per day with the consumption of gas; but, taking an average, we calculate the gas to cost us about 8d. per hour.

We find the "Otto" Gas Engine does *well* all we require, and we have recommended it for similar works.

We are, yours faithfully,
pp. THE HASTINGS PATENT STONE CO.
ARCHD. WM. HARRISON, *Director*.

LIST OF USERS.

This List consists chiefly of JOINERS AND BUILDERS, CABINET MAKERS, PICTURE FRAME MAKERS, CARRIAGE AND SHIP BUILDERS, &c.

For Users of Engines for Driving Wood-working Machines in Engineering Works, see separate List.

TOWN.	HP.	NAME AND ADDRESS OF USER.
ABERDEEN	½	John Kesson, Diamond Street.
ASHTON-UNDER-LYNE	7	J. H. Williamson, Henry Square.
ACCRINGTON	½	Alfred Walker, Oxford Street.
ALTON	1	J. B. Blake, Victoria Foundry.
ALTRINCHAM	6	James Hamilton, Hall Road.
"	2	Thomas Vernon.
AMBLOR THORN	8	John Farrell, Joiner and Builder.
"	7	J. W. Williamson, Henry Sq., Ashton-under-Lyne.
BALLINROBE (Co. Mayo)	1	T. Mitchell.
BATH	12	F. C. Norris, Albion Cabinet Works.
BEDFORD	14	J. T. Hobson, Saw Mill, New Wharf.
"	½	H. Howkins, Midland Road.
BELFAST	4	H. Keith, Brewer, Glenravel Street.
"	3½	Samuel Shaw, 26, Meruel Street.
BIDEFORD	12	J. Howe & Co., Commercial Wharf.
BIRMINGHAM	16	J. Hough, Essex Street.
BIRMINGHAM	16	Lorenzo Field, 24, St. Mary's Street, Ladywood, Cabinet Maker.
"	12	J. & B. Smallwood Leopold Street.
"	12	James Moffatt, South Road, Camp Hill.
"	9	T. Woodyatt, Bishop Street.
"	8	Alexander McKnight, Stanhope Street.
"	8	T. Savage, Great Hampton Street.
"	6	E. Mander & Son, Branston Street.
"	6	W. H. Parton, Mary Street, Balsall Heath.
"	6	Patchett & Co., Farm Street.
"	6	W. H. Foster, Steelhouse Lane.
"	6	The School Furnishing Co., King Street, Sparkbrook.
"	3½	Woodward & Co., Holloway Head.
"	3½	Alfred Lynex, Vicarage Place, Walsall.
"	3½	Clarke & Son, Exeter Street.
"	3½	F. Restall, Great Hampton Street.
"	1	T. Pettit, 72, Broad Street.
"	½ VERT.	J. Wilkins, 1, Blucher Street.

TOWN.	HP.	NAME AND ADDRESS OF USER.
BIRMINGHAM ..	½	E. Worrall, Newdegate Street.
" ..	½	Yardley & Knott, Cradley.
" ..	½	W. Edwards, 41, Ellis Street.
BLACKBURN ..	6	— Thomas, Cabinet Maker.
BOLTON	3½	Henry Walker, Frame Maker.
"	½	James Smith, 20, Mount Street.
BONCHURCH ..	3½	J. E Joliffe, Builder.
BOSTON	7	Boston Ice Company.
"	6	Samuel Sherwin, Contractor.
BRADFORD	8	Christopher Pratt & Sons, North Parade.
"	8	E. Stansfield, Leeds Road.
"	6	J. E. Rhodes, Cabinet Maker, Leeds Road.
"	6	G. H. Clarke, Hall Lane.
BURY	6	Pilling & Halliwell, Edenfield.
BRIGHTON	6	C. Cheeseman & Co., 33, Kensington Street.
BROMLEY......	3½	J. B. Day, 119, St. Leonards Street.
BRISTOL	12	Jonathan Hill & Sons, Merchant Street. (Sawing Mahogany.)
"	12	Humphries & Son.
"	12	— Beavan, Builder, Bedminster.
"	8	— Forse, Builder.
"	8	— Perkin, Builder, Redland.
"	8	H. & T. Hatherley, 84, Stoke's Croft.
" TWIN	6	H. Williams, St. Paul's.
"	6	James Bigwood, Redcliffe Street.
"	3½	Smith & Son, Drawbridge.
"	3½	— Vowles, Organ Builder.
"	2	J. Jones, Organ Works, Broad Plain. (Organ Work.)
BURNLEY......	6	J. Holgate & Son, Old Hall Street.
"	6	Hirst & Simpson, Elm Street, Burnley Lane.
BUSHEY	12	H. Herkomer, Esq., Dyreham.
CAINSCROSS ..	3½	George Keene, Builder.
CAMPBELTOWN.	8	P. Mackay & Co., Joiners.
CARDIFF	16	Solomon Andrews, Roath. (Carriage Factory.)
CARRICKFERGUS	8	Cambridge & Co., Joiners.
CHESTER	12	W. Brown, Cabinet Maker.
COLNE	8	J. Watson, Saw Mills.
CROOK(Durham)	5 NP.	B. W. Bird, Church Street.
DARWEN	12	Seth Harwood, Joiner and Builder, Hindle Street.
"	12	Joseph Westwell, Builder.
DENTON	3½	J. Naish, Market Street.
DERBY........	½	Wilson Bros., Builders.
DUBLIN	12	Tramways Company.
"	2	C. Bull, Suffolk Street.
DUDLEY	3½	— Slater, Wolverhampton Street.
DUNDEE	8	J. & A. Stewart, Small's Wynd.
"	6	Thomas Justice, 7, Tally Street.
"	½	G. Liddle, 32, King's Road.
DUMFRIES	4	J. McLachlan, Joiner.
EASTBOURNE ..	2	J. A. Skinner, Upperton Road.
" ..	½	George Towler, 24, Longstone Road.
EAST BARNET.	1	The Boys' Home, Church Farm.
EASTDEREHAM	6	Stibbins & Co.
EDINBURGH ..	8	J. Greig, Son & Co., Regent Road.
" ..	6	P. Croall & Son, 133, George Street.
" ..	6	J. Brown, 57, St. Leonard Street.
" ..	2	Calder & Co. (Venetian Blinds.)
ENFIELD	2	George Ross, Chase Side.
ETON	3½	A. & F. Halliday, 53, High Street.
EXETER	16	R. W. & F. C. Sharpe, Queen's Road.
"	6	G. L. Stile, Summerland Street.
"	3½	W. Brock & Co. (Cabinet Making.)
"	3½	Stansfield & Co., Coach Builders.

TOWN.	HP.	NAME AND ADDRESS OF USER.
EXETER	3½	— Gillard, Builder.
"	½	E. C. Brand, Cathedral Yard.
FARNHAM	½	George Elliott, West Street.
GLASGOW	12	D. Stirrat & Son, Port Dundas Road.
"	8	Clyde Shipping Company, Carlton Place.
"	6	J. Myles & Co., 11, Rosevale Street, Patrick.
"	6	J. & G. Brown, 25, Douglas Street.
"	4	Bennett Furnishing Company, Dalmarnock Road.
"	4	Cooper & Co., Rutherford Lane.
"	4	G. C. Robertson, 170, Buchanan Street.
"	3½	Thomas Taylor, 60, Montrose Street.
"	2	J. Wilson & Co., 468, Gallowgate.
" ..	2 VERT.	P. Campbell & Co., 87, Dunlop Street.
"	½	H. Wilson, Buchanan Street.
GLASTONBURY.	2	Henry Hawkins, Magdalene Street.
GLOUCESTER ..	16	D. C. Jones & Co., Cromwell Street.
" ..	16	Matthews & Co., Parliament Street. (Cabinet Making.)
" ..	8	Matthews & Co., Parliament Street. (Cabinet Making.)
GODALMING ..	12	G. Horn, Builder, High Street.
" ..	6	Smith & Son, Coach Builders.
GT. MALVERN.	8	James Davies & Sons, Waterloo House.
GREENFIELD ..	1	J. Haytack, Joiner.
GREENOCK	6	Malcolm & Co., Charles Street.
"	6	— Black, 6, West Stewart Street.
GRIMSBY	16	R. Atkinson, Chapman Street, West Marsh.
"	2	Bates & Quash, Fish Dock.
GUILDFORD	8	Pearce & Clark, Waterden Road.
"	8	W. Smith & Sons, Farnham Road.
"	6	May & Jacobs, High Street, Coach Builders.
GUERNSEY	2	H. Winterflood, Longstore.
HALIFAX	12	A. Goodall, Northgate. (Logwood Working.)
"	8	Thomas Holyroyd, Stainland.
"	4	James Foster, Pattern Maker.
"	1	Robinson Brothers, Cork Growers.
HALSTEAD	2	J. W. Ward, Newstead.
HAMILTON	3½	Maxwell & Turner, Joiners.
HASTINGS	6	John Walders & Sons, Prospect Place.
"	4	W. Wingfield, St. Leonards-on-Sea.
HAYWARDS HEATH	3½	J. Finch, Builder.
HECKMONDWIKE	4	George Mann, Batty Street. (Drives 20-in. Saw, cutting 3 in. to 8 in. timber.)
HEMEL HEMPSTEAD ..	8	William Sear, Builder, Marlow.
HIGHAM FERRERS ..	2	William Foskett, Rusden.
HIGHWYCOMBE	2	J. C. Summerfield, 1, Baker Street.
"	1	W. A. Bailey, 96, Oxford Street.
HOLMFIRTH ..	3½	Hollingworth Brothers, Hinchliffe Mill.
HORNCASTLE ..	8	Walter & Hensmen.
HUDDERSFIELD	7	A. Taylor & Sons, Cabinet Makers.
HULL	16	Blundell, Spence & Co., Coopers.
"	12	A. W. Stanley, 12, Midland Street.
"	8	John Holmes, Neptune Street.
"	6	T. Walker & Co., 180, High Street.
"	6	J. F. Sharpe, Corporation Yard.
"	2	J. B. Nield, 1, Temple Street, Beverley Road.
"	2	C. Drury, Langdale Buildings, Beverley Road.
ILFORD	½	Charles Barnes, Builder.
IPSWICH	3½	William Singleton, 73, Woodbridge Road.

TOWN.	HP.	NAME AND ADDRESS OF USER.
IPSWICH	3½	Smith & Sons, Builders.
ISLE-OF-MAN	12	Goole & Qualtrough, Castletown.
KEIGHLEY	3½	Thomas Burwin & Co., Wire Mills.
KELSO	3½	Redpath & Co.
,,	2	J. Forrest, Fishing Tackle Makers.
KINGSTON-ON-THAMES	8	J. F. Collinson, Teddington.
KIRKCALDY	1	D. Barnett & Sons.
LANCASTER	8	Williamson & Sons.
,,	6	Coupland & Ball, Cabinet Makers, King Street.
LEEDS	12	Russum & Co., Marsh Lane.
,,	8	Craven & Umpleby, Hartley Hill.
,,	6	John Lund, Wellington Bridge.
,,	3½	Henry Atkinson & Son, Carlton Hill.
,,	½	E. Huggins, Golden Cock Yard, Kirkgate.
LEICESTER	12	H. T. Mortimer, 24, St. Nicholas Street.
,,	8	George Hewitt, Builder.
,,	6	Weston Brothers, High Street.
,,	3½	J. C. Kellett & Sons, 24, Asylum Street.
,,	5 MP.	W. Vicars, Builder, Stamford Street (Fretwork).
LEITH	6	Industrial Schools.
,,	3½	South Leith Parochial Board.
,,	3½	Edinburgh and Leith Gas Company.
,,	1	J. W. Dow, 7, John's Lane.
LESLIE	2	Henry Archibald and Sons, Builders.
LINCOLN	6	Cowan & Lansdowne, Builders, Newton Street.
,,	3½	W. Wright, Park Street.
LINDLEY	2	J. W. Ellam, Joiner.
LITTLE-HAMPTON	8	N. O'Reilly, Esq., Shelton House.
LIVERPOOL	12	Haigh & Co., Frazer Street, London Road.
,,	12	Hutton & Cookson, 1, Mersey Road.
,,	12	J. Wilson, 183, Regent Road.
,,	8	R. Singlehurst & Co., 11, Redcross Street.
,,	8	H. Firth, Oldham Street.
,,	8	T. Carter, St. Anne's Street.
,,	8	Thomas Remer, 81, Pembroke Place.
,,	8	S. J. Waring, 42, St. Anne's Street.
,,	8	James Ashcroft, Victoria Street.
,,	8	W. Rosenberg & Co., 50, Lime Street.
,,	6	F. H. Parkinson, 7, May Place, Mount Place.
,,	6	Thomas Ray, 43, Seel Street.
,,	6	Bell & Birnie, 4, Keble Road, King's Road, Bootle.
,,	6	— Hall, Christian Street.
,,	3½	— Metcalf, Seymour Street, London Road.
,,	3½	J. Ashcroft, Victoria Street (Billiard Table Maker).
,,	3½	Robert Pitt, Grafton Street, Parliament Street.
,,	2	J. Austin, White Street, St. George's Square.
,,	1	Lowe and Robinson, 13, St. Anne's Street.
,,	1	Thomas Newton, 131, Dale Street.
LLANELLY	½	D. Evans, Faughan Street.
LONDON	16	Clark & Co., 9, Allen Terrace, High St., Kensington (Cabinet Makers).
,,	16	Orlando Jones & Co., Battersea.
,,	16	Aldin & Plater, Roland Gardens, South Kensington.
,,	14	H. Lebus, 70, Tabernacle Street, E.C.
,,	12	W. Groom, Albany Road, Camberwell.
,,	12	F. Sage, 80, Gray's Inn Road.
,,	12	Kinnimont & Son, 26, Chilworth Street.
,,	12	Lucas & Son, Kensington Square.
,,	12	Tasman & Sons, Sun Court, Golden Lane, E.C. (Packing Case Making).
,,	12	J. Swaagman, 24, Featherstone Street.

TOWN.	HP.	NAME AND ADDRESS OF USER.
LONDON	12	A. Burrows, Timber Merchant, Camberwell New Rd.
,,	12	Cox, Son & Buckley, Esher Street, Westminster.
,,	12	J. Harvey, 57, Redcross Street.
,,	12	Dyer, Harper & Dyer, 2, Northampton St., Islington.
,,	12	J. F. Farwick & Co., 36, Queen Street, E.C.
,,	12	W. Groom, Albany Road, Camberwell.
,,	12	T. Heath, 40, South Eaton Place, S.W.
,,	12	Shepherd & Co., St. Peter's Wharf, Hammersmith.
,,	12	R. N. Cattle, Portland Works, Portland Street.
,,	9	G. Lyford, 266, Uxbridge Road, W.
,,	8	J. & A. Stroud, 287, Kingsland Road.
,,	8	J. S. Sergeant, The Triangle, Hackney.
,,	8	E. J. Page & Co., 188, Kennington Park Road.
,,	8	E. Laurance, 16, Wharf Road, City Road.
,,	8	J. Axford, 4, Henry Street, Gray's Inn Road.
,,	8	W. Groom, Albany Road, Camberwell.
,,	8	Richardson, Koolman & Isger, Farringdon Street.
,,	8	George Feldon & Co., 42, Upper Marsh St., Lambeth.
,,	8	Dottridge Brothers, East Road, City Road, E.C.
,,	8	Stewart & Son, Blackwall Ironworks, E.
,,	8	J. Woodward, Wilson Street, Finsbury.
,,	8	John Anley, 27, Dalston Lane, West Hackney.
,,	8	J. T. Laurence, Wine Office Court, Fleet Street.
,,	8	G. Scammell & Nephew, Fashion Street, Spitalfields.
,,	8	A. Ransome & Co., King's Road, Chelsea.
,,	8	J. Shoolbred, Tottenham Court Road.
,,	8	Mattock Bros., Winkfield Road, Wood Green.
,,	8	Colls & Sons, Dorking.
,,	8	Henry Howell & Co., 180, Old Street.
,,	8	W. Royal, Penton Works, Pentonville.
,,	8	William Mason, Builder.
,,	7	R. Johnson & Co., Gurney Street, S.E.
,,	6	W. A. S. Benson, 1, Eyot Terrace, Chiswick Wall Hammersmith.
,,	6	F. W. Lucas, 240, Brixton Hill, S.W.
,,	6	Boys' Home, Wandsworth.
,,	6	Lewis & Co. Limited, Shepherd's Lane, Brixton.
,,	6	J. Hathway, 43, York Street, Walworth.
,,	6	J. Hathway, 43, York Street, Walworth.
,,	6	A. Slade & Co., 4, Oval, Hackney.
,,	6	B. S. Cohen, Great Prescott Street, E.
,,	6	Hall, Bedall & Co., Pitfield Wharf, Waterloo Bridge.
,,	6	T. Bateson & Son, 42, Brewer Street, W.
,,	6	Dr. Barnardo's Home, 626, Commercial Road.
,,	6	Richmond & Graveson, 6, Appold Street, E.C.
,,	6	Johnson & Watts, 40, City Road.
,,	6	R. Perkins, 134, Great Titchfield Street, W.
,,	6	J. & H. Rickitts, 99, Drummond Street, N.W.
,,	6	J. Bowie, 21, President Street, Clerkenwell, E.C.
,,	6	W. H. Mason, Carriage Factory, Kingsland Road.
,,	4	Elliott Brothers, Strand, W.C.
,,	3½	Marks, Slade & Co., 462, Hackney Road.
,,	3½	The Kensington Vestry.
,,	3½	The Islington Vestry Stables.
,,	3½	James Hildersley, 33, Berwick Street.
,,	3½	Baalam Brothers, 8, Shenton Street, Old Kent Road.
,,	3½	Boys' Home, Regent Park Road.
,,	3½	W. H. Brand, 3 and 4, Hoxton Square.
,,	3½	Lenzberg & Co., 33, Sun Street.
,,	3½	Lillywhite, Froude & Co., Cricket Bat Manufacturers, 73, Bow Road.
,,	3½	M. B. Viscardini, 42, Gough Street, Gray's Inn Roa d.
,,	3½	F. W. Reynolds & Co., 73, Southwark Street.

TOWN.	HP.	NAME AND ADDRESS OF USER.
LONDON	3½	H. J. Fletcher, 161, City Road.
"	3½	F. Goddard & Co., 1, High Street, Peckham.
"	3½	G. Hare, 26, Calthorpe Street, Gray's Inn Road.
"	3½	Hildesheimer & Co., Silk Street.
"	3½	Boys' Home, 95, Southwark Street.
"	3½	Guynan & Son, 11, Carburton Street, Great Portland Street.
"	3½	Peel & Co., Duke Street Square.
"	3½	J. Collis, Ironmonger Row, E.C.
"	3½	J. Crowley, 121, Aldersgate Street.
"	3½	F. G. Ernst, 80, Charlotte Street, Fitzroy Square.
"	3½	— Watts, 123, Camberwell Road, S.E.
"	3½	V. A. Hallpike, 11, Mentmore Terrace, London Fields
"	3½	Cockerill & Co., Vine Court, E.C.
"	3½	R. How, Durant Iron Works, Bethnal Green.
"	2	Hunter & Hyland, 37, Park Street, Drury Lane.
"	2	S. Robertson, 181, Kensington Lane, Vauxhall.
"	2	Stewart & Co., Blackwall Ironworks, E.
"	2	Henry Bassant, Wells Street, Oxford Street.
"	2	C. A. Priest, Fell Street, Cable Street, E.
"	2	T. Collier, 2, Moor Lane, E.C.
"	2	— Futvoye, 61, St. John's Square, E.C.
"	2	J. Fry, 42, Stephen Street, Lisson Grove.
"	2	T. Warner, 42, Brunswick Place, City Road.
"	2	A. Willis, Huggin Lane, Queen Victoria Street, E.C., Packing Case Maker.
"	2	A. J. Wetherilt & Co., Chapel Street West, Mayfair
"	2	S. Robertson, 181, Upper Kensington Lane.
"	2	A. Bush, 17, Gower Street, Bedford Square.
"	2	W. F. Stanley, Great Turnstile Street, W.C.
"	1	Hayward Brothers, Cigar Box Manufacturers, Queen's Road Bridge, Dalston.
"	1	J. Adams, Jun., 75, Roman Road, Victoria Park (Picture Frames).
"	1	G. S. Dutton, 90, Walton Street, Chelsea.
"	1	George Munt, Cross Street, Farringdon Road.
"	1	J. H. Montague, 29, Oval, Hackney Road.
"	1	J. Campion, Ellesmere, Old Ford.
"	1	St. Vincent's Home for Boys.
"	1	J. King, 21, Price Street, Exmouth Street, E.C.
"	1	R. Ayton, 5, Whitechapel Road.
"	1	Greenwich Training School, Greenwich Hospital.
"	1	J. C. Mineard & Co., 24, Barnsbury Road.
"	1	F. Orme & Co., St. Andrew's St., Holborn Viaduct.
"	1	M. Isaacs, Victoria Mews, Oldford Road.
"	1	J. Adams, 75, Roman Road, Victoria Park.
"	¾ VERT.	W. Clark, 137, Vauxhall Road Walk.
"	½	Herbert Lea, Warwick Street, Regent Street.
"	½	W. Roebuck, New Inn Yard, E. (Cabinet Maker).
"	½	R. Thacker, Page's Walk, Old Kent Road, S.E.
"	½	W. J. Shaw, Tabard Street, S.E.
"	½	J. W. Harker, 46, Old Street, E.C.
"	½	F. Pulser, 1, West Square, St. George's Road, S.E.
"	½	T. Pettit, 2, Richmond Street, East Street, Walworth.
"	½	Lowe & Sons, Bedford Works, Gillespie Road, Highbury.
"	½	J. Ayres, 13, Winchester Street, King's Cross, N.
"	5 MP.	H. W. Prickett, 13, Shrubland Grove, Dalston.
MACCLESFIELD	2	A. G. Dawson, Alma Buildings.
MAIDENHEAD	9	J. K. Cooper & Son, Castle Hill.
MAIDSTONE	12	Fremlin Brothers, Brewers.
"	3½	E. Vaughan, Builder.
MARGATE	12	Paramor & Sons, Eaton Road.
MARGATE	5 MP.	Kent Coal Company (Firewood Cutting).
MANCHESTER	14	J. Ramsbottom, Contractor, Pendleton.
"	12	Southern & Wheelden, Collier Street, Liverpool Road, Packing Case Makers.
"	9	H. Davies, Cornice Pole Manufacturer, Salford.
"	8	J. L. Ward, Robert Street, Brook Street.
"	8	Morgan Morgan, Great Marlborough Street, Packing Case Maker.
"	8	Baltic Cooperage Company, George Leigh Street.
"	8	Ellis, Pugh & Co., Granby Row.
"	7	Levi Laufmann, Cabinet Maker, 47, Goolden Street, Rochdale Road.
"	7	— Wilkinson, Cabinet Maker, Blake Street, Hulme.
"	6	Thomas Kay, Case Maker.
"	6	Joseph Wood, Port Street, Case Maker.
"	6	George Johnson, Case Maker.
"	6	Boys' Refuge, Strangeways (Firewood).
"	6	R. R. Heap, 13, Park Street, Greenheys.
"	4	— Jackson, Picture Frame Maker, 23, Prussia Street, Oldham Road.
"	3½	William Arbuckle, Cornbrook Park, Cabinet Maker.
"	3½	Hildesheimer & Co., Dantzic Street.
"	3½	— Shaw, Mulberry Street, Hulme, Joiner & Builder.
"	3½	Howarth & Smith, Fetter Lane, Minshull Street.
"	3½	Peter Gobble, Worsley Street, Hulme.
"	3½	Brooks & Power, Long Millgate.
"	3½	G. H. Slack, Hardman Street, Deansgate.
"	3½	Cordingley & Stopford, Boyd Street, Stockport Road.
"	3½	Lewis Glass & Co., Mill Street.
"	3½	Gough & Co., Cross Street, Oldham Road.
"	2	T. H. Lawton & Co., 6, Watling Street.
"	2	James Coop, 41, Broad Street, Pendleton.
"	½	J. S. Higgins, 7, Green Street, Tib Street.
"	½	J. Collins, 23, Hood Street, Ancoats.
MERTON PARK (SURREY)	9	Innes Brothers, Kingston Road.
MILLFIELD	3½	R. Hudson, Contractor.
MONTROSE	3½	J. Raitt, Lower Hall Street.
MOSSLEY	8	J. Robinson & Sons, Builders.
"	3½	Henry Bradbury, Joiner.
NEWARK	½	D. Slater, Fishing Rod Manufacturer, 8, Portland St.
NEWCASTLE-ON-TYNE	8	Spencer & Co., Newburn Works.
"	½	C. J. Vincent, 30, Bridge Street.
"	½	J. T. Jones, 1, Stepney Lane.
"	½	Joseph Rose, Richmond Place, Gibson Street.
NOTTINGHAM	8	J. Wright & Sons, Builders, Raleigh Street.
"	8	W. Woodsend, Builder, Toll Street.
"	1	— Grundy, Joiner, Plumtree Street.
"	1	Ford & Co., Box Makers, Mount Street.
OLDHAM	1	Thomas Woodward, Union Street.
"	½	T. Whittaker, Rochdale Road.
OMAGH	8	H. Houston, Builder.
OTLEY	3½	W. Debb, Cabinet Maker.
PADDOCK	6	Marsden & High, Joiners.
PENRITH	12	W. James, Timber Merchant.
PETERBORO'	16	John Thompson, 43, Wood Street.
PITTENWEEM	6	W. Fulton, Joiner and Boat Builder.
PLYMOUTH	9	J. H. Harley, Builder.
"	8	Isaac Foote, Builder, Notte Street.
"	8	W. Trevana, Barley Estate Building Yard.
"	6	W. Palk, Builder, Coburg Street.
PORTSMOUTH	7	Biggs Brothers, Albert Road, Southsea.
"	6	Camper & Nicholson, Yacht Builders, Gosport.

TOWN.	HP.	NAME AND ADDRESS OF USER.
PORTSMOUTH ..	3½	T. P. Hall, Bedford Road, Southsea.
,, ..	2	W. Lowe, 12, The Green, Gosport.
,, ..	2	Scammell & Dowdell, Builders, 174, Wingfield St., Landport.
,, ..	1	R. Payne, 32, St. James' Road, Southsea.
,, ..	1	J. Hatherley, 35, Great Southsea Street.
,, ..	½	F. Holmes, 26, Silver Street, Southsea.
,,	5-MP.	W. Learmouth, Emsworth Road, Kingston Cross, Portsmouth.
PRESTON	12	— Whiteside, Builder.
RAMSGATE	½ VERT.	Kent Coal Company (Firewood Cutting).
REDHILL	3½	Joshua Fielding, Esq., Nutfield Priory.
RETFORD	2	John Wilson, Builder.
RHONDA VALLEY	1	— Morris, Builder, Ferndale.
RICHMOND	1	Charles Eldridge, Ormond Road.
ROCHDALE	4	Ashworth & Wolfenden, 109, Milnrow Road.
,, ...	4	Henry Matthews, Builder, Norden.
SALTAIRE	½	G. W. Philpson, Wood Turner.
SALTBURN-BY-SEA	8	T. Wharton, Esq., Skelton Estate.
,, ...	2	T. Wharton, Esq., Skelton Estate.
SCHOLES ,....	2	Joseph Batley, Joiner.
SELBY	3½	Thomas Robinson, Canal Side.
,, ...	3½	J. Crooke & Son, Builders.
SEVENOAKS ..	4	W. Wiltshire, Builder, St. John's Hill.
SHEFFIELD	6	John Holmes, 55, Arundel Lane.
,, ...	2	Lister & Sons, 91 and 93, Southgate Moor.
SHIPLEY	3½	A. Hamsworth, Joiner, &c.
SOUTHAMPTON.	3½	W. Vandrey, Esq., Langley Manor, Ealing.
SOUTHPORT ..	½	J. C. White, 91, Eastbank Street.
SOUTH SHIELDS	6	F. B. Dobson, 4, Chichester Road.
SOUTHALL	6	Abbott Brothers, Fairlawn.
,, ...	8	St. Mary's Orphanage.
SOUTH WIMBLEDON	8	E. C. Ackerman.
SOWERBY BRIDGE	8	J. Hardy, Cabinet Maker.
SPALDING	8	E. P. Marples, Esq.
STALYBRIDGE ..	12	Saxon Brothers, Mottram Road.
ST. HELENS ..	6	Nuttall & Co.
STRATFORD-BY-BOW	16	J. W. Martin, Grove Saw Mills.
ST. NEOTS	12	W. A. Atkinson, Builder.
STOCKTON-ON-TEES	8	M. Pearse & Co., North Shore.
,, ..	½	George Benson, Norton Road.
STROUD	6	H. Dorrington, Esq., Syppiat Park.
,, ...	3½	George Keene, Cainscross.
SUNDERLAND ..	16	Short Brothers, Pallion Shipbuilding Yard.
,, ..	12	Earl of Durham, Lambton Drops.
SUNDERLAND ..	6	G. & F. Hildrey, Builders.
,, ..	3½	R. Hudson, Jun., Contractor, St. Mark's Crescent Yard.
,, ..	3½	W. Scott & Son, Tunstall Road.
,, ..	1	W. Woodward.
,, ..	½	James Queenan, 8½, High St. W. (Picture Framer).
,, ..	½	John Coates, 33, Fawcett Street.
TANSHELF	4	W. & C. Wilcock. Drives 26-in. Saw, cutting 7-in. and 8-in. timber.
THAMES DITTON	2	Rev. — Barrett, Glenwood.
TORQUAY	12	T. S. Barker, Timber Merchant, Union Street.
,, ...	12	— Crossman, Saw Mills.
WAKEFIELD ..	6	W. Holdsworth & Son, Cabinet Makers.
WALLINGTON ..	6	R. Owen, Builder.
WALSALL	8	James Proffitt, Jun., 29, Wallhouse Street.
,, ...	6	W. Cox, Lichfield Street.
,, ...	3½	A. Lynex, Builder, Vicarage Place.
WARWICK	3½	Glover & Sons, Eagle Works (Cart and Wagon Builders).
WELLINGBORO'.	6	George Henson, Builder.
WEST HARTLEPOOL	16	E. Withy & Co., Ship Builders.
WICKHAM MARKET ..	8	Whitmore & Binyon.
WILLENHALL ..	1	Hulse & Son, Somerford Place.
WILMSLOW	12	J. K. Coates, Station Road.
WINDERMERE ..	3½	Latham & Dobson, Builders.
WINDSOR	3½	William Holderness, Timber Merchant.
,, ...	2	J. L. Hollis, Victoria Street.
WORCESTER ..	12	Smith & Son, Brush Manufacturers.
,, ..	8	— Pemberton.
,, ..	3½	Henry Spicer, Silver Street.
WREXHAM	12	Davies Brothers, Builders.
YORK	3½	John Taylor, 48, Coney Street, Cabinet Maker.
YARMOUTH	5-MP.	J. W. Easton (Wood Turning.)

STONE WORKING.

TOWN.	HP.	NAME AND ADDRESS OF USER.
BRIDGEWATER.	8	W. & J. W. Pritchard, Bridgewater Docks.
CARSHALTON ..	8	R. G. How, Marble Works.
HASTINGS	6	The Patent Hydraulic Freestone Co., Earl Street.
PADDINGTON ..	8	Edwin Tildesley, 11, Iron Gate, Wharf Road.
PLYMOUTH	12	Henry Ede & Son, 29, Park Street.
,, ...	6	J. Snawdon, North Road.
SOUTHPORT ..	3½	R. Hallsall, 33A, King Street.
TORQUAY	6	H. T. Jenkins, 56, Lower Union Street.

CROSSLEY BROTHERS LIMITED,

Openshaw, Manchester.

Selection of Testimonials

FROM USERS OF

CROSSLEY'S "OTTO" GAS ENGINE

FOR

DRIVING PRINTING MACHINERY.

THE MORNING NEWS.

16-HP. *The "Morning News," Belfast, September 25th*, 1884.

Messrs. Crossley Brothers Limited.

Gentlemen,—I have pleasure in saying that the "OTTO" Gas Engine erected by you is giving great satisfaction.

I consider it much superior to steam for Printing purposes. It is easily started, and when driving Victory Machines for a moderate circulation, say 25,000, effects a very great saving.

The "OTTO" is particularly useful in case of extra numbers wanted, or in case of second editions, as a plentiful supply of papers can be had in five minutes after the order is given.

Yours truly,
C. J. DEMPSEY, *Manager.*

LEEDS DAILY NEWS.

16-HP. *"Daily News" Office, Leeds, June 8th*, 1883.

Messrs. Crossley Brothers Limited.

Dear Sirs,—Referring to yours of yesterday's date, I am glad to be able to say the 16-HP. "OTTO" Gas Engine you supplied us with recently is working daily with every satisfaction.

Faithfully yours,
F. C. MACASKIE.

DUNDEE ADVERTISER.

16-HP. *7 to 25, Bank Street, Dundee, January 22nd*, 1885.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We adopted your large 16-HP. Gas Engine to save boiler space. It more than answers our expectations in respect of power, speed, and efficiency.

We also find the cost of gas in proportion to the amount of work done very moderate.

We have now four Gas Engines in the establishment showing our appreciation of gas in preference to steam power.

(Signed) JOHN LENG & CO.

LONDON CITY PRESS.

12-HP. *"City Press," 148 and 149, Aldersgate Street, London, E.C., June 13th*, 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to your inquiry, we have found the 12-HP. Gas Engine work in a very satisfactory manner, and frequently the work demanded from it is beyond the nominal power.

Yours respectfully,
W. & T. COLLINGRIDGE & CO.

LONDON EVENING NEWS.

12-HP. *The "Evening News," 12, Whitefriars Street, London, E.C., June 12th*, 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to yours of 8th inst. to hand, the two 12-HP. Gas Engines supplied by you have worked very satisfactorily, and have given very little trouble. We find them quite up to their work.

Yours faithfully,
HENRY R. BARTLETT.

A third 12-HP. Engine has lately been added.—C. B. Ltd.

IRISH TIMES.

12-HP. *"Irish Times," Westmoreland Street, Dublin, September 17th*, 1884.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In answer to your inquiries as to the suitability of your Engines (of which I have two 12-HP.) to drive Victory Printing Machines, I have very great pleasure in informing you that I have been driving three Victory Machines for the last two years and eight months, and find that they do their work uncommonly well, and I may say that I would not exchange them for steam.

I have recommended several newspaper proprietors who came to me to make inquiries about them, and who have Web Machines, to use your Engines.

Yours truly,
JAMES PENNY, *Engineer.*

DUBLIN GENERAL ADVERTISER.

8-HP. *"General Advertiser" Office, Dublin, October 21st*, 1878.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 8-HP. "OTTO" Silent Gas Engine supplied by you is giving great satisfaction. It works two Four-feeder Middletons, two Folding Machines, a Four-demy Perfecting Machine, a Wharfedale, a Cropper, and a Minerva, and appears to have power to spare.

GUNN & CAMERON.

8-HP. *Linenhall Works, Belfast, October 18th*, 1878.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—The 8-HP. Silent Gas Engine we had from you is giving us every satisfaction. All the machinery it is intended to drive is not on it yet, so that we are not using its full power; but, after a careful comparison of the cost of steam and gas, we can say that the difference is a long way in favour of using the Gas Engine, to say nothing of the cleanliness and economy of space. The cost, from an indication taken, appears to be 6¼d. per hour.

Yours faithfully,
McCAW, STEVENSON & ORR.

8-HP. *The Liverpool Printing and Stationery Co. Limited, November 1st, 1878.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 8-HP. Gas Engine recently had from you is, so far, very satisfactory. It drives about twenty machines, and is attached to the Hoist. The 3½-HP. Gas Engine drives seven Lit ho. Machines and six Presses. Both Engines exceed anything we anticipated.

JOHN HOWDEN, *Manager.*

THE LIVERPOOL PRINTING & STATIONERY CO.

Have superseded steam by gas power. They have two of our "OTTO" Silent Engines, of 8 and 3½-HP. respectively.

The 8-HP. Engine drives—

1 Double Royal Printing Machine (two colours).
1 do. Main do.
5 Double Demy do.
2 Double Crown do.
1 Demy Heading do.
1 Foolscap Folio Main do.
1 Post Folio Platen do.
2 Foolscap Folio Minerva do.
6 Litho Presses.
1 Rolling Machine (heavy).
4 Guillotine Cutting Machines.
1 Roller-washing Machine.
1 Hoist.
1 Label-cutting Machine.
In all 27 Machines and Presses, and 1 Hoist.

The 3½-HP. Engine drives—

6 Litho. Machines and
1 Stone-grinding Machine.

The whole of the above work is done by the two Engines, to the complete satisfaction of the Company, and the Manager, Mr. John Howden, has permitted reference to be made to him at any time.

6-HP. *Caxton Works, Birkenhead, May 4th, 1883.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to yours of 30th ult., we have pleasure in stating that the 6-HP. "OTTO" Engine which we had from you gives us even more satisfaction than the two previous ones of smaller power did, and they were satisfactory.

The 6-HP. drives three Litho. Machines, one Quad Demy, one Double Demy, one Double Crown, one Demy, two small Platen Letterpress Machines, and an Ink Mill. Since we have had it running (now a year-and-a-half) it has not cost us one penny for repairs, nor even got out of gear, and we have sometimes to run it day and night.

Yours very truly,

E. GRIFFITH & SON.

DEVONPORT INDEPENDENT.

6-HP. *"Independent" Office, Devonport, November 13th, 1880.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—I have had more than six months' experience of the working of the 6-HP. Gas Engine supplied by you. It drives one of Dawson & Sons' large size Double-feeder Newspaper Machines, with flyers, another full-size Newspaper Machine single-feeder, and a Newspaper Folding Machine; but there is power, I think, sufficient to do double that work if it were required. I am more than pleased with the Engine, for its advantages have far exceeded my expectations, and in the important matter of expense its cheapness has been very marked. The cost is simply trifling as compared with steam for my occasional work, and especially so in this respect—that the Engine does not require the attention of a skilled workman; an ordinary labourer to keep it clean and supply it with oil, being all that is necessary to ensure its successful working. Besides these advantages there is also the convenience of always having the Engine ready for work without "getting up steam;" and then what makes the working of the Engine so inexpensive is the fact that immediately the work is finished the cost at once ceases; and again the fact that the cost is regulated by the power required to do the work. Thus—although I use a 6-HP. Engine, yet I can work it at 3-HP. or any other power, at a proportionate reduction of cost.

I am, gentlemen, yours faithfully,

A. W. BOOLDS.

AYR OBSERVER.

3½-HP. *"Ayr Observer" Office, July 11th, 1884.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 3½HP. Engine ordered December 3rd, 1883, is used by me for printing the *Ayr Observer* newspaper. It has given me the greatest satisfaction. It saves time, is more economical than the steam engine I formerly used, and is more to be relied on. I have not lost five minutes with it yet.

G. M. FERGUSON.

NORTHERN CHRONICLE & GENERAL ADVERTISER FOR THE NORTH OF SCOTLAND.

3½-HP. *"Northern Chronicle and General Advertiser for the North of Scotland," Inverness, 31st March, 1881.*

Dear Sirs,—I have much pleasure in testifying to the very satisfactory manner in which your 3½-HP. "OTTO" Gas Engine has done its work since it was fitted up here.

The machinery it drives is a Dawson's Double-feeder News Machine, a Single-feeder Wharfedale (Double Royal), an Arab, and a Folding Machine.

Yours truly,

R. LIVINGSTON, *Manager.*

Messrs. Crossley Brothers.

DERBY GAZETTE.

3½-HP. *"Gazette" Office, Full Street, Derby, October 24th, 1878.*

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—Your 3-HP. "OTTO" Silent Gas Engine has, since we got it in June, given us great satisfaction. It works off, on a Wharfedale Machine, from 15,000 to 20,000 copies of our papers weekly.

Yours faithfully,

BEWLEY & ROE.

IRISH FARMERS' GAZETTE.

3½-HP. *"Irish Farmers' Gazette," 23, Bachelors' Walk, Dublin. London Office: 29, Moorgate Street, E.C. Dublin, 9th October, 1879.*

Dear Sirs,—It is with much pleasure we are enabled to report most favourably upon the working of the "OTTO" Silent Gas Engine 3½-HP., supplied by you about eighteen months ago. We find a great saving in cost of working, consumption of gas being much less than coal. Attention: Boiler and steam engine dispensed with, and our Printing Machines worked as steadily, if not more so, than with steam. The starting of the Gas Engine could not be easier, and our foreman states that in every way it is the greatest comfort he has had in getting through his work. He will recommend the use of the Silent "OTTO" to all who require engine power.

Yours faithfully,

For the Irish Farmers' Gazette Co., Limited,

JOHN PURDON, *Sec.*

WEST OF ENGLAND EXPRESS.

3½-HP. *"West of England Express" Offices, Crewekerne, October 29th,* 1878.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have great pleasure in stating that your 3½-HP. "OTTO" Silent Gas Engine answers our purpose admirably. It gives but little trouble, is almost noiseless, and drives our Two-feeder Wharfedale Machine with the greatest ease. We believe it capable of driving the whole of our Machinery at one time if required. We confidently recommend it.

J. WHEATLEY & G. F. MUMFORD.

COVENTRY HERALD.

3½-HP. *"Herald" Office, Coventry, October 23rd,* 1878.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We are very well satisfied with your Silent Gas Engine (3½-HP.). We use it for driving a Two-feeder Wharfedale News Machine, and for our purpose we could desire nothing better.

Yours truly,
J. M. SCOTT.

3½-HP. *Castle Printing Works,* 12, *Preeston's Row, Liverpool, July 12th,* 1877.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—In reply to your inquiry, I have pleasure in stating that every day's experience confirms my good opinion of your "OTTO" Silent Gas Engine. I had the second Engine you sent out; it is really noiseless, needs no attention, except occasional cleaning and a supply of gas and oil; and adjusts itself to a light or heavy load, while maintaining an evenness and regularity of speed that is remarkable. Its consumption of gas is quite within your estimate, and, as indicated, when doing light work, its consumption is light. Example:—Our Engine is 3½-HP. For three weeks, when we are not running all our machines continuously—though all of them at times—the cost of gas was 7s. to 7s. 2d. per week of 51 hours, compared with 17s. 6d., which your calculation would give for the same time running at full power—price of gas, 4s. per 1,000 feet. I am able to speak with confidence as to the superiority of your new type of Engine, having had about three years' experience of your Atmospheric Engine.

Yours respectfully,
B. HARAM.

P.S.—March 16th, 1878 (after 12 months' use of Engine).

We drive five Letterpress Machines from the "OTTO"—viz., a Double Royal and a Double Demy Dawson's Wharfedale; a Demy Miller and Richard's; a Demy Folio and a Crown Folio Universal; the two latter Platen Machines. They frequently all run together at full speed with plenty of Engine power to spare.

B. HARAM.

3½-HP. 17, *Trinity Street, Leeds, May 5th,* 1880.

My Dear Sirs,—Our "OTTO" Silent Gas Engine (3½-HP.) drives, easily and smoothly, four Cylinder Machines (one of which is a Quadruple Crown) and two Minervas, as well as a large and powerful Guillotine, by Dawson & Sons, Otley. We are well satisfied with its performance, for it renders good and efficient service.

Yours very truly,
WHITEHEAD & SON.

3½-HP. *Harrogate, May* 3, 1880.

Dear Sirs,—The Engine does its work in the most satisfactory manner possible, and at a cost less than stated on the prospectus. For the information of Printers who may ask (as I did), "What machinery will it drive?" I may state that the 3½-HP. Engine drives three "Wharfedale" Machines (one a news size with flyers), a Livesey's Folding Machine, and a Steam Litho. Press (Double Royal size) with the greatest ease.

ROBERT ACKRILL.

BLACKPOOL TIMES.

3½-HP. *"Blackpool Times" Office,* 34, *Church Street, Blackpool, November 29th,* 1877.

Messrs. Crossley Brothers.

Gentlemen,—In reply to your inquiries respecting the working of our Gas Engine, the new 3½-HP. "OTTO" Silent, we beg to state that it is doing its work well, and has given us the greatest satisfaction in every respect. As you are aware, we have a Double Demy News and Jobbing Machine, a Crown and Folio Machine, together with a Folder, all of which your 3½-HP. Engine drives at the same time; and should we require more machinery, there will be power enough to drive it. As regards the noise whilst running, we may state that it is practically silent. The shop belonging to our stationery department adjoins the machine room, and the working of the Engine is not heard there. We speak after a six months' trial, which we consider a fair time to test the qualities and capabilities of the Engine. Several gentlemen have called upon us to inspect it, all of whom have expressed themselves as entirely satisfied that it is what you represent it to be.

On behalf of the Blackpool Printing Co. Limited,
R. A. TUNNICLIFFE, *Manager.*

3½-HP. *Bradford, May* 4, 1880.

Dear Sirs,—The 3½-HP. Gas Engine supplied by you has worked remarkably well so far, and drives two Lithographic Presses, Rolling Machine, three Guillotines, and two Ruling Machines with perfect ease. In fact, it seems capable of doing at least as much more work effectually. The cost of working is very small.

I am, yours very truly,
B. F. HARDWICK.

2-HP. *The Sussex Steam Lithographic Printing Works,* 15, *Ship Street, Brighton, May 3rd,* 1883.

Dear Sirs,—In reply to yours, have had the 2-HP. in work for two years, and up to the present time it has not cost a penny for repairs. Does its work wonderfully well. It works a Demy Litho. Machine, 36-in. Self-clamp Guillotine Machine, and a 20-in. Label Punching Machine: also, a Brass Polishing Machine, all at one time. Shall be most happy to show anyone the same at work.

Yours truly,
J. HOLMES.

2-HP. *Printing Office,* 74, *Abbey Crescent, Dublin, October 4th,* 1879.

Gentlemen,—We heard such uniformly favourable reports of the advantages of your Gas Engine as compared to steam, that, nearly a year ago, we took down a comparatively new 3½-HP. steam engine and boiler, and had you to put up a 2-HP. Gas Engine. We are more than satisfied with the change. Our place is now safe from any possibility of an explosion; the saving is very great in working; our Machines do better and more work per hour than formerly, from the steady and uniform speed of the Gas Engine as compared to steam; and we can run them fully an hour longer in the day, as there is no loss of time in getting up steam in the morning and after meals. With the exception of a thorough clean out once a week, and oiling each morning, we find the Gas Engine requires no attention. Our Fire Assurance premium has been reduced; and if we have had to put in a small stove for winter, our machine room is now—what it never was before in summer—cool and comfortable. We can keep our place much cleaner than formerly, and our neighbours have ceased complaining of smoke nuisance. The Engine drives two Double Medium Wharfedales, and, we find, runs at the same speed whether they are standing, or one or both are on. Unless your Engines have some defect or weakness, which we have not as yet discovered, they must entirely supersede steam for work such as ours; and the first cost, great as it is, even if one's steam engine be only sold for old iron, is nothing compared to the advantage of the change.

Yours respectfully,
R. D. WEBB & SON.

1-HP. *37, 39, and 41, Henry Street, St. John's Wood, London, N.W., December 13th, 1880.*

Gentlemen,—We have much pleasure in stating that having now given the 1-HP. Engine you fixed for us a fair trial—18 months—we can say it has exceeded our highest expectation, and the cost per week averaged for the past 12 months is only 2/6 per week, whilst its working is most satisfactory.

We are, yours truly,

HUTCHINS & CROWSLEY.

Messrs. Crossley Brothers.

This firm have now 3 Engines, viz., 6-HP., 3½-HP., and 1-HP.

1-HP. *133, Cleethorpe Road, Grimsby, March 25th, 1878.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to your enquiry, I have much pleasure in informing you that the 1-HP. "OTTO" Silent Gas Engine I had of you gives satisfaction in every respect. I have never experienced any trouble with it; the chief requirement appears to be to keep it well cleaned and oiled. It drives a Double Demy Cylinder Machine, upon which we do all kinds of work, from a pamphlet to a broadside poster. I have a separate meter for the Engine, and I find it costs me rather under 1d. per hour, with gas at 3/9 per 1,000 feet.

I am, gentlemen, yours truly,

CHAS. H. DAWSON.

1-HP. *St. Vincent's Boy's Home Steam Printing Works, Woodfield Terrace, Harrow Road, London, W., May 8th, 1884.*

Messrs. Crossley Brothers Limited.

Gentlemen,—The 1-HP. Gas Engine which we purchased of you for our printing works some three years ago has far exceeded our expectations of it; in fact, it is a regular gem. It has never given us the slightest trouble, running by itself from morning till night, driving, too, very heavy machinery; the consumption of gas being, at the same time, a mere item. During this time it has never had a breakage or a stoppage of any sort. I can safely advise any printer wanting an engine of any sort to save him time, trouble, danger or expense, to avail himself of one of Crossley Brothers' Gas Engines.

I remain, gentlemen, yours obediently,

J. S. CARTY, *Manager.*

P.S.—Any one is welcome to visit our works and see the Engine at work any time from 8.30 a.m. to 6.30 p.m. Hundreds watch it at work daily from outside the windows of our works.

IMPARTIAL REPORTER NEWSPAPER AND FERMANAGH, CAVAN, AND LEITRIM FARMERS' JOURNAL.

½-HP. *Offices:—7, East Bridge Street, Enniskillen, August 13th, 1883.*

Messrs. Crossley Brothers Limited.

Gentlemen,—I made a slight mistake in reference to the low pressure the "OTTO" we have works with. I stated 6-10ths, and the fact is it works with 5-10ths, driving a Crown and a News Machine at a quick speed—800 or 900 an hour. So that our "OTTO" working up to 2-HP. (which it does) works with as light a pressure as the boy-power Hutchinson, which can only drive a Post Folio Treadle Machine.

On Wednesday night the Engine drove the News Machine (with our newspaper working) at such a rate that I went over to the gas works to get the pressure reduced. The pressure I found to be 7-10ths. The men on duty informed me that if they made it less the Bisschop in the other office (a 4-man power) would not work, and as it was they had already sent down complaining about the low pressure, and that they were hardly able to work with it.

I think the inference to be drawn from this important fact is valuable to any provincial printer about to buy an engine. Small towns have but light pressure on in day-time, in fact, always; and often having bad mains the company objects to put on a good pressure. This town, for instance, will not put on a good pressure in day-time so as to work the Engine in another office. Yet their 5-10ths pressure satisfies us.

The Engine should always be put up by a competent man, as ours never worked well till your own man came and altered the position of the tank pipes. This latter, and the use of the proper oil (Price's), has made ours give great satisfaction.

I state this as some country printer might like to hear word from a confrere before he purchased.

I am, gentlemen, yours very faithfully,

SAM DELMEGE TRIMBLE.

½-HP. *Mere Street Diss, April 13th, 1883.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The ½-HP. "OTTO," 5,207, you supplied last September is used for driving two Printing Machines—viz., a Double Crown and a Demy Folio. It does its work admirably, and far surpasses our expectations, both in point of economy and utility. Yours truly,

LUSHER BROTHERS.

½-HP. *June 25th, 1883.*

The ½-HP. "OTTO," No. 4,459, I received the second week in January, 1882. It gives perfect satisfaction. Runs Double-demy Wharfedale and Foolscap-folio Sun. Very little trouble to manage it, though I never had anything to do with an engine of any sort before.

Yours respectfully, JOHN FLETCHER.

CROSSLEY BROTHERS LIMITED,

Engineers,

OPENSHAW, MANCHESTER.

2,000. 11/87. CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

List of a few Users of

CROSSLEY'S "OTTO" GAS ENGINES

FOR

MEAT CHOPPING (ONLY.)

TOWN.	HP.	NAME OF USER.
Aberaman	½	John Howell, 33, High Street.
Alfreton	1½	W. Peel.
Bangor	3½	Hughes & Son.
Barnsley	1	Henry Owram, New Street.
Barrow-in-Furness	2	William Happold, 62, Duke Street.
Basingstoke..	1	W. Robinson.
Batley	5-MP.	C. Wagner, Commercial Street.
Bedford	½	— Sell, Pork Butcher.
"	½	J. Benson.
Belfast	1	James Ferguson, Ann Street.
"	1	Andrew Munce.
Belper	½	J. Ash.
Birmingham..	5-MP.	J. Martin, Acock's Green.
Blackburn ..	5-MP.	James Witton, Pork Butcher, 5, Lark Hill.
Blackpool..	½ vert.	Henry Edwards, 7, Church Street.
Blaydon-on-Tyne	1	Blaydon Co-operative Society.
Boston (Lincoln)	½	— Haag, 11, High Street.
Bradford	3½	Co-operative Society. (And other machinery.)
"	2	Philip Smith, 21, Iregate.
"	2	J. Pearson, Junr., 14, White Abbey Road.
"	1	W. Brenninger, Pork Butcher, 150, Lister Hills Road.
"	1	William Korner, 80, Barker End Road.
"	1	William Smith, 110, Westgate.
"	1	Maria Scheu, 152, Leeds Road.
"	1	William Moulson, Pork Butcher, Lumb Lane.
"	½	F. Pfeiffer, Wakefield Road.
"	½	Co-operative Society.
"	5-MP.	S. A. Moulson, Lumb Lane.
Brighton	2	— Spencer, 136, Queen's Road.
"	½	— Jeater, 3, George Street.
"	½	— Hamilton, 49, Livingstone Road.
Cambridge ..	2	— Dring.
Cardiff	1	— Richards, Bridge Street.
"	½	E. J. Poole, 64, Bridge Street.
"	5-MP.	R. J. T. Hillier, Spital Buildings.
Chertsey (Surrey)	½	James Hill, St. Ann's Road.
Chesterfield.	9	S. Redfern. (This Engine also drives a Lightfoot Dry-air Refrigerator; for particulars of which apply to Crossley Brothers Limited)
Chichester ..	3½	C. Shippman, East Street.
Cleckheaton.	2	Co-operative Society, Market Place. (And other machinery.)
Coleraine....	½	Charles Schneider.
Colchester ..	5-MP.	F. J. Gosling, 9, Long Wyre Street.
Creiff	½	John Comrie, King Street.
Croydon	2	W. H. Polhill, 124, Church Street.
"	1	Stowell Brothers, 112, High Street.
"	½	Stowell Brothers, 112, High Street.
Derby	2	R. Morley, Queen Street.
"	1½	James Cope, 36, Irongate.
"	1	Thomas Ravensdale, Osmaston Road.
"	1	J. H. Hurd, Victoria Street.
"	1	George Hill, New Normanton.
"	1	George Bounds, 95, Shaftesbury Street.
Derby	5-MP.	Smith & Turton, Cheapside.
Doncaster ..	½	Co-operative Society.
Dover	1	H. Zoller, 6, Bench Street.
Dumbarton ..	½	Co-operative Society. (Butchering department.)
Dundee	½	James Waddell.
Dunfermline.	½	Thomas Addison.
Earlsheaton.	½	Joseph Scott.
Eastbourne ..	½	J. Betteridge, 42, Pevensey Road.
Edinburgh ..	½	Johnstone & Waters, 3, Queensferry Street.
" ..	5-MP.	Brechin Brothers, 1, West Newington Terrace.
Glasgow	1½	J. Tulloch, 279, Argyle Street.
"	½	J. Finlay Bell, 259, Argyle Street.
"	½	H. Forsyth, 311, New Dalmarnock Road.
"	½	William Brown, 164, Gallowgate.
"	½	W. W. Watt, 205, Parliamentary Road.
"	½	J. & J. Wallace, 56A, Maitland Street. (Chops 42 lb. in eleven minutes.)
"	½	James Wylie, Butcher, 321, Paisley Road.
"	½	John Knott, 86, Govan Street.
"	½	Thomas Hawie, 126, Castle Street.
"	½	H. Forsyth, 311, Dalmarnock Road.
"	½	William Brown, 7, Elderslie Street.
"	½	J. & J. Wallace, 202, Main Street, Anderston.
"	½	W. McKean, 280, St. George's Road.
"	½	Alexander Young, 581, Duke Street.
"	½	W. Danks, Rokeby Terrace, Hillhead.
"	½	William Brown, Parliamentary Road.
" ..	½ vert.	H. McPherson, 143, New City Road.
"	5-MP.	Thomas Hawie, 4, King Street.
"	5-MP.	James Young, 368, Duke Street.
"	5-MP.	Mrs. McCallum, 375, Dumbarton Road, Partick.
"	5-MP.	A. Nimms, 50, Wilson Street, Partick.
"	5-MP.	A. Young, North Albion Street.
"	5-MP.	James Ferguson, 33, St. George's Road.
"	5-MP.	Robert Borland, 324, Cathcart Road.
"	5-MP.	James A. Kirkwood, Byars Road.
"	5-MP.	Hugh Irving, 230, High Street.
Goole	1	F. Horlaker, Pork Butcher, 18, Ouse Street.
Grantham....	5-MP.	H. Robinson, Pork Butcher.
"	5-MP.	C. Carley.
Great Horton (*nr. Bradford*)	½	N. Bousfield, High Street.
Grimsby	2	C. Schulke, 104, Victoria Street.
"	½	— Morrison.
"	5-MP.	— Fenwick.
"	5-MP.	— Broadbent.
Guernsey	½	— Everatt, 18, Fountain Street.
Hartlepool..	½	James Gardner, Northgate Street.
Heckmondwike	½	James Ingham.
Huddersfield	1	F. Miskelbarker, Pork Butcher, 54, Buxton Road.
Hull	1	G. Wittman, 7, Waterwork Street.
"	½	— Most.
"	½	— Banerle, 39, Charles Street.
"	5-MP.	C. H. Schumm, 7, Myton Place.
Ilkley........	5-MP.	George Fox, 3, Leeds Road.
Ipswich	1	*Per* J. Popplewell & Son.
Keighley	½	— Andracy, High Street.
Kendal	1	Joseph Robinson, Pork Butcher, Highgate.
Kettering ..	½	R. Hall, Newland Street.
" ..	½	Co-operative Society.
Lancaster ..	5-MP.	Thomas Mullins, 29, Perny Street.
Llandudno ..	3½	John Jones, Central Buildings.
Leeds	9	R. Wood, Pork Butcher.
"	8	Illingworth & Wilson, West Street. (And other Grocers' Machinery.)
"	2	Richard Wood, 139, Woodhouse Lane.
"	2	Edward Curtis, 43, Burnley Road.

List of a few Users of Crossley's "OTTO" Gas Engine for Meat Chopping (only).

TOWN.	HP.	NAME OF USER.
LEEDS	1	Elliott Moss, Pork Butcher, Wellington Road.
,, ...	5-MP.	J. Earnshaw, Glasshouse Street, Hunslet.
LEICESTER	3½	William Dunmore, Humberstone House.
,, ...	3½	George Allen & Co., 16, Cobden Street.
,, ...	3½	William Taylor, Spinney Hill Road.
,, ...	1	— Folwell, Market Place.
,, ...	½	Edwin Edge, East Bond Street.
,, ...	½	W. Stead, 111, Briggate.
,, ..	¾ VERT.	E. Moss, 164, Briggate.
,, ...	5-MP.	W. H. Munro, Hunslet Road.
LIVERPOOL	1	J. M. Huppold, 20, Paddington.
LONDON	6	W. Bowron, 279, Edgware Road, W. (And Electric Light.)
,, ...	3½	J. W. Martell, 84, High Street, Marylebone, W.
,, ...	3½	J. S. Silk, Clapton.
,, ...	2	Thomas Robinson, 119, Bishopgate St. Within, S.E.
,, ...	2	R. Brazil, 60, Caledonian Road, N.
,, ...	2	E. Hollis, 283, Oxford Street, W.C.
,, ...	2	E. Hollis, 283, Oxford Street, W.C.
,, ...	2	W. Hillier, 267, Caledonian Road, N.
,, ...	2	W. Hillier, 300, Gray's Inn Road, W.C.
,, ...	2	A. Ginger, 25, Market Place, Oxford Market, W.
,, ...	2	T. P. Baines, 165, Blackfriars Road. S.E.
,, ...	2	George Jenkins, 35, Upper Marylebone Street, W.
,, ...	2	G. Robinson, 66, Essex Road, Islington, N.
,, ...	2	J. F. Clarke, 49, Moorgate Street, E.C.
,, ..	1½ VERT.	Dunstan & Elliot, 237, Old Kent Road, S.E.
,, ..	1½ VERT.	J. Machell, Bedfordshire Farmers' Meat Supply Association, 137, South Lambeth Road, S.E.
,, ...	1	J. Thompson, 21, Boston Street, Dorset Square, N.W.
,, ...	1	A. F. Wilcocks, 77, Tottenham Court Road, W.
,, ...	1	James Wolsey, 122A, High Street, Peckham, S.E.
,, ...	1	John Guyer, 14, Churton Street.
,, ...	1	F. L. Rohrbach, 50, Old Compton Street, Soho, W.
,, ...	1	Reuben Tarrant, 3, Queen's Terrace, St. John's Wood, N.W.
,, ...	1	William Eustace, 78, Middleton Road, Dalston, E.
,, ...	1	Thomas Todd, 64, High Street, Kensington, W.
,, ...	1	Joseph Fox, 6, London House Yard, St. Paul's.
,, ...	1	Charles Bates, 13, Ladbrook Grove Road, Notting Hill, W.
,, ...	1	James Taylor, 2, Station Terrace, Balham, S.W.
,, ...	1	J. Loomes, Upper Street, Islington, N.
,, ...	1	P. H. Clisby, Pork Butcher, 167, Marlborough Road, Chelsea, S.W.
,, ...	1	Sadler & Co., 203, Oak Lane, Horsey Down, S.E.
,, ...	1	E. Hollis, 301, Edgware Road, W.
,, ...	1	C. Hutchinson, Brixton Road, S.W.
,, ...	1	E. Searle, Elizabeth Ter., Primrose Hill Rd., N.W.
,, ...	1	B. Atkin, High Street, Highgate.
,, ...	1	Thomas Williams, 8, West Smithfield, E.C.
,, ...	½	H. J. Gilbert, 86, High Street, Peckham, S.E.
,, ...	½	D. Loomes, 316, Holloway Road, N.
,, ...	½	J. Elmslie, 241, Battersea Park Road.
,, ...	½	G. Meacock, Broadway, Turnham Green, W.
,, ...	½	Frank George, 55, Lambeth Walk, S.E.
,, ...	½	S. Loomes, 211, High Road, Kilburn, N.W.
,, ...	½	T. Williams, 8, West Smithfield, E.C.
,, ...	5-MP.	W. F. Masters, 32, Rosman Street, Clerkenwell, E.C
,, ...	5-MP.	T. Williams, 8, West Smithfield, E.C.
,, ...	5-MP.	G. C. Rathmann, 211, Salmon's Lane, E.
,, ...	5-MP.	W. & T. Ovens, 54, St. John Street, E.C.
,, ...	5-MP.	W. & T. Ovens, 54, St. John Street, E.C.
,, ...	5-MP.	W. & T. Ovens, 54, St. John Street, E.C.
,, ...	5-MP.	Swan & Co. Limited, 63 and 65, Chrisp Street, Poplar, E.
,, ...	5-MP.	C. Dunger, 79, Three Colts Street, E.
LOWESTOFT ..	3½	Maconochie Brothers.
MANCHESTER ..	1	E. May, 138, Oxford Street.
,, ...	1	John Bell & Sons, 86, Oxford Street.
,, ..	½	Anglo-Australasian Frozen Meat Co., 1, Tonman Street.
,, ..	½	J. P. Hartley, 17, Northenden Road, Sale.
,, ..	½	Auguest Zeltner, 10, Long Millgate.
,, ..	½	W. Reed, Viaduct Street, Ashton Old Road.
MARKET HARBOROUGH	½	John Garner, Adam and Eve Street.
MERTHYR TYDVIL......	5-MP.	Mrs. Morris, 12, High Street.
MORLEY	½	— Beck.
MIDDLESBRO' ..	1	William Newbold, 77, Linthorpe Road.
MOTHERWELL ..	5-MP.	Co-operative Society. (Butchery department.)
NELSON	5-MP.	F. Retz, 59, Scotland Road.
NEWCASTLE-ON-TYNE......	2	Charles Anderson, Pork Butcher, Newgate Street.
,, ..	½	American Meat Company, 56, Newgate Street.
,, ..	½ VERT.	Stephen Holmes, 23, Northumberland Street.
,, ..	½	D. Murray, Pork Butcher, Clayton Street.
NEWPORT (Monmouthshire) ..	1	J. Jeffreys & Son, 74, Commercial Street.
NORTH SHIELDS	½	W. Fowles, Prudhoe Street.
NORWICH	5-MP.	— Thoms, Exchange Street.
,, ..	½	George Kuch, 25, Saville Street West.
NOTTINGHAM ..	1	Mrs. M. Green, 128, Waterway Street.
,, ..	½	— Dalton, Clumber Street.
,, ..	5-MP.	Joseph Gee, 10, Alfred Street.
OTLEY	½	Thomas Brown, Westgate.
OXFORD	8	Co-operative Society. (This Engine is used for driving general Grocers' Machinery as well as Sausage Machines.)
PAISLEY	¾	Provident Co-operative Society.
,, ...	½	Mrs. A. Caldwell, Cotton Street.
,, ...	5-MP.	A. Barr, 11, Gauge Street.
PENARTH	5-MP.	Richard Guy, Glebe Street.
PONTYPRIDD ..	5-MP.	A. Davies, Penistone House.
PUDSEY (*via Leeds*)	1	F. Beerman, Pork Butcher, Lowton.
RAMSGATE	1	J. Richford & Co., 7, Queen Street.
,, ...	½	C. Wood, Butcher.
RETFORD (Notts)	1	A. Hollins, Pork Butcher, Carrolgate.
ROCHESTER ..	1	*Per* Collis & Stace, Strood.
ROTHERHITHE.	2	J. Taylor, 18, Albion Street.
RUTHERGLEN ..	5-MP.	T. Morton, 112, Main Street.
SALE..........	½	J. P. Hartley, 17, Northenden Road.
SCARBOROUGH ..	1	Dobson Morris, Pork Establishment, 5, North Street.
,, ..	½	W. Greenlay, 5, Bar Street.
SHEFFIELD	2	N. Lister & Sons, 91 and 93, South Street, Moor.
,, ...	1	F. Elliott, Pork Butcher, 9, George Street.
SOUTHAMPTON.	5-MP.	Rose & Rogers, Canal Walk.
SOUTHPORT ..	½	John Morrell, 8, Tulketh Street.
SOWERBY BRIDGE	1	Sowerby Bridge Industrial Society Limited, West End. (Butchery department.)
STAFFORD	½	— Cooper, Pork Butcher.
ST. HELENS ..	½	Peter Waywell, 19, Higher Parr Street.
STIRLING......	½	W. J. & J. Cullens, 10, Baker Street.
STOCKTON-ON-TEES........	½	Mr. Darbyshire, Pork Butcher, Yarm Lane.
,, ..	½	— Marston, Pork Butcher.
STRATFORD-ON-AVON	1	Thomas Pearce, 7, Wood Street.
SUNDERLAND ..	½	J. J. Green, 12, Hylton Road.
,, ..	½	R. B. Wilson, 74, High Street.
SWANSEA	½	Thomas Woodward, 229, High Street.
TODMORDEN ..	½	F. Davies, Pork Butcher, Patmoss.
,, ..	½	Priestley & Halstead, 6, Strand.
TUNBRIDGE WELLS......	1	Charles Tibbs, 2, Grosvenor Road.
WAKEFIELD ..	5-MP.	F. Schwab, 205, Kirkgate.
WALSALL......	1	Mr. Allan, Pork Butcher, Park Street.
WARRINGTON ..	1½	J. B. Isaac, Sankey Street.
,, ..	5-MP.	Christian Bower, 47, Church Street.
WEST HARTLEPOOL........	½	Mr. Lofthouse, Lynn Street.
,, ..	½	James Gardner, 44, Northgate Street.
WIGAN........	5-MP.	L. Mynekyme, 54, Standishgate.
WIMBLEDON ..	½	George Ely, 3, Wimbledon Hill Road.
WISHAW	½	John Brown, Butcher, High Street.
WINDSOR......	1	— White, Esq.
WORCESTER ..	5-MP.	— Morris, Tything.

References to Engines engaged in almost every other branch of Trade can be had on application.

CROSSLEY BROS. LIMITED, OPENSHAW, MANCHESTER.

MAY, 1888.

List of a Few Users

OF

CROSSLEY'S "OTTO" GAS ENGINE

FOR DRIVING

GROCERS' MACHINERY

(ONLY),

To whom Reference is permitted.

CROSSLEY BROTHERS LIMITED, Engineers, OPENSHAW, MANCHESTER.

	HP.	
ALEXANDRIA	8	Vale of Leven Co-operative Society (Dumbarton).
ALLOA	8	Co-operative Society.
ARBROATH	8	Arbroath Westport Association.
ASHTON-UNDER-LYNE	7	Marsden & Bradwell.
"	2	Charles Brooke & Co., 6, George Street.
"	½	G. Hyde, George Street.
BACUP	3½	E. Gledhill & Co., Tea Merchants.
"	2	William Bentham, Tea Merchant.
"	2	Bacup Co-operative Society.
BARNET	6	C. Stevens, High Street.
BARNSLEY	8	British Co-operative Wholesale Society.
BARROW-IN-FURNESS	3½	W. Postlethwaite, Duke St. (Also for Electric Lighting.)
"	1	McIntyre & Osborne, Ramsden Square.
BATH	2	— Stoffel.
BATLEY	3½	Co-operative Company Limited.
BELFAST	12	John Lytle & Sons.
"	2	Lepper & Co.
BINGLEY	3½	Co-operative Society.
BIRMINGHAM	1	H. Royce, 5, Upper Priory.
"	½	R. Lodge, Broad Street.
BISHOP AUCKLAND	12	Co-operative Society.
BLACKLEY, *near Manchester*	4	Co-operative Society.
BLAYDON-ON-TYNE	1	Blaydon Co-operative Society.
BRADFORD	4	Bradford Industrial Co-operative Society.
"	3½	Bradford Industrial Co-operative Society.
"	3½	Brumfit, Firth & Co.
"	3½	J. T. Greenwood & Sons.
"	3½	D. E. & R. Tuke.
"	2	Sellars & Wood, White Abbey.
"	2	J. Smith & Son.
"	1	Bradford Industrial Co-operative Society.
"	5-MP.	Jabez Smith.
BRECHIN	3½	United Co-operative Society.
"	3½	Equitable Co-operative Society.
BRIGHTON	6	Reeves & Son, Queen Street.

	HP.	
BRIGHTON	6	Wallis & Hack, Market Place.
BRISTOL	16	H. H. & S. Budgett & Co., Nelson Street.
"	12	H. H. & S. Budgett & Co., Nelson Street.
"	6	H. Jones, Broadmead. (Also Baking Machinery.)
"	6	T. G. Northam & Co., Bath Street.
"	3½	Clutterbuck & Griffin, Lewins Mead.
"	3½	Corner & Co., Old Post Office, Tea Warehouse.
"	3½	Symes & Co., Provision Merchants, Victoria St.
"	2	H. H. & S. Budgett & Co., Nelson Street.
"	2	T. G. Northam, Clare Street.
"	2	Clarke & Son, Provision Merchants, Victoria St.
"	2 (Vert.)	T. Bidgett, Redcliffe Hill.
"	2	— Brown, Victoria Street.
BURNLEY	2	Hargreaves & Son, 9, St. James's Row.
CANTERBURY	6	Finns Co-operative Stores, St. Margaret's St.
CARDIFF	5-MP.	Buchanon & Co., St. Mary Street Buildings. (Coffee Grinding.)
CHELTENHAM	4	F. D. George.
CHERTSEY *(Surrey)*	½	James Hill, St. Ann's Road.
CHESTER-LE-STREET	1	Co-operative Society.
CLECKHEATON	2	Co-operative Society.
COATBRIDGE	½	A. Paterson, Grocer.
COCKERMOUTH	½	C. Mayson.
COLCHESTER	3½	Evatt, Sanders & Son, 31 and 32, High Street.
COLNE	1	W. F. Richmond.
CORK	6	Newson & Son, Patrick Street.
"	2	Newson & Son, Patrick Street.
"	2	Oglive & Moore, Warren's Place.
COVENTRY	3½	Co-operative Society.
CRAWSHAWBOOTH, *nr. Rawtenstall.*	3½	District Industrial Society.
CREWE	8	Co-operative Society.
DALTON-IN-FURNESS	2	Co-operative Society.
DARLINGTON	1	D. Fox, 1, High Row.
DERBY	6	Co-operative Provident Society.
DONCASTER	6	Hodgson and Hepworth, Grocers.
"	2	Co-operative Society.
"	1½	Co-operative Society.

	HP.	
DONCASTER	½	Co-operative Society.
DUBLIN	3½	Wood, Webb & Phœnix, Temple Lane.
,,	2	Baker, Wardell & Co., Thomas Street. (Tea Mixing.)
DUMBARTON	6	Co-operative Society.
,,	1	Co-operative Society.
DUNDEE	8	Eastern Co-operative Society.
,,	4 (TWIN)	Low & Co., Blackness Road. (Also for Hoisting.)
,,	3½	Amier & Co.
,,	½	James Ogilvie, 80, High Street.
DUNFERMLINE	8	Co-operative Society.
EARLSHEATON	3½	Co-operative Society.
EDINBURGH	8	The Professional and Civil Service Supply Association, 4, St. Andrew Square.
,,	3½	The Professional and Civil Service Supply Association, 4, St. Andrew Square.
,,	3½	The Professional and Civil Service Supply Association, 4, St. Andrew Square.
,,	1	R. McLeod, 7, Royal Exchange.
ELLAND	9	R. Beaumont, Grocer.
FERNDALE	½	Co-operative Society.
GALASHIELS	3½	Eastern Co-operative Society.
GATESHEAD	2	Robinson & Co., Provision Merchants, Bottle Bank.
,,	½	Co-operative Society, Asken Road.
GLASGOW	12	Scottish Co-operative Wholesale Society Limited, Clarence Street.
,,	8	Scottish Industrial Wholesale Society, 119, Paisley Road.
,,	6	Cooper & Co., Tea Merchants, 359, Sauchiehall Street. (Also for Electric Light.)
,,	6	Scottish Industrial Wholesale Society, 119, Paisley Road.
,,	½ (Vert.)	Charteris & Co., Jamaica Street.
,,	½ (Vert.)	Pringle & Crichton, York Street.
GLOUCESTER	8	Co-operative Society Limited.
,,	8	Industrial Society Limited.
GODALMING	2	C. Burgess, Grocer, High Street.
GOSPORT (*Hants*)	2	Parham & Son, Grocers, Forton. (Also Chaff Cutting.)
GREAT HORTON	½	W. E. Ryder, Wholesale Grocer.
GREENOCK	¾ (Vert.)	McSimon & Co., Argyle Street.
HALIFAX	½	E. Bray & Son, Northgate.
HASTINGS	3½	S. Chester, West Marina.
HAVERFORDWEST	3½	J. Rees, Grocer.
HEBDEN BRIDGE	8	Co-operative Society.
,,	½	Co-operative Society, Heptonstall.
HERNE BAY	1	Barnwell & Son, 53, William Street.
HEXHAM	8	Gray & Son, Provision Merchants.
HUDDERSFIELD	½	Eli Wadsworth & Sons, Spring Street.
,,	½	Jackson & Fitton, Market Place.
HULL	12	White, Sun & Stratton.
,,	3½	Cussons Brothers, Beverley Road.
,,	3½	Cussons Brothers, Beverley Road.
,,	3½	Bristowe & Co., Tea Dealers. (Also for Electric Lights.)
,,	1	Tasker & Richardson.
IPSWICH	8	Burton & Sons. (Sugar Grinding, &c.)
KEIGHLEY	3½	Co-operative Company.
KETTERING	½	Co-operative Society.
LEEDS	8	Illingworth & Wilson, West Street.
,,	3½	Industrial Co-operative Society, Marshall St.
LEEDS	3½	Dixon Bros., Grocers' Warehousemen, Crown St.
,,	3½	R. Brownhill & Sons, Grocers' Warehousemen, Saville Street.
,,	3½	J. & P. Firth, Grocers, New Wortley.
,,	2	Mutual Supply Society, Albion Street.
,,	2	Staples & Co., Briggate.
,,	1	Industrial Co-operative Society, Albion Street.
LEICESTER	12	The Co-operative Society.
,,	3½	Simpkin & James, Market Place.
LEITH	14	Scottish Wholesale Co-operative Society, Links Place.
,,	14	Scottish Wholesale Co-operative Society, Links Place.
,,	6	Scottish Wholesale Co-operative Society, Links Place.
LESLIE	3½	The Dysart Co-operative Stores.
LINCOLN	3½	A. W. Hall. (Currant Washing, &c.)
,,	1½	H. K. White.
LIVERPOOL	8	Richard, Sharpe & Co., 11, Sir Thomas Buildings. (Coffee Roasting.)
,,	6	J. W. Wood & Co., Peter Lane. (Coffee Roasting.)
,,	3½	J. Musker & Co., Stanley Street.
,,	3½	Geddes & Son, 31, Matthew Street.
,,	2	German Confectionery Co., 35, West Derby St.
,,	1	Scott & Keen, Lime Street.
,,	1	Joseph Lloyd, Falkner Street, Islington.
,,	½	— Renault, London Road.
,,	5-HP.	German Confectionery Co., 35, West Derby St.
LONDON	20	Anderson, Webber & Anderson, Metropolitan Wharf, Wapping. (Coffee Husking.)
,,	16	Junior Army and Navy Stores Limited, York House, Regent Street, W.
,,	16	Co-operative Wholesale Society, Hooper Square, Leman Street, E.
,,	16	Co-operative Wholesale Society, Hooper Square, Leman Street, E.
,,	12	Pearson & Co., Lavender Wharf, Rotherhithe, S.S.
,,	12	W. A. Higgs & Co., 30 & 39, High St., Islington.
,,	9	W. Teetgen, 52, Old Kent Road, S.E.
,,	9	Game, Harrison & Lanner, 2, Eastcheap, E.C.
,,	8	Phillips & Co., Upper Thames Street, E.C.
,,	8	Laine, Longman & Co., 32, Southwark St., S.E.
,,	8	Wholesale Co-operative Society, Rupert St., E.C.
,,	8	Army and Navy Co-operative Society, Lupus Street, Pimlico, S.W.
,,	6	Compressed Tea Company, 129, Whitechapel, E.
,,	6	Junior Army & Navy Stores, 15, Regent St., W.
,,	6	Brooke, Bond & Co., 128, Whitechapel, E.
,,	4	United Kingdom Tea Co., Leman St., E.
,,	4	*Per* A. Lee. (Coffee Grinding.)
,,	4	F. Wale & Co., 34, Little Pulteney Street, W.
,,	3½	J. W. Moore & Co., 35, King William St., E.C.
,,	3½	Foster & Sons, Philpot Lane, E.C.
,,	3½	Shoolbred & Co., Tottenham Court Road, W.C.
,,	3½	Civil Service Stores, Hart St., Covent Garden, W.C.
,,	3½	Phillips & Co., 8, King William Street, E.C.
,,	3½	City of London Co-operative Association, Newgate Street, E.C.
,,	3½	Ridgway & Co., 4 & 5, King William St., E.C.
,,	3½	R. Hall & Co., 66, Christian Street, E. (Coffee Roasting.)
,,	3½	Dockerill, Duchesne & Bennet, 16, Bury St., E.C.
,,	3½	Capon, Brine & Co., 17, Camomile Street, E.

Place	HP.	User
London	3½	Ashton & Parsons, 30, Bishopsgate Street, E.C.
"	3½	United Kingdom Tea Company, Imperial Buildings, Leman Street, E.
"	2	Lewis & Co., King Street, Aldersgate Street, E.C. (Tea Machinery.)
"	2 (Vert.)	W. Teetgen, 29, Bishopsgate Street, E.C.
"	2	J. Buckley, Grocer, &c., Newland Terrace, Kensington, W. (Tea Machinery.)
"	2	W. T. Chapman, 62, Aldersgate Street, E.C. (Tea Machinery.)
"	1	W. T. Chapman, 62, Aldersgate Street, E.C. (Coffee Mills.)
"	1	Page & Co., 74, High Holborn, W.C.
"	1	Phillips & Co., King William Street, E.C.
"	1	W. Parnell, High Street, Camden Town, N.W.
"	½	Pearce, Duff & Co., 118, Western Bermondsey, S.E. (Egg Powder.)
Manchester	8	John Chadwick, Hanging Ditch.
"	6	T. Seymour Mead, Stretford Road.
"	6	Burgon & Co., Ackers Street, Upper Brook St.
"	3½	D. Melia & Co., Cranworth Street, Ardwick.
"	3½	A. F. Brook, 47, Dantzic Street.
"	3½	The Co-operative Society, Broughton Park, Pendleton.
"	3½	— Crampton, Upper Jackson Street, Hulme.
"	2	Excell Brooks & Co., Shudehill.
"	2	Bratt & Hobson, 15, Swan Street.
"	2	Fox & Kay.
"	2	Household Stores.
"	2	Atcherley & Lund.
"	½	Black & Green.
Masborough	2	Equitable Co-operative Society, Station Road.
Middlesborough	1	Amos Hinton, 10, 12, and 14, South Street.
"	½	J. Newbold, 173, Newport Road.
Middleton-in-Teesdale	6	Co-operative Society.
Morley	6	Co-operative Society.
Mossley	3½	Industrial Co-operative Society Limited.
Newcastle-on-Tyne	16	Co-operative Retail Society, Newgate Street.
"	12	Co-operative Wholesale Society, Waterloo Street.
"	8	Co-operative Wholesale Society, Waterloo Street.
"	7	Thomas Galloway, Dispensary Lane.
"	6	Co-operative Retail Society, Newgate Street.
"	4	Thomas Pumphrey, Cloth Market.
"	4	Johnson & Dodd, Pilgrim Street.
"	4	Carrick Watson, Blackett Street.
"	3½	The Co-operative Society, Waterloo Street.
"	3½	Robert Johnson & Co., Market Lane, Pilgrim St.
"	3½	London and Newcastle Tea Co., Charlotte Square.
"	3½	Hudson, Son & Pritchard, Provision Merchants, High Bridge Street.
"	2	Fraser & Brough, High Friar Street.
"	2	The Co-operative Society, Gloucester Street.
Newcastle (*Staff.*)	2	Henry Watson, Grocer, &c.
Newton-le-Willows	6	Co-operative Society, Earlestown.
Norwich	8	J. & J. Colman.
"	½	R. Fisher, St. George's.
Nottingham	1	Spencer & Co., Grocers.
Oldham	¾ (Vert.)	Co-operative Society, Coppice Branch.
"	½	James Cooper & Co., Grocers.
Oldham	½	Co-operative Society, Central Branch.
"	½	Co-operative Society, Ratcliffe Street Branch.
"	½	S. Mellor.
Ormskirk	3½	G. Garside & Son. (Fodder Cutting.)
Oxford	8	Co-operative Society.
Paignton	¾ (Vert.)	E. Deller & Co., Supply Stores.
Perth	12	Co-operative Society.
Peterborough	6	Co-operative Society.
Plymouth	9	Brown, Wells & Nicholson, Abbey Stores.
"	8	Mutual Co-operative and Industrial Society.
"	4	Co-operative Society.
"	1	Wills, Son & Box, 18, George Street, Borough Tea Warehouse.
"	¾ (Vert.)	H. Matthews, Confectioner, &c.
Portsmouth	3½	Reeves & Co., Wholesale Provision Merchants.
"	3½	Portsea Island Co-operative Society.
Preston	3½	E. N. Booth & Co.
"	3½	Co-operative Society.
Queenstown	½	F. Nolan, 17, Beech. (Also Bottle Washing.)
Radcliffe	8	Radcliffe and Pilkington Co-operative Society.
Ramsgate	2	Crux & Page, Harbour Street. (Also Fodder Cutting.)
Ravensthorpe	6	Self-help Co-operative Society.
Rawtenstall	1	Conservative Industrial Co-operative Society.
Reading	6	Salmon & Son.
Rochdale	8	J. Duckworth.
Rugby	8	The Co-operative Society.
Runcorn	3½	Co-operative Society, 8, Church Street.
Saltaire	½	G. W. Phillipson, Catherine Street.
Scarborough	2	— Wallis, Grocer.
"	½	W. Birdsall & Sons, 78, Newborough.
Seaton Delavel	3½	Co-operative Society.
Sheffield	8	E. Nichols & Co., 231, Gibraltar Street.
"	1	Porter & Son, King Street. (Coffee Roasting.)
"	½	Smith & Carter. (Coffee Grinding.)
Slaithwaite	12	Co-operative Society.
Sowerby Bridge	1	Industrial Society Limited.
Stalybridge	6	Co-operative Society.
Stirling	8	D. & J. McEwen & Co.
Stockport	3½	J. Dutton, Gallery Street.
"	1	W. Smith, Grocer.
Stockton-on-Tees	6	F. W. Pumphrey, Sugar Mills, South Stockton.
"	2	Bennington & Son, Silver Street.
"	1	Reid & Son, 5 and 6, West Row.
"	½	Alexander Holmes & Co, Supply Stores.
Sunderland	½	W. Grimshaw & Sons, High Street.
Taunton	5-MP.	Charles Lewis, 15, Five Street.
Todmorden	8	Wholesale Co-operative Society, 8, Dale Street.
Ulverston	7	James Dickenson, 15, Queen Street.
"	2	Co-operative Society, Market Street.
"	¾	James Dickenson, 15, Queen Street.
"	5-MP.	Parker Brothers, Grocers, Market Street.
Wakefield	6	Industrial Co-operative Society, Westgate.
Wallsend	3½	Co-operative Society.
Warrington	3½	The Co-operative Society, Sankey Street.
Wigan	8	W. D. Brown, Tea Merchant.
"	5-MP.	W. D. Brown, Tea Merchant.
Wirksworth	½	Charles Wright & Son. (Coffee Roasting, Fodder Cutting, &c.)
Worcester	3½	Lea & Perrins, Broad Street.
West Pelton	3½	Co-operative Society.

Town	HP.	User
BIRMINGHAM	8	Pickford & Co. Fodder Chopping.
"	6	R. Smith, Lower Loveday Street. Chaff Cutting, Oat Crushing, &c.
"	6	Coldicott Bros., Heath Mill Lane. Chaff Cutting.
"	3½	T. Fawdrey, Great Hampton Street. Chaff Cutting, Oat Crushing, &c.
"	3½	W. C. B. Cave, Moseley Street. Chaff Cutting and Hoisting.
"	3½	Birmingham Tramway Company, Butlin Street Depôt. Fodder Machinery.
"	2	Corporation Water Department, Broad Street. Chaff Cutting, Oat Crushing, &c.
"	2	W. King, Maltster, Ashton New Town. Chaff Cutting and Hoisting.
BISHOP AUCKLAND	12	Co-operative Society, 84, Newgate Street. Hoisting, Corn Grinding, and other Machinery.
BOSTON	8	Franks & Son.
BOURNEMOUTH	2	Hayter & Son, Wolverton Terrace, Lansdowne. Corn Grinding and Chaff Cutting.
"	½	Bournemouth Commissioners. Chaff Cutting.
BOX	2	Pictor & Sons. Chaff Cutting, &c.
BRACKWELL (Berks)	3½	Sir John Errington, Bart., Warfield Park. Chaff Cutting and Oat Bruising.
BRADFORD	3½	George Hetherington, Corn Merchant, 34, Aldermanbury. Crushing Oats, Bean Splitting, Hoisting, &c.
"	3½	Wm. Seed, Maltster, Clayton. Grinding Malt, &c.
"	3½	J. Tordorf & Sons, Brewers, Thornton Road. Hoisting, Pumping and Grinding Malt at Brewery.
"	2	J. Smith & Son, 50, White Abbey Road. Wheat Grinding Machines, &c.
"	2	J. Harrison, 15, Otley Road. Oat Crushing, Bean Splitting, Hoist, &c.
"	1	Bridge Street Industrial Co-operative Society, 63, Bridge Street (Stables). Fodder Chopping, &c.
"	1	Angus Holden, Esq., Woodlands. Stable Work.
"	1	W. Hilton, Sedgwick Street, White Abbey. Hay Cutting.
BRECHIN	12	Brechin Agricultural and Trading Company. Corn Crushing, &c.
BRENTFORD	9	Jupp & Son, The Mattings.
"	8	Jupp & Sons, High Street. Large Chaff Cutter, Grist Mill, Oat Crusher, and Barley Meal Mill, 3 ft. 6 in. stones.
"	3½	E. Underwood & Sons, High St. Chaff Cutting.
BRIDGENORTH	1	Deighton & Son. Malt Crushing.
BRIDGEWATER	8	T. Ware & Son, Corn Merchants.
"	3½	Spiller & Co., Corn Merchants.
"	3½	A. Pearce, Railway Carrier, Bridgewater. Chaff Cutting.
"	2	George Ricks, Livery Stable Keeper. Chaff Cutting.
BRIGHOUSE	2	North Cheshire Brewery Company, Calder Street. Malting.
BRIGHTON	6	W. Wood & Son, 108, Gloucester Road. Corn Grinding and Chaff Cutting.
"	3½	S. Hunt, Bedford Place. Chaff Cutting.
"	3½	United Omnibus Company, 17 & 18, Upper St. James Street. Chaff Cutting.
"	3½	J. H. Levett, 23, Gloucester Street, Corn Merchant. Corn Crushing, Chaff Cutting, &c.
"	3½	Shoesmith & Sons. Chaff Cutting and Crushing.
BRIGHTON	3½	Shoesmith & Sons, 25, Western Road. Cutting Fodder.
"	2	C. J. Wooley, Lewes Road. Chaff Cutting, &c.
"	½	Banfield & Co., Station Street. Chaff Cutting.
BRINKWORTH, *near Chippenham*	16	H. Hitchcock. Corn Mill Work in connection with Dowson's Patent Economic Gas.
BRISTOL	16	Chamberlain & Pole, Broadmead. Mill Stones, Corn Crushing Machinery, &c.
"	16	H. H. & S. Budgett, Corn Crushing and Hoists for Warehouse.
"	16	W. E. Gardner, Bodminster. Mill Stones, Corn Crushing, &c.
"	8	Bristol Tramways Company. Chaff Cutting and Corn Grinding.
"	8	James Cox, Queen Street Works. One pair of Stones, 3 ft. 10 in.; one Crusher, one Hoist.
"	8	Bobbitt & Sons, West Street. Grinding Corn, Chaff Cutting and Hoisting.
"	8	J. & R. Rush, Princess Street. Corn Elevator, &c.
"	8	J. & R. Rush, Princess Street. Corn Elevator, &c.
"	6	H. Jones, Broadmead. Flour Machinery & Hoist.
"	6	T. G. Northam & Co., Bath Street. Corn Crushing and other Grocer's Machinery.
"	6	W. Baker & Sons, Millers. Hoisting, Pumping and Chaff Cutting.
"	6	James Bigwood, Redcliff Street. Chaff Cutting and Hoisting.
"	6	B. Perry, 127, Redcliff. Machinery, Flour Mixing and Hoisting.
"	4	A. T. Morse & Co.
"	3½	Chandlers & Mawer, Ashley Road. Malt Crushing, &c.
"	2	The Standard Bakery Company. Chaff Cutting, Corn Crushing and Doughing Machine.
"	2	James Farmer, Clifton Mews. Fodder Cutting.
"	½ (Vert.)	W. Grindall, St. Georges. Chaff Cutting, &c.
"	½	— Feltham, Corn Dealer. Chaff Cutting, &c.
"	½	E. Ball, Princes Street. Chaff Cutting and Corn Grinding.
BROMLEY	3½	W. Lowndes, White Hart Hotel. Chaff Cutting, &c.
"	2	E. Hambro, Hayes Place. Pumping and Chaff Cutting.
BURNLEY	12	T. Hargreaves & Son, Church Street. Bean Splitting, Oat Rolling, Hoisting, &c.
BURY ST. EDMUNDS	9	Rolfe & Sons. One pair 4 ft. 6 in. Stones, one Oat Crusher, one Corn Grinding Mill.
"	3½	Goldsmith Brothers. Cracking, Crushing and Dressing Corn, and Hoisting.
CAMBRIDGE	6	Foster Brothers, Mill Lane. Wheat Dusting, &c.
"	2	Hy. Marshall, Coal Office, Market Hill. Chaff Cutting.
CANTERBURY	8	D. Collard & Co., Stour Street. Chaff Cutting, Sawing, &c.
"	1	F. Finn. Chaff Cutting, Seed Crushing, &c.
CARDIFF	3½	J. S. Corbett, Bute Estate Office, 12, Duke Street. Chaff Cutting, Corn Crushing, Pulping Turnips, &c.
"	½	John Moon, Hay Merchant, Splotlands.
"	½	W. Rees & Son, Hay Merchants, Westgate Street. Corn Crushing, Chaff Cutting, &c.

	H.P.	
CARLISLE	16	C. Hammond, Provision Merchant. Two pairs 4-ft. 6-in. Stones, Grinding Indian Corn, &c.
"	3½	J. A. Stephenson, Low Row. Grinding.
"	2	C. Ling, Corn Merchant.
"	2	J. & W. Maxwell & Son, King's Arms Lane, Oil Cake Machinery, &c.
"	2	Carlisle Carriage Co. Grinding and Chopping Fodder, Pumping, Hoisting, &c.
"	½	Joseph Graham, Caldergate. Grinding Malt, &c.
CARSHALTON	½	J. Smith, Engineer. Chaff Cutting.
CASTLE EDEN	8	Nimmo & Son, Brewers. Hoisting and Crushing Malt.
"	3½	Nimmo & Son, Brewers. Elevators, &c.
CHATHAM	2	Percy Legg. Chaff Cutting, &c.
CHELTENHAM	3½	J. Bloodworth, 7, Albion Street. Driving Chaff Cutter, Corn Crusher, &c.
"	2	Queen's Hotel Livery Stables. Cutting Fodder for forty horses; also Wood Working, &c. Machines for Coach Building.
"	1	W. H. Freeman, Esq., Thirlstain Hall. Pumping and Chaff Cutting.
CHESTER	3½	F. A. Dickson & Sons, St. John Street. Seed Cleaning, &c.
"	2	James Hunter, Seedsman. Winnowing, &c.
CHIPPENHAM	16	H. Hitchcock, Brinkworth. Corn Mill Work, in connection with the **Dowson Economic Gas.**
CHISWICK	2	John Ball, Contractor, Lavender House, Swancombe Rd., Devonshire Rd. Chaff Cutting, &c.
CLAYTON, *near Bradford*	3½	William Seed. Malting, &c.
CLECKHEATON	3½	Firth & Blackburn, Maltster. Elevators, &c.
CLIFTON	2	James Farmer, Mews. Fodder Cutting.
COCKERMOUTH	½	Christopher Mayson, Seedsman, &c.
CORK	6	Newsom & Son, Patrick St. Oat Crushing, &c.
"	3½	J. W. Green & Co., Naylor St. Corn Hoisting.
"	2	Newsom & Son, Patrick St. Oat Crushing, &c.
CRANLEIGH	5 (Vert.)	H. Stedman, Rye Farm. Wheat Grinding.
CROYDON	6	*Per* Hammond & Hussey. Chaff Cutting.
"	3½	W. Lock & Co., 51A, George Street. Hoisting and Chaff Cutting.
"	1	Croydon Tramway Company. Fodder Cutting.
DALTON-IN-FURNESS	2	Co-operative Society. Hoisting, Crushing, &c.
DARLINGTON	3½	John Toes, near Bank Top Station. Corn and Hay Chopping, Chaff Cutting, &c.
DEAL	1	H. Page, Esq., Walmer Court. Pumping, Chaff Cutting, &c.
DEPTFORD	6	Southwark & Deptford Tram Co. Chaff Cutting.
"	3½	George Banks, Church Street. Chaff Cutting and Soda Water Machinery.
"	3½	T. Norfolk, Brewery.
DERBY	3½	Derby Tramway Company. Stable purposes.
DERRY	3½	McCormack & King, Grain Merchants. Grain Grinding.
"	2	Macory, Stevenson & Co., Grain Merchants
"	2	C. L. Schwind, Broomfield. Corn Crushing, Bone Mill, &c.
DEWSBURY	5-HP.	J. & J. Stubbs, Wellington Road. Chaff Cutting.
DEVONPORT	2	James Higman, Mouse Town. Fodder Cutting.
DONCASTER	2	The Co-operative Society. Hoisting, Flour Grinding, and other Grocers' Machinery.
DUBLIN	12	W. Haughton, City Quay. Grinding and Elevating Corn.
DUBLIN	12	United Dublin Tramways Company. Fodder Chopping, &c.
"	8	Dublin Warehouse Company. Elevators and Distributing Grain.
"	3½	Pim Brothers, Angier Street. Corn Bruising.
"	3½	R. Worthington, Island Bridge. Chaff Cutting, &c.
"	3½	Dublin Warehouse Company. Elevators and Distributing Grain.
"	3½	Dublin Warehouse Company. Elevators and Distributing Grain.
"	3½	Dublin Tramway Company. Fodder Chopping.
"	2	Southern Tramway Company. Fodder Chopping.
"	2	*Per* J. L. Bacon & Co.
DUNBAR	½	Alex. Annandale, Billside. Hay Cutting, &c.
DUNFERMLINE	6	Hugh Elder, Grain Merchant. Bruising Oats, &c.
EALING	2	Local Board Office, The Broadway. Oat Crushing, Pumping, &c.
EAST BARNETT	1	W. J. Gullum, Church Hill, Howe. Chaff Cutting.
EASTBOURNE	16	E. Hurst, St. John's Mill. Grinding Wheat.
"	8	Universal Carrying Co. Fodder Chopping.
"	3½	Stevenson & Son, Pevensey Rd. Corn Crushing, Chaff Cutting.
EAST DEREHAM	6	Smith & Son. Malting, &c.
ECCLESHILL (Yrks.)	3½	T. Mitchell, Esq., The Park. Farm Work.
EDGWARE	3½	Alfred Fox, Bridge Farm. Chaff Cutting.
EDINBURGH	3½	G. Hall, 2, Hope Street. Hay Choppers, &c.
EGHAM	2	The Hon. Sir W. V. Field. Chaff Cutting, Oat Crushing, and Corn Grinding.
ELLAND	9	Robson Beaumont, Cross. Two Corn Grinding Mills (Barford and Perkins'), one Oat Crusher, &c.
"	6	James Kershaw. Maltings and Hoisting.
"	3½	James Kershaw. Maltings and Hoisting.
EPSOM	4	W. Dorset.
EWELL	16	Hall & Davidson, Millers. Driven by **Dowson's Patent Economic Gas.**
EXETER	8	— Carthew, Porthay Mills. Auxiliary to Water Wheel.
"	6	E. Pine, Fore Street Hill. Mill Stones (auxiliary to water wheel).
"	½	Rev. D. M. Hughes, Clist Hyden Rectory. Chaff Cutting, Laundry Work, Electric Light, &c.
EXMOUTH	8	J. James, Corn Merchant. One pair 4-ft. Stones, one Corn Crusher, one Chaff Cutter, one Hoist.
FAILSWORTH	2	James Wild, 563, Oldham Road. Chaff Cutting and Oat Crushing.
FALKIRK	1	Aitkins & Co., Brewers. Corn Crushing.
FARNINGHAM	16	William Moore, Corn Miller. Millstones working in connection with **Dowson's Patent Economic Gas.**
FAVERSHAM	2	A. W. Fulcher, Syndall Park. Pumping, Chaff Cutting, &c.
FLEETWOOD	8	W. Shuttleworth, Albert St. Corn Grinding, &c.
FORDINGBRIDGE (Hants)	2	John Jeffries, Brewer. Malt Grinding.
"	½	A. Quertier & Co., Corn Marchants. Corn Crushing and Hoist.
GLASGOW	6	Krüger Brothers, 107, Clyde Street. Seed Crushing (large machine, 100 sacks per day). "Engine would work 3 of these machines."—F. R. M. & Co.
"	4	Cooper & Co., Rutherford Lane Stables, Renfield Street. Bruising Corn, Hay Chopping, Driving Saws and Fans for Smiths' Fires.
"	3½	A. & R. Scott, 59, Crookston St. Grinding Flour.

	HP.	
GLASGOW	1	G. Richardson & Son, 12, Commerce Street. Hay Cutting.
"	½	(Vert.) Main & Giffen, 30, Howard Street. Seed Cleaning Machines.
GLOUCESTER	8	Co-operative Society. Corn Crushing, &c.
"	6	R. T. Smith & Co., Railway Agents. Corn Crushing, Chaff Cutting, &c.
"	3½	Gloucester Tramways Company Limited, India House Lane. Chaff Cutting, Oat Crushing, Kibbling Beans and Maize.
GODALMING	3½	Major-Gen. Marshall, Broadwater. Farm purposes.
"	3½	Holland & Son. Chaff Cutting and Hoisting.
GOOLE	½	W. Welldrake, Lower Bridge St. Chaff Cutting.
GRAVESEND	2	W. & T. A. Boorman, 17, Milton Road. Chaff Cutting.
"	½	F. W. Simes, 71, New Road.
GREENWICH	3½	D. Noakes, Billingsgate Dock Wharf. Chaff Cutting, &c.
"	3½	F. J. Corder, Hope Wharf. Hoisting and Grinding.
"	3½	John Lovibond & Sons, Greenside Brewery. Chaff Cutting.
"	2	Greenwich Local Board. Chaff Cutting.
GRIMSBY	8	Arthur Soames & Son, New Malting Warehouse. Armstrong's Accumulator Corn Elevator, Chaff Cutting, &c.
"	6	Great Grimsby Tramways Company. Pumping, Chaff Cutting and Corn Crushing.
"	3½	J. Archer. Chaff Cutting, Oat Crushing, &c.
GUILDFORD	1	J. S. Bridgett, Stoke Park. Farm purposes, Chaff Cutting, &c.
"	1	C. P. Shrubb, Esq., Merrist Wood Hall, Worplesdon.
HADDINGTON	3½	J. M. Montgomery. Grinding Malt, Seed Cleaning, Driving Elevators, Pump, &c.
"	3½	— Binney. Grinding Malt.
"	3½	Roughhead & Park. Seed Machines.
HADLEIGH	3½	— Wilson, Merchant and Maltster. Grinding Malt, Pumping, &c.
HALESWORTH	3½	R. W. Burleigh, Maltster and Corn Merchant. Sack Hoist and Pair of 3-ft. Stones.
HUDDERSFIELD	16	B. & T. Hirst, Outlane. Two Pair French Stones, Bean Splitter, Oat Roller, Elevator, &c.
"	6	J. Taylor & Son. Machine Tools & Corn Grinding.
"	6	Mills & Son, Corn Merchants, King Street.
HALIFAX	3½	Samuel Shaw, Brooklands. Thrashing Machine, Corn Crushing, Hay Chopping, &c.
"	½	Egland Bray, Northgate.
HARDSTONE	3½	*Per* Weeks & Son.
HARROW	8	Alexander Sim, Weald Park. Chaff Cutting, &c.
HASTINGS	3½	Banks' Exors., Queen's Road. Chaff Cutting, &c.
"	2	G. Straikland, Station Yard.
"	½	J. Vine, 38, High Street. Chaff Cutting.
HATFIELD (Herts.)	6	T. W. Carlisle, Esq., Ponsbourne Park. Farm Work, &c.
HAVANT	3½	H. J. Green.
"	¾	(Vert.) S. Clark. Chaff Cutting.
HAVERFORDWEST	8	Ellis & Co. Seed Crushing.
"	8	Ellis & Co. Seed Cleaning.
"	3½	J. Rees, Grocer. Corn Grinding, Hoisting, &c.
HECKMONDWIKE	6	Whitworth Brothers.
"	½	W. H. Brooke, Market Place. Chaff Cutting.
HENDON	3½	Mr. Ward, Horse Jobber. Chaff Cutting.
HEREFORD	3½	Rogers & Co. Chaff Cutting, Crushing and Cleaning Grain, Hoisting, &c.
HEXHAM	8	Joseph Dixon, Tyne Mills. Corn Mills.
HIGHAM FERRERS	2	W. Nichols & Son, Rounds. Cutting Fodder.
HIGH WYCOMBE	1	W. A. Bailey, 96, Oxford Street. Chaff Cutting, Aërated Water Machinery, &c.
HOLYWOOD (Co. Down)	6	R. Harrison, Esq. Driving Thrashing Machines, Churning, Sawing, and General Farming Purposes, Straw Cutting, &c.
HORNCASTLE	3½	Dunham & Pollecfen, Millers. Grinding Corn, &c.
HULL	16	George Stevenson, 41, High Street. Lifting, Splitting, Crushing and Washing Grain, Seed Cleaning, &c.
"	8	George Stevenson, 41, High Street. Lifting, Splitting, Crushing and Washing Grain.
"	6	D. Starkey, Middle Street. Crushing Corn and Cutting Hay and Straw.
"	3½	E. P. Dixon, Seed Merchant, 52, High Street.
"	3½	W. Smith, 102, Hessle Road. Crushing Oats, and Hay Chopping.
"	3½	W. Gray, Seed Merchant. Corn Crushing Hoist, &c.
"	½	J. Baron, 36, Chariot Street. Corn Cutting, &c.
"	½	W. Smith, Corn Factor, Hessle Road.
"	½	T. W. Rich, 83, Hessle Road. Hay Chopping, Oat Rolling, &c.
"	½	W. Laughton, Rullyman. Chaff Cutting and Oat Crushing.
"	½	R. Stephenson, Rullyman. Chaff Cutting and Oat Crushing.
"	½	T. D. Wing, Cab Proprietor. Chaff Cutting and Oat Crushing.
ILFRACOMBE	3½	Carthew & Copp, Queen's Hotel, High Street. Chaff Cutting and Corn Crushing, average 3 tons of Hay per week, besides large quantity of Corn.
IPSWICH	6	G. Mason & Co. Crushing Seed for Extracting Oil.
"	3½	J. Thurman, Corn Merchant, Vernon Street. Corn Mill Work.
"	2	Morse & Woods, Princess Street. Screening Malt.
ISLE OF MAN—DOUGLAS	2	W. Beck, Corn Dealer.
"	1	M. W. Carron, North Quay. Chaff Cutting, Hoisting, &c.
"	½	(Vert.) — Cowin, Baker.
ISLEWORTH	2	F. Sillick, 2, Wilmot's Place, London Road.
KEIGHLEY	2	W. E. Wallbank, Chapel Lane. Hay Chopping, Oat and Cake Crushing.
KESWICK	2	J. Barran, Main Street. Crushing Oats, &c.
KIDDERMINSTER	14	Clement Dalley & Co. Grinding Corn.
"	6	Squire & Daly. Corn Crushing, &c.
"	½	Isaac Hampton & Son, Maltsters. Crushing Malt.
KILMARNOCK	½	J. Templeton & Sons. Hoisting & Seed Cleaning.
"	½	Sanson Brothers, Nelson Street. Hoist and Seed Cleaning.
KILKENNY	4	T. Murphy. Corn Crushing, &c.
KINGSTON-ON-THAMES	1	Guy & Stevens. Chaff Cutting.
"	½	W. Alder, 22, St. Mary's Road, Kingston. Chaff Cutting.
LANARK	½	Hunter & McMoran, High Street. Thrashing and Chaff Cutting.

	HP.	
LANDPORT	3½	G. & G. Curtis, 209, Commercial Road. Chaff Cutting, &c.
"	2	Mr. Kent, Stubbington. Pulper and Chaff Cutter.
"	2	A. Hatchard, Victoria Street. Chaff Cutting.
LANGHOLME	3½	— Easton, Corn Merchant. Corn Mill Work.
LANSDOWNE	2	E. Hayter & Sons, Wolverton Terrace.
LEATHERHEAD	4	J. Hutchinson. Chaff Cutting & Corn Grinding.
LEE	3½	Wedlake & Co. Chaff Cutting.
LEEDS	8	G. Kitching, Meadow Road. Malt Mills.
"	8	William Turton, Hay and Corn Dealer, 3, Crown Point Bridge.
"	7	James Turton, Hay and Corn Dealer,
"	6	Leeds Tramway Co., Crown St. Cutting Fodder.
"	3½	Warne Bros., Wellington Street, Corn Merchants. Hoisting, Oat Rolling, Bean Splitting, and Chaff Cutting.
"	1	T. Whittaker, Elland Road. Hay Chopping.
LEICESTER	6	Borough Stables, Jarvis St. Fodder Machinery.
"	3½	William Prentice, 89, Grafton Street. Corn Crushing Mills and Chaff Cutter.
"	3½	J. Taylor, Belgrave Gate. Malt Crushing, &c.
"	3½	Alfred Else, Friar's Road. Malt Crushing, &c.
"	3½	T. Yates, Tanbey Gate. Crushing and Fodder Cutting.
LEITH	6	W. & J. Metcalfe, 137, Constitution Street. Oil Cake Making, Bruising Corn, &c.
LESLIE	2	Thomas Young, Contractor. Fodder Cutting.
LEWES	3½	William Bannett, Hay and Corn Merchant.
LICHFIELD	½	Lichfield Brewery Company. Malt Crushing.
LITTLEBOROUGH	1	Elisha Whitworth, Corn Dealer. Corn Crushing.
LIVERPOOL	12	Cannington, Shaw & Co., The Albany. Chaff Cutting, &c., Ford Street Stables.
"	8	A. F. Jones, 18, Back Goree. Corn Splitting and Crushing.
"	6	J. Cannington & Co., Albany. Bean Splitting and Hoisting.
"	6	Pickford & Co., Bannister St. Fodder Cutting.
"	3½	R. D. Hewitson & Co., 15, Goree Piazzas. Hoisting and Crushing.
"	3½	Robert Pitt, Contractor, Grafton Street. Fodder Chopping and Sawing.
"	3½	Richmond & Norton, 62, South John Street. Chaff Cutting and Corn Crushing.
"	3½	J. Jarvis, 4, Back Goree. Fodder Cutting.
"	2	John Dobson, 26, Admiral Street, Toxteth Park. Corn Crushing, &c.
"	1	John Atkinson, 1, Moira Street. Chopping Hay.
"	1	John Wilson, 32, Hope Street. Chopping Hay.
"	1	Joseph Lloyd, Faulkner Street, Islington. Coffee Grinding and Hay Chopping.
"	½	Gatehouse & Yates, 18, Market Place, Birkenhead. Chaff Cutting.
"	½	G. Hall, 8, Murat St., Waterloo. Chaff Cutting.
"	5-MP.	Hugh Cullen, Oak Hill Park. Chaff Cutting.
LONDON	16	New Fodder Stores, Great Northern Railway, Holloway. Fodder Cutting, &c.
"	16	New Fodder Stores, Great Northern Railway, Holloway. Fodder Cutting, &c.
"	16	Pickford & Co., City Road Basin, E.C. Chaff Cutting and Pumping.
"	16	London Road Car Co., 9, Grosvenor Rd., S.W.
"	12	East & Co., Curzon Street, W.
"	8	T. Cane, Rochester Row, Pimlico. Chaff Cutting.
LONDON	8	J. & A. Stroud, 287, Kingsland Road. Chaff Cutting.
"	8	W. B. Worthington, 153, Buckingham Palace Road. Chaff Cutting.
"	8	Hugh & McIntosh, Lambeth Vestry Wharf, Belvedere Road, E. Chaff Cutting.
"	8	Muir & Co., 26, Old Broad Street, E.C. Wheat Cleaning.
"	6	South London Tramway Company, Battersea. Chaff Cutting, &c.
"	6	London and Southern Tramway Co., Loughborough Junction.
"	6	S. Crews, 289, High Street, Camden Town. Chaff Cutting.
"	6	Southwark and Deptford Tramway Company. Chaff and Corn Crushing Mills.
"	6	A. & E. Whittome, Liverpool Road, W. Chaff Cutting, &c.
"	3½	Midland Railway Company, Kentish Town.
"	3½	Kensington Vestry Stables. Fodder Cutting.
"	3½	Seth Taylor, Commercial Road, Lambeth. Chaff Cutting.
"	3½	Islington Vestry Stables, Islington. Chopping Fodder and Sawing.
"	3½	J. Shoolbred & Co., Upper Gower Mews, Farringdon Place. Chopping Fodder.
"	3½	William Mead & Co., No. 5 Wharf, North Side, Paddington Basin. Electric Light and Chaff Cutting.
"	3½	Peter Robinson, 9, Margaret Street, Cavendish Square. Chaff Cutting.
"	3½	Osborne & Young, Coldharbour Lane, Camberwell, S.E. Chaff Cutting.
"	3½	Rathbone & Son, Stone End, Borough. Chaff Cutting.
"	3½	Catley, Gridley & Co., 9, Duke Street, London Bridge. Chaff Cutting.
"	3½	Whitmore & Binyon, 28, Mark Lane. Chaff Cutting.
"	3½	North London Tramway Co. Chaff Cutting, Hoisting, &c.
"	3½	Thomas Horn & Sons, Millbank, Westminster. Chaff Cutting.
"	3½	South London Tramways Co. Chaff Cutting.
"	3½	Piggott & Co., 63, New Kent Rd. Chaff Cutting.
"	3½	B. Andrews, Engineer, Grosvenor St., Millbank. Chaff Cutting.
"	3½	M. Sankey, 18, The Crescent, Edmonton. Chaff Cutting.
"	3½	R. & G. Neal, Wandsworth Common, S.W. Chaff Cutting.
"	3½	H. Roads, 400, Caledonian Road. Chaff Cutting.
"	3½	West Metropolitan Tramway Co., Shepherd's Bush, W. Chaff Cutting.
"	3½	Richmond & Co., Hastie Road, Wapping, E.
"	3½	Holland & Son, Old Godalming.
"	3½	W. H. Larcelles & Co., 121, Bunhill Row, E.C.
"	3½	H. & G. Duffield, 28, Upper East Smithfield, E. Chaff Cutting.
"	3½	Parcels Post Stables, Seward Street, Goswell Road, E.C. Chaff Cutting, &c.
"	3½	Parcels Post Stables, Seward Street, Goswell Road, E.C. Chaff Cutting.

	HP.	
London	3½	F. Jennings, 137, Walmer Rd., Notting Hill, W. Chaff Cutting, &c.
"	3½	S. J. Best & Co., Kirkman's Folly, Bermondsey, S.E. Chaff Cutting.
"	3½	Lee & Arlswood.
"	3½	T. Norfolk, Deptford Brewery, Deptford, S.E. Chaff Cutting.
"	3½	Bucholtz & Co., Royal Flour Mills, Vauxhall. Corn Grinding.
"	3½	Nowell & Robson, Warwick Rd., Kensington, S.W. Chaff Cutting and Oat Bruising.
"	3½	A. Fox, Bridge Farm, Edgware, N. Chaff Cutting.
"	3½	Nutting & Sons, 60, Barbican, E.C. Seed Cleaning.
"	3½	Mann, Crossman & Paulin, New Stables, Cambridge Rd., E. Chaff Cutting and Hoisting.
"	3½	Mann, Crossman & Paulin, New Stables, Cambridge Rd., E. Chaff Cutting and Hoisting.
"	3½	J. Watkins, South Grove, Highgate, N. Chaff Cutting.
"	3½	D. W. Noakes, Dock Wharf, Greenwich. Chaff Cutting, &c.
"	2	Robt. Glover, 90, New Cross Rd. Chaff Cutting.
"	2	— Felton, Iveson Stables, Iveson Rd., Brondersbury, N.W.
"	2	W. P. Hall, 9, Call Street, Chelsea, S.W. Chaff Cutting.
"	2	Geo. Irons, 100, High St., Stoke Newington, N. Chaff Cutting.
"	2	Walter Smith, 49, Edgware Rd. Chaff Cutting.
"	2	A. Scott, 22, South Molton St., W. Chaff Cutting.
"	2	W. Brass, 47, Old Street, E.C. Pumping.
"	2	Stone & Swanson, 85, Tottenham Court Road. Chaff Cutting and Hoisting.
"	2	Regent's Canal Co., City Road, Basin. Chaff Cutting.
"	2	C. Rutland, 41, Brixton Rise, S.W. Chaff Cutting.
"	2	Arnold & Stone, Chelsea Wharf, S.W. Chaff Cutting.
"	2	London Gas Company, Crown Granary, North End Road, Fulham, S.W. Chaff Cutting.
"	2	Fairclough & Son, 10, Christian Street, Commercial Road.
"	2	Cab Yard, 8, Earl Street, Westminster, S.W. Chaff Cutting.
"	2	E. H. Smith, 222, Strutton Ground, Westminster, S.W. Chaff Cutting.
"	2	W. & A. Robinson, Holywood Road, Red Cliffe Garden, South Kensington, S.W. Chaff Cutting.
"	2	Lavington Brothers, Railway Carriers, 68, Old Bailey, E.C. Chaff Cutting.
"	2	J. Hetherington, Cricklewood, N. Chaff Cutting.
"	2	J. Simmonds, Lonsdale Yard, Lonsdale Road, Bayswater, W. Chaff Cutting.
"	2	W. C. Poulter, Broad Street, Ratcliffe, E. Fodder Cutting.
"	2	A. Hazel, 4, Junction Road, Holloway.
"	2	Nichollo Baker, 1, Oxford Market, Oxford St., W.
"	1½	(Vert.) H. Rymill, Repository, Barbican, E.C. Chaff Cutting.
"	1	F. Hicks, 15, Old Street, E.C. Chaff Cutting.
"	1	Robert Kew, Ledbury Mews, Ledbury Road, Bayswater, W. Chaff Cutting.
London	1	James Neal, Mendip Wharf, Old Wandsworth. Chaff Cutting.
"	1	William Bowron, 279, Edgware Road, W. Chaff Cutting.
"	1	A. Gadsden, 76, Grove Road, Mile End, E. Chaff Cutting.
"	1	G. Hustler, 162, High Street, Camden Town, N.W. Chaff Cutting and Oat Bruising.
"	1	W. Lee, Sons & Co., 16, Upper Ground Street, Blackfriars Road, S.E. Chaff Cutting.
"	1	W. Hughes, 72, Sutherland St., Pimlico, S.W. Chaff Cutting.
"	1	W. Thorogood, Pavilion Yard, Whitechapel, E. Chaff Cutting.
"	1	Sawyer Bros., Cottage Grove, Stockwell, S.W. Chaff Cutting.
"	1	G. W. Bryant, 80, Seymour Place, W. Chaff Cutting and Corn Crushing.
"	1	— Leppard, West Farrine, Worthing. Chaff Cutting.
"	1	Sargent, Longstaffe & Co., Regent's Canal Dock Wharf, Ratcliffe. Chaff Cutting.
"	1	*Per* A. Reed, 84, Exmouth St. Chaff Cutting.
"	1	T. W. Mead, 15, Broadway, London Fields, N. Chaff Cutting.
"	1	W. Chandler, 147, Stepney Green, E. Fodder Cutting.
"	1	E. Bramley, Catherine Wheel Street, Bishopsgate, E.C. Chaff Cutting.
"	1	J. Harding, 84, Denmark Hill, Camberwell, S.E. Chaff Cutting.
"	1	*Per* Matthews & Tillcock.
"	½	(Vert.) Stephen Sanger, 17, Rathbone Place, W. Chaff Cutting.
"	½	(Vert.) Samuel Stacey, Queen Street Granaries, Hammersmith. Chaff Cutting.
"	½	T. L. Butler, 72, Shaftesbury Road, W. Chaff Cutting.
"	½	F. A. Weatherstone, 137, High Street, N.W. Chaff Cutting.
"	½	A. H. Schneider, 7, St. Leonard's Terrace, Streatham, S.W. Chaff Cutting.
"	½	J. K. Cook, Seven Sisters Rd., N. Chaff Cutting.
"	½	T. E. Wright, Corn Road, E. Chaff Cutting.
"	½	Longford & Dear, 6, Cotton Street, Oxford Street, W. Seed Cleaning.
"	½	W. Dawes, 22, Goldsmith Row, Hackney, E.
"	5-MP.	*Per* H. Garner, 118, Walworth Road, S.E. Chaff Cutting.
"	5-MP.	Walton, Hassell & Port, Spring Place, Kentish Town.
Londonderry	3½	McCormick & King. Malt Rolling, Hoisting, &c.
Low Moor	1	Youngman & Preston, 69, High Street. Chaff Cutting.
Maidenhead	1	W. Nicholson, High Street. Chaff Cutting.
Maidstone	12	Storr & Hodgson. Rape Seed Crushing, &c.
"	8	Wright & Pine, Corn Merchants. Rape Seed Crushing and Cleaning, Hoisting, &c.
"	3½	G. Youngman & Co., Corn Merchants.
"	3½	*Per* Balls, Garrett & Co., Medway Iron Works. Corn Grinding and Chaff Cutting.
"	3½	*Per* Weeks & Son, Perseverance Works. Chaff Cutting.

HP.

MANCHESTER ... 16 Thompson, McKay & Co., Lomas Street Stables, Store Street, London Road. Provender Machinery; 2 large Chaff Cutters; Oat Mill; Bean Mill; Bran Hopper; Cake Mill; Grindstone.

" ...... 12 London and North Western Railway, Sheffield Street Stables. Fodder Chopping.

" ...... 9 George Harrison, 65, Oldham Road. Corn Grinding.

" ...... 8 A. McDougall, City Flour Mill, Poland Street.

" ...... 8 E. Bowler & Co., 7, Rochdale Road. Chaff Cutting.

" ...... 6 E. S. Partington, Crumpsall Green, Cheetham Hill. Chaff Cutting and Farm Work.

" ...... 6 Boddington & Leigh, 20, Shudehill. Hay Cutting, Hoisting, &c.

" ...... 6 W. Garner, Corn Dealer, Hightown. Chaff Cutting, &c.

" ...... 6 — Wallworth, Great Ancoats Street. Corn Grinding, &c.

" ...... 6 Pickford & Co., Mosley Street. Chaff Cutting and Corn Crushing for 150 Horses, at Travis Street Stables; works 6 hours per week; cuts 5 Tons of Chaff, 46 Bags of Indian Corn, 13 Bags of Oats.

" ...... 6 — Walker, York Street, Cheetham.

" ...... 3½ Thompson, McKay & Co., Grocers' Warehouse, Castlefield. Chaff Cutting, &c.

" ...... 3½ James Robinson, Grove Mews, Bury New Road. Corn Grinding and Chaff Cutting.

" ...... 3½ C. Hemingway, 24, Radnor Street, Hulme. Malt Crushing, &c.

" ...... 3½ The Co-operative Society, Broughton Park, Pendleton. Hay Chopping and Grocers' Machinery.

" ...... 3½ Joseph Grange & Co., Great Ancoats Street. Corn Grinding, &c.

" ...... 3½ Samuel H. Kettle, 30, Oldfield Road, Salford. Chaff Cutting, &c.

" ...... 2 — Walmsley, Regent Road. Corn Grinding, &c.

" ...... 1 Jewsbury & Brown, Chorlton Place, Downing Street. Chaff Cutting, Oat Crushing.

" ...... 1 F. & W. Richmond, Victoria Bridge. Chaff and Turnip Cutter.

" ...... ½ W. Knowles & Co., 40, Coupland Street.

" ...... ½ T. Hewitt, 145, Regent Road. Chaff Cutting.

" ...... ½ John Stanley Holme, Eccles Old Road. Hay Chopping.

" ...... ½ J. A. Musgrave, Cab Proprietor. Fodder Cutting.

" ...... ½ Coop & Rothwell, 19, Percival Street. One Richmond & Chandler Chaff Cutter, One Oat Crusher, &c.

MARGATE .... 2 W. Beerling, 4, Martin's Villas. Chaff Cutting.

MARYPORT .... 2 William Irving, Corn Merchant, King Street. Corn Crushing.

MERTON .... 2 Johnson & Co., Single Gate. Chaff Cutting and Bruising.

" .... ½ G. Innes, Esq., Merton Park, Surrey.

MERTHYR TYDVIL.. ½ Thomas Williams, Esq., Caemaydieu. Chaff Cutting and Corn Grinding.

MICHLEDOVER .... 1 A. Wallroth. Farm Work.

MIDDLEWICH ...... 3½ E. H. Moss, Ravenscroft Hall. Chaff Cutting, Root Pulping, &c.

MORETON-IN-MARSH .... 1 Farmer & Horne, Corn Dealers. Corn Grinding.

MORRISTON, *near Swansea* .... ½ John Williams, Hay Merchant. Chaff Cutting, &c.

NEWCASTLE-ON-TYNE .... 8 Joseph James, Chimney Mills, Town Moor. Hoisting and Driving Mill Stones.

" .... 8 Newcastle Corporation, Stables, Friar's Yard. Corn Crushing and Hay Chopper.

" .... 8 Robert Cairns, Watergate, Sandhill. Mill Stones, Bean Splitting, Oat Crushing, &c.

" .... 6 Turton & Bushby, Newcastle Tramways. Chaff Cutting and Corn Crushing.

" .... 6 Thurtell & Kersey, 20, Broad Chare. Hoisting and Maize Crushing.

" .... 6 R. Bell, Big Market. Grinding Corn, Hoisting, &c.

" .... 3½ Robert Jefferson, Barrack Road. One pair of plain Metal Rollers for Oat Crushing, small Kibbling Mill and Grist Mill.

" .... 2 John Robinson, Wholesale Provision Merchant, Pudding Chare. Corn Crushing, Hoisting, &c.

" .... 2 Co-operative Society, Gloucester Road. Hoisting, Driving Mill Stones, &c.

NEWCASTLE (Staff.) 2 Henry Watson, Grocer, &c. Chaff Cutting, Baking, &c.

NEW BARNETT.... 2 T. Higgs, Whittingham Lodge. Chaff Cutting.

NEWPORT .... ½ — Thomas, Commercial Street. Corn Crushing.

NEWPORT (Mon.) 1 John Hodgson, 118, Commercial Street. Chaff Cutter and Corn Mill.

NEW STATLEY, *near Nottingham* ....5-MP. Midland Railway Company. Chaff Cutting, &c.

NORTHAMPTON .... ½ Convent Notre Dame. Cutting Fodder, Laundry Work, &c.

NORTHWICH ......5-MP. George Wakefield, 30, Church Street. Chaff Cutting.

NORWICH.......... 3½ J. & J. Colman, Carrow Works. Chaff Cutting, Pulper, &c.

" .... ½ Norwich Omnibus Company. Chaff Cutting and Crushing.

NOTTINGHAM .... 8 C. Wright, London Road. Hoisting Corn and Driving Corn Crushing Machinery.

" .... 2 Shaw & Co., Sneinton. Driving Corn Crushing Machinery.

OLDHAM .... 2 Joseph Battersby, Hay and Straw Dealer. Corn Crushing, &c.

" .... ½ J. Cavanagh, Henshaw Street. Chaff Cutting, &c.

ORMSKIRK .... 3½ G. Gartside & Son. Hoisting, Grocers' Machinery and Fodder Cutting.

OXFORD .... 6 Thorrell's Trustees' Brewery. Screening Barley and Malt.

" .... 3½ Mathew's Tramway Works. Chaff Cutting.

PENGE .... 2 J. Langlands, Esq., Kent House Farm. Chaff Cutting.

PETERBORO' ...... 2 T. Hill, Corn Merchant. Malt Mills, Grinding Malt and Bean Splitting.

PLYMOUTH ...... 16 Western Counties Agricultural Association. Mill Stones, Bone Mill, Corn Crushers, Hoists, &c.

" ...... 12 Western Counties Agricultural Association, Plymouth Docks. Disintegrator, Corn Crusher, Chaff Cutting and Hoists.

" .... 8 Plymouth Mutual Co-operative and Industrial Society Limited. Dough Mixing, Cutting Chaff, &c., cost about 10/- weekly.

" .... 8 Lang & Co. Corn Cleaning and Hoisting in Corn Warehouse.

	HP.	
PLYMOUTH	6	Pitts, Son & King. Malt Grinding, &c.
„	4	N. Barker & Son, Russell Street. Corn Crushing, Chaff Cutting, &c.
„	3½	J. Bailey, 62, Notte Street. Crushing and Grinding Corn, Chaff Cutting, &c.
„	2	The Plymouth Omnibus Company. Chaff Cutting.
„	2	J. Wainwright, The Octagon. Chaff Cutting and Corn Crushing.
POOLE	3½	Oakley Brothers. Corn Crushing and Hoisting.
„	2	W. H. Yeatman, Corn Stores, Quay. Hoisting, Corn Crushing and Chaff Cutting.
PORTADOWN	3½	A. Shemeld & Co. Nicholson's Disintegrator and Hoisting.
PORTMADOC	8	R. Hughes. Corn Grinding.
PORTSEA	½	T. Fletcher, 35, Daniel Street. Corn Crushing, Chaff Cutting.
PORTSMOUTH	½	Henry Heath, High Street. Chaff Cutting, &c.
QUEENSBURY	4	H. Chatburn. Corn Grinding, &c.
RADCLIFFE	8	Radcliffe and Pilkington Co-operative Society. Corn Grinding, Hoisting, and other Grocers' Machinery.
RAMSGATE	2	Crux & Page, Harbour Street. Fodder Cutting, and Grocers' Machinery.
„	1	F. Wooton. Chaff Cutting, &c.
RASTRICK	16	F. Sutcliffe. Corn Mill Work, three pair 4-ft. French Stones, two Corn Crushers, Hoist, Elevator, Grindstone, &c.
READING	6	Mr. Oakshott, Corn Factor. Hoisting and Chaff Cutting.
„	6	Sutton & Sons. Seed Cleaning.
„	3½	Sutton & Sons. Seed Cleaning.
„	2	F. Shoolbred, Esq., Pangbourne. Chaff Cutting and Pumping.
RICHMOND	½	Mr. Cockburn, Duke Street. Chaff Cutting.
„	½	E. Elliott. Corn Crushing, &c.
ROCHDALE	8	William Cunliffe, Corn Miller, 12 and 16, Cheetham Street. Turning a pair of Stones for Grinding Indian Corn, &c., a pair of Rollers for Crushing Oats, Malt, &c., a pair of Splitters, and Hoisting Sacks into third storey.
„	8	Charles Kershaw, The Butts. Crushing and Grinding Corn, and Hoisting.
ROCHESTER	16	Messrs. Arcoll, Lion Brewery.
„	½	A. C. Richman, 1, Gazeneuve Street, Troy Town. Chaff Cutting.
ROMFORD	2	Mr. Shove, Blackheath. Chaff Cutting, &c.
ROTHERHAM	3½	S. Whitworth, Farmer, Wathe. Chaff Cutting and Pulping.
RUGBY	½	J. Wingell, Little Church St. Chaff Cutting, &c.
RUNCORN	1½	(Vert.) Samuel Dobson, Corn Dealer, 15, Bridge Street. Corn Crushing, &c.
RYE	2	A. Thorpe. Chaff Cutting and Hoisting.
SALISBURY	8	Henry Scott, Corn Merchant. Grinding and Crushing Corn.
„	8	H. Bowle. Corn Grinding, Crushing, &c.
„	2	Woodrow & Sons, Corn Merchants. Grinding and Dressing Oil Cakes, Hoisting, &c.
SALTBURN-BY-THE-SEA	2	T. Wharton, Esq., Skelton Estate. Chaff Cutting.
SANDWICH	1	B. Coleman. Driving Chaff Cutters.
SCARBOROUGH	2	J. B. Westwood, Corn Factor.
SEATON DELAVEL	3½	Co-operative Society. Drives Corn Crusher, Grist Mill, Hay Cutter, and other Grocers' Machinery.

	HP.	
SEVENOAKS (Kent)	2	T. Smith & Co., Brewery. Grinding Malt, &c.
„ „	1	F. A. Forbes, Godden Green. Chaff Cutting, Pumping, &c.
SHEFFIELD	2	E. Hall, Esq., Abbey Dale Park. Chopping Fodder and Pumping.
„	2	N. Lister & Sons, 91 and 93, South Street Moor. Chaff Cutting and Sausage Machine.
„	½	Joshua Tyzack, Esq., Beauchieff. House and Stable Work.
SHEERNESS	8	The Economic Society. One pair 4-ft. Stones, one Wheat Cleaning Machine, &c.
SHOREHAM (Stayning)	6	J. W. Holloway. Chaff Cutting.
SHREWSBURY	3½	James Watson, Esq., Berwick House. Chaff Cutting, Corn Crushing, Pumping, &c.
„	3½	— Mullard, Maltster. Grinding Malt.
SLEAFORD	12	J. T. Exton. Corn Grinding, &c.
„	2	H. Muirhurst, Brewitt's Westgate Maltings. Malt Crushing, &c.
SNARESBROOK (Essex)	2	T. Stevens, Tittlehurst, Cleveland Road.
SOUTHAMPTON	2	H. Glasspool, East Street. Chaff Cutting, Corn Crusher, and Oat Mill.
„	2	G. Buxey, East Street. Corn Grinding.
SOUTHEND-ON-SEA	½	(Vert.) J. C. Underwood.
SOUTHPORT	6	Southport Tram Company. Stable purposes.
SOUTHSEA	8	Morris Welch, Dock Mill. Corn Grinding and other Flour Mill Machinery.
SOUTH SHIELDS	3½	Tramway Company. Fodder Cutting.
SPILSBY	8	B. Robinson, Corn Mills. 4-ft. Stones.
STALYBRIDGE	½	S. & J. Wood. Hay Cutting, &c.
STIRLING	8	D. & J. McEwan & Co. Driving two Hoists, Chaff Cutter, Corn Bruising Machine, Oil Cake Grinding Machine, and Bottle Washer.
„	2	J. Gray & Co., 7, Craigs. Oat Crushing, Hoisting, &c.
ST. HELENS	3½	St. Helens Tramway Company. Chaff Cutting.
„	5-HP.	John Burgess, 11, Edward Street. Hay Cutting.
ST. LEONARDS-ON-SEA	2	P. H. Ellis, Hollington. Chaff Cutting.
STOKE	12	G. E. Edwards, 19, Hill Street. Two pair of Stones, Grinding Meal, Kibbling Mill and Oat Roller, also Hoist—all at the same time.
STOCKPORT	12	J. Norbury. Corn Mills.
„	8	Brooke & Co., 36, Great Underbank. Corn Crushing.
„	8	William Kitchen, Corn Mills. Corn Crushing.
„	7	Thomas B. Deaville, King Street East. Corn Crushing, &c.
„	2	Walter Yates, Warren Street, Park. Corn Crushing.
„	5-HP.	J. Blackshaw, Fletcher Street. Chaff Cutting, &c.
STOCKTON-ON-TEES	6	Stockton Tramway, Bridge Road. Chaff Cutting and Engineers' Tools.
„	2	George Thwaites, Church Row. Hoisting and Chopping Herbs.
„	2	Gaudy Brothers. Hoisting, Grinding, and Crushing.
„	2	H. Sanderson, Silver Street. Corn Work, Crushing and Hoisting.
STOCKWELL	1	Sawyer Brothers, Cottage Grove. Chaff Cutting.
STREATHAM	2	A. H. Bristoe. Chaff Cutting.

	HP.	
STROOD	6	Horsnail & Reynolds, Corn Merchants. Hoisting Corn, driving two pair small Mill Stones, one Bean Splitting Mill, &c.
STROOD (Kent)	6	Stewart Brothers & Spencer. Seed Crushing, &c.
STROUD	6	H. Dorrington, Esq., Lyppiatt Park.
SUDBURY	1	E. Cowley, Vale Farm. Chaff Cutting and Milk Separating.
SURREY	1	C. P. Shrubb, Merrist Wood Hall, Worplesdon. Chaff Cutting.
SUNDERLAND	6	Sunderland Corporation, Millfield Stables. Chopping Hay and Crushing Oats.
,,	6	G. Ryder, Geldbridge Avenue. Corn Crushing.
,,	3½	Sunderland Tramway Company. Hoisting, Crushing, and Chopping.
,,	½	Lockie & Co. (Stables.) Fodder Cutting.
SUTTON VALENCE	3½	W. R. Ward. Corn Grinding.
SWANSEA	½	Thomas H. Day, Strand. Chaff Cutting, &c.
SYDENHAM	1	Crystal Palace District Gas Company. Chaff Cutting, &c.
TAMWORTH	8	A. B. Foster, Esq., Canwell Hall. Pumping and Stable Work.
TAUNTON	3½	J. White, Jobmaster. Chaff Cutting, &c.
THAME	6	John Loader, 18, Corn Market. Corn Grinding.
THETFORD	12	— Norris, Esq, Wrentham Hall. Farm Work.
TORQUAY	3½	The Local Board. Pumping, Mortar Mill, Chaff Cutting, &c.
TRURO	6	Samuel J. Polkinhorne, Corn Merchant, Malpas Road. Corn Mill Work.
,,	6	S. & S. Trounson. Hoisting and Chaff Cutting.
TUNBRIDGE WELLS	½	C. Peacock, Lower Green. Chaff Cutting, Bean Crushing.
ULVERSTON	7	James Dickinson, Neville Street. Corn Crushing, &c.
UXBRIDGE	2	James Leno, Windsor Street. Chaff Cutting, &c.
VENTNOR	2 (Vert.)	H. Brown, 10, Mill Street. Chaff Cutting and Corn Crushing.
WADHURST (Sussex)	1	E. Thurbon, The Mount. Pumping and Chaff Cutting.
WAKEFIELD	16	J. Wade, Corn Factor, Kirkgate. Corn Grinding.
,,	8	William Pettinger, Corn Merchant. Cranes and Corn Crushing Machines.
,,	6	Co-operative Society. Grinding, &c.
WALLSEND	3½	Wallsend Co-operative Society. Crushing Corn, Hoisting, and Driving General Grocers' Machinery.
WALMER, *near Deal*	1	Thompson & Sons, Walmer Brewery. Chaff Cutting.
WANDSWORTH (Surrey)	2	Carter & Howick, Corn Merchants, 20, High Street. Chaff Cutting and Grinding.
WARRINGTON	8	Geddes & Son. Hoisting and Grinding.
WARWICK	3½	E. Glover & Sons, Eagle Works. Chaff Cutting.
,,	3½	W. Glover & Son, Corn Exchange. Food Preparing Machines for Veterinary Department.
WATERFORD	½	R. Fennesey & Son. Three Seed Cleaning Machines—sometimes four.
WATERFORD	½	William Power, 23, King St. Seed Cleaning.
WATERLOO	½	George Hall, Cowkeeper. Chopping and Crushing Corn.
WATFORD	3½	F. G. King. Mill Granary.
WATHE, *near Rotherham*	3½	S. Whitworth, Farmer, &c. Chaff Cutting, Pulping, &c.
WELLINGBOROUGH	6	W. Blott & Co., Corn Merchants. Hoisting, Working Creepers for moving the Grain, and a Dressing Machine.
,,	3½	Charles J. K. Woolston, Corn Merchant.
WEST BROMWICH	1	John Tickle, Engineer. Chaff Cutting, Oat Crushing, Bean Splitting, and Hoisting.
WEST HARTLEPOOL	3½	Captain J. W. Cameron, Lion Brewery. Malt Grinding, &c.
WETHERBY	2	Thomas S. Cundy, Esq., Hall Orchard. Pumps and Hay Chopping.
WIGTON	6	Joseph Graham. Grinding and Crushing.
WIMBLEDON (Surrey)	2	G. Ely, Poulterer, &c., 3, Wimbledon Hill Road. Chaff Cutting and Sausage Chopping.
WINDSOR	1	J. Braizier, Clarence Street. Chaff Cutting and Oat Bruising.
WIRKSWORTH	½	Charles Wright & Son. Chopping Hay, Coffee Roasting, Sugar Chopping.
WOLVERHAMPTON	6	Wolverhampton Tramways Company, Darlington Street Granaries. Chaff Cutting and Corn Crushing.
,,	2	Savage & Son, Cleveland Street. Crushing Malt.
WOODBRIDGE	3½	H. Edwards & Son, Wine Merchants. Chaff Cutting and Bottle Washing.
WOOLWICH	6	Woolwich Tramway Co. Chaff Cutting, &c.
WOOTON BASSETT	16	Mr. Hitchcock, Corn Mills, Brinkworth. Grinding. Driven by **Dowson's Patent Economic Gas.**
WORKINGTON, *via Penrith*	3½	William Irving, Central Station. Corn Crushing and driving Mill Stones.
WORKSOP	3½	H. P. Forrest, Market Place. Chaff Cutting and Engineer's Tools.
WORTHING	3½	H. H. Gardner, West Tarring. Chaff Cutting, &c.
,,	1	C. Fuller, Manor Farm, Broadwater. Chaff Cutting, Turnip Crushing, Corn Crushing.
,,	1	— Leppard, West Farring. Chaff Cutting.
YEOVIL	6	Joseph Bruton. Grinding Corn with Mill Stones, 2 ft. 9 in. diameter, Chaff Cutting, Dairy Work, Malting, &c.
YORK	6	H. Leetham & Sons, Anglo-Hungarian Roller Flour Mills.
,,	3½	Tramway Company Limited. Fodder Cutting.
,,	3½	Agar & Chadwick, Hirst Yard, Walmgate. Oat Crushing, &c.
,,	2	G. E. Barton, Baker, &c. Baking Machinery, Aërated Water Plant, and Fodder Chopping.

CROSSLEY BROTHERS LIMITED,

OPENSHAW, MANCHESTER.

TOWN.	HP.	NAME AND ADDRESS OF USER.	CLASS OF WORK FOR WHICH ENGINE IS USED.
Crewe	8	Co-operative Society	Hoisting and kneading machinery for bakery.
Dalton-in-Furness	2	Co-operative Society	Hoisting flour, grinding coffee, fodder chopping, &c.
Derby	6	Co-operative Provident Society	Hoisting, grinding coffee, driving pump, &c.
Doncaster	6	Doncaster Co-operative Society	Baking.
,,	2	Doncaster Co-operative Society	Grocers' machinery.
,,	1½	Doncaster Co-operative Society	Hoisting.
,,	½	Doncaster Co-operative Society	....
Dumbarton	6	Co-operative Society	Baking machinery: Doughing machine, seventy dozen 2-lb. loaves' capacity, or 4½ bags of flour (280lb. each). Consumption of gas doing baking and necessary hoisting, about 3,500 cubic feet per week.
,,	½	Co-operative Society	Sausage chopping and knife sharpening machine.
Dundee	8	Eastern Co-operative Society	....
Dunfermline	8	Co-operative Society	Baking machinery.
Earlsheaton	3½	Earlsheaton Co-operative Society	Hoisting.
Edinburgh	8	The Professional and Civil Service Supply Association, 4, St. Andrew Square	....
,,	3½	The Professional and Civil Service Supply Association, 4, St. Andrew Square	One ton hoist, coffee grinding, &c.
,,	3½	The Professional and Civil Service Supply Association, 4, St. Andrew Square	Doughing machines.
Galashiels	3½	Eastern Co-operative Society	Baking machinery.
Gateshead	6	Co-operative Society, Jackson Street	Electric lighting: Drives seven arc lamps of 1,500-candle power each (six inside the shop and one outside). Also used for hoisting.
,,	½	Co-operative Society, Asken Road	Flour hoist and coffee mill.
Glasgow	12	Scottish Co-operative Wholesale Society Limited, Clarence Street	....
,,	8	Scottish Industrial Wholesale Society, 119, Paisley Road	....
,,	6	Scottish Co-operative and Industrial Society, 119, Paisley Road	Baking machinery.
Gloucester	8	Gloucester Co-operative Society Limited.	Baking machinery, corn crushing, &c.
Hebden Bridge	8	Co-operative Society	....
	½	Co-operative Society, Heptonstall	....
Keighley	3½	Co-operative Company	Grocers' machinery, hoisting, &c.
Kettering	½	Co-operative Society	Sausage chopping, &c.
Lancaster	1	Co-operative Society	Grocers' machinery.
Leeds	3½	Industrial Co-operative Society, Marshall Street	Hoisting, grocers' machinery, boot and shoe machinery, &c.
,,	3½	Mutual Supply Society, 25, Cockridge Street	Hoisting.
,,	1	Industrial Co-operative Society, Albion Street	....

TOWN.	HP.	NAME AND ADDRESS OF USER.	CLASS OF WORK FOR WHICH ENGINE IS USED.
LEICESTER	12	The Co-operative Society	Baking machinery, hoisting, and chopping fodder.
"	8	The Co-operative Society	Boot and shoe machinery.
LEITH	14	Scottish Wholesale Co-operative Society, Links Place	....
"	6	Scottish Wholesale Co-operative Society, Links Place	Cage hoist and cranes.
LESLIE	3½	The Dysart Co-operative Stores	Grocers' machinery.
"	3½	Leslie Co-operative Bread Society	Baking machinery.
LONDON	16	Junior Army and Navy Stores Limited, York House, Regent Street, W.	Pumping for hydraulic lift.
"	16	Co-operative Wholesale Society, Hooper Square, Leman Street, E.	Pumping, hoisting, &c.
"	16	Co-operative Wholesale Society, Hooper Square, Leman Street, E.	Pumping, hoisting, &c.
"	12	Army and Navy Co-operative Society, Lupus Street	Grocers' machinery.
"	12	Army and Navy Co-operative Society, Lupus Street	Grocers' machinery.
"	12	Civil Service Bread Supply Association, Horseferry Road, E.	Bakers' machinery, electric lighting, and ventilating fan.
"	12	Civil Service Bread Supply Association, Horseferry Road, E.	Bakers' machinery, electric lighting, and ventilating fan.
"	8	Civil Service Supply Association, Hart Street, Covent Garden	Hoisting.
"	8	Co-operative Wholesale Society, Hooper's Square, E.	Hydraulic hoist.
"	8	Army and Navy Co-operative Society, Lupus Street, Pimlico, S.W.	Printing.
"	6	Junior Army and Navy Stores, 15, Regent Street, W.	Hoisting.
"	3½	Civil Service Stores, Hart Street, Covent Garden, W.C.	Hoisting.
"	2	Army and Navy Auxiliary Co-operative Supply Limited, Frances Street	Chaff cutting and oat bruising.
MANCHESTER	3½	The Co-operative Society, Broughton Park, Pendleton	....
"	2	Household Stores	Grocers' machinery.
MASBOROUGH	2	Equitable Co-operative Society, Station Road	....
MIDDLETON-IN-TEESDALE	6	Teesdale Workman's Provident Industrial Society	Hoisting.
MORLEY	6	Morley Co-operative Society	Grocers' machinery, hoisting, &c.
MOSSLEY	3½	Mossley Industrial Co-operative Society Limited	Grocers' machinery.
NEWCASTLE-ON-TYNE	16	Co-operative Retail Society, Newgate Street	Electric lighting; 112 incandescent lamps, and four 2,000-candle power arc lamps.
"	12	Co-operative Wholesale Society, Waterloo Street	Hoists, tea mixers, millstones, and general grocers' machinery.
"	8	Co-operative Wholesale Society, Waterloo Street	....
"	6	Co-operative Wholesale Society, Waterloo Street	Hoists, and in hardware department.
"	6	Co-operative Retail Society, Newgate Street	Hoist, tea mixer, and general grocers' machinery.
"	3½	The Co-operative Society, Waterloo Street	....
"	2	The Co-operative Society, Gloucester Street	Hoisting flour, coffee grinding, &c.
NEWTON-LE-WILLOWS	6	Co-operative Society, Earlestown	Grocers' machinery.
OLDHAM	½ VERT	Co-operative Society, Coppice Branch	....
"	½	Co-operative Society, Central Branch	....
"	½	Co-operative Society, Ratcliffe Street Branch	....

TOWN.	HP.	NAME AND ADDRESS OF USER.	CLASS OF WORK FOR WHICH ENGINE IS USED.
OXFORD	8	Co-operative Society....................................	Lindop's dough mixer, &c., in bakery; hoist, sugar cutting, corn crushing, chaff cutting, sausage chopping, &c. Costs about 3d. per hour.
PERTH	12	Co-operative Society....................................	....
PETERBOROUGH....	6	Co-operative Society....................................	Baking machinery.
PLYMOUTH	8	Mutual Co-operative and Industrial Society Limited.........	Dough mixing, kneading about thirty sacks, 280 lbs. each, per day; working cage hoist, fruit machine, chaff cutting for eight horses, &c. Costs about 10/- per week.
"	4	Plymouth Co-operative Society	....
PORTSMOUTH......	3½	Portsea Island Co-operative Society..........................	....
PRESTON	3½	Co-operative Society....................................	....
RADCLIFFE........	8	Radcliffe and Pilkington Co-operative Society	Hoisting.
RAVENSTHORPE ..	6	Self-help Co-operative Society	....
RAWTENSTALL	1	Conservative Industrial Co-operative Society	....
READING..........	6	Reading Industrial Co-operative Society....................	Baking machinery.
RUGBY	8	The Co-operative Society....................................	Baking machinery.
RUNCORN	3½	Co-operative Society, 8, Church Street	Grocers' machinery.
SEATON DELAVEL..	3½	Seaton Delavel Co-operative Society	Corn crusher, grist mill, hay cutter, and general grocers' machinery.
SLAITHWAITE	12	Slaithwaite Co-operative Society	Grocers' machinery.
SOWERBY BRIDGE..	1	Sowerby Bridge Industrial Society Limited	Sausage chopping in butchery department.
STALYBRIDGE......	6	Co-operative Society....................................	....
TODMORDEN	8	Co-operative Wholesale Society, 8, Dale Street	....
ULVERSTON	2	Co-operative Society, Market Street	....
WAKEFIELD	6	Wakefield Industrial Co-operative Society, Westgate........	Grocers' machinery and 20-cwt. hoist.
WALLSEND	3½	Wallsend Co-operative Society	Hoisting, grinding coffee, corn crushing, currant cleaning, &c.
WARRINGTON	3½	The Co-operative Society, Sankey Street	Hoisting.
WEST PELTON	3½	Co-operative Society....................................	Hoist, crusher, and general grocers' machinery.

For Engines used by others than Co-operative Societies for driving Grocers' Machinery, Baking Machines, &c., see separate Lists.

CROSSLEY BROS. LIMITED,

Openshaw, Manchester.

CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

HP.

HADDINGTON .... 3½ Mark Binnie, Brewer. Malt Mill, Water and Wort Pumps, Hoists, Malt Crushing, &c.

HADLEIGH (Suffolk) 3½ — Wilson, Maltster. Pumping, Hoisting, &c.

HALESWORTH .... 3½ R. W. Burleigh, Maltster. Hoisting and pair of 3-ft. Stones.

HALIFAX .... 2 S. Webster & Sons, Brewers. Hoisting.

HECMONDWIKE .. 3½ Whitworth Bros., Maltsters. Hoisting.

HORSHAM .... 3½ H. Mitchell, West Street Brewery.

HUDDERSFIELD .. 8 Bently & Shaw, Lockwood Brewery.

" .. ½ (Vert.) Bently & Shaw.

HULL............ ½ Thos. Lindsley, 7, Dagger Lane.

IPSWICH.......... 2 Morse & Woods, Princess Street. Malt Screening.

KIDDERMINSTER.. ½ Isaac Hampton, Son & Co. Malt Crushing.

KIMBERLEY ...... 2 Thomas Hardy, The Brewery. Hoisting.

LEDBURY .... ½ C. M. Edwards, Brewer. Pumping and Hoisting.

LEEDS .... 8 G. Kitching, Meadow Maltings, Meadow Road, Malt Mills.

" .... 2 Wright Bros., Brewers, Durham Street. Hoisting, Pumping and Malting.

LEICESTER ...... 3½ John H. Taylor, Wenlep Street. Hoisting and Malt Crushing.

" ...... 3½ Alfred Else, Friar's Road. Malt Crushing.

" ...... ½ — Parkinson, Brewer, Seleby Street. Pumping.

LEITH .... 8 Bernard & Co., Seafield Maltings. Hoisting.

LINLITHGOW .... 2 J. & A. Dawson, Distillers. Pumping.

" .... 2 J. & A. Dawson, Distillers. Hoisting.

LANGOLLEN ...... 1 Hawthorne & Co., Magdolen Distillery.

" ...... ½ — Baker, Sun Brewery. Malt Crushing.

LIVERPOOL ...... 3½ Preston & Co., Distillers. Hoisting, &c.

LONDON..........16 Tomkins, Courage & Cracknall, Brewers, Limehouse Pier. General Work.

" .... 3½ A. W. R. & N. Potts, 22, Southwark Buildings Road. For Vinegar.

" .... 3½ City of London Brewery Company, 89, Upper Thames Street.

" .... 2 T. Norfolk, Deptford Brewery.

" .... 2 Mure, Warner & Co., Hampstead Brewery.

LUDLOW .... 2 W. H. Lloyd, Corve Street. Pumping, Malt Crushing, &c.

MAIDENHEAD .... 1 W. Nicholson, High Street. Chaff Cutting.

MAIDSTONE ......12 Fremlin Bros., Brewers.

MANCHESTER .... 3½ Charles Hemmingway, 24, Ratcliffe Street, Hulme, Maltster.

NAILSWORTH .... ½ Clissold & Sons, Nailsworth Brewery. Rousing 8 Fermenting Tuns, running 144 hours a week.

" .... ½ Clissold & Sons, Nailsworth Brewery. Rousing 8 Fermenting Tuns, running 144 hours a week.

NEWBURY (Berks.) 3½ Hawkins & Co., The Maltings. Pumping and Hoisting.

NEWCASTLE-ON-TYNE .... 3½ Campbell & Erskine, Westgate Road.

NORTHAMPTON .. 3½ Radcliffe & Jeffreys, Maltsters. Hoisting.

NORWICH .... 2 Bullard & Sons, Anchor Brewery. Hoisting.

OSWESTRY ...... ½ Enoch Evans, Grapes Brewery.

PETERBORO' ...... 2 T. Hill. Malt Mills and other Machinery.

RATHDOWNEY .... 6 R. Perry & Sons, Limited.

RICHMOND ...... 1* D. Watney & Co., Brewers. Pumping.

ROCHDALE ...... 3½ T. Sutcliffe, Molesworth Street Brewery. Hoisting.

ROCHESTER ...... 16 Messrs. Arcoll. Pumping.

ROTHERHAM .... 3½ S. Whitworth, Maltster. Wathe.

SEVENOAKS (Kent) 2 T. Smith & Co., Sevenoaks Brewery. Pumping and Malt Grinding.

HP.

SLEAFORD........ 2 H. Muirhurst, Brewell's Westgate Maltings. Malt Crushing, &c.

SHREWSBURY .... 3½ — Mullard, Maltster. Malting and Hoisting.

SHEPLEY .... 4 Seth Senior & Sons, Highfield Brewery.

" .... 4 Seth Senior & Sons, Highfield Brewery.

STROOD .... ½ H. L. Dampier, Findsbury Brewery. Pumping.

STOWMARKET .... 3½ E. Green & Son, Ale Stores. Pumping.

WALLINGFORD.... ½ E. Wells.

WAKEFIELD ...... 2 Saunderson & Sons, Maltsters.

" ...... 2 Saunderson & Sons, Maltsters.

" ...... 2 Saunderson & Sons, Maltsters.

WALMER (nr Deal) 1 Thompson & Sons, Walmer Brewery. Chaff Cutting.

WOLVERHAMPTON 2 Savage & Son, Cleveland Street. Malt Crushing.

WORKINGTON (Via Penrith) ...... 1 Iredale Bros., High Brewery. Rousing Beer.

WEST HARTLEPOOL 6 J. W. Cameron, Lion Brewery. Brewery Purposes.

" .. 3½ J. W. Cameron, Lion Brewery. Electric Lighting.

YEOVIL .... 6 J. Brutton. Malting.

Selected list of AËRATED WATER MANUFACTURERS using the "OTTO" Gas Engine to whom reference is permitted.

HP.

ABERYSTWYTH.... 5 MP. J. P. Thomas, Chemist.

ABERDEEN ...... ½ George Broomhead, Union Place.

AIRDRIE.......... 1 — Bell, South Street.

ALRESFORD (Hants) 5 MP. F. C. Batchelor, Broad Street.

AMBLESIDE ...... ½ Thomas Bell, Chemist.

ANDOVER .... 1 J. Poore & Son.

AYLESBURY ...... 3½ S. Gulliver & Co., Wine Merchants, Kingsbury Square.

ALDERSHOT...... ½ (Vert.) James Williams, Chemist.

BARNSTAPLE .... 2 Ross & Co.

BASINGSTOKE .... 1 J. Schofield. Also Chaff Cutting and Oat Crushing Machinery.

BATH............ 5 MP. Tylee & Co., Chemists, 7, Bridge Street.

BELPER.......... ½ C. W. Southern, Chemist.

BELFAST ....12 W. A. Ross & Co., Police Square.

BELLINGBORO' .... ½ Trolley T. Houghton.

BINGLEY .... 1 Slicer Brothers & Co., Main Street.

BIRKENHEAD .... 2 Mackie & Gladstone, 88, Hamilton Street. Also Hoisting, Bottle Washing, Hay Cutting, Corn Crushing, &c.

" .... ½ Gatehouse & Yates.

BIRMINGHAM .... 6 Birmingham Coffee House Co., Bull Ring.

" .... 2 J. Arblaster, Five Ways.

" .... 2 Stafford Aërated Water Co.

" .... ½ W. Bott, High Street, Deritend.

BLACKBURN...... 2 W. Meadowcroft, Old Bank Street.

" ...... 5 MP. J. Atack, 17, Bold Street.

BLACKPOOL ...... 3½ J. Singleton, East Warbeck Street.

BOSTON .... 1 R. O'Connell, Angel Hotel Court.

BOURNEMOUTH .. 2 John Martin, 16, Triangle.

BOWNESS .... ½ J. J. Johnston.

BURNLEY .... ½ Exors. of H. Mitchell.

BRADFORD ...... 2 Waller & Smith, Spotted Ox Stores.

" ...... 1 F. M. Rimington & Sons, 9, Bridge Street.

" ...... 1 Central Coffee Tavern Co. Limited.

" ...... ½ W. E. Ryder, Grocer, Great Horton.

	HP.	
BRADFORD	½	J. Keighley, Garnet Street, Leeds Road.
"	½	Eau de Seltz Co., 30, North Parade.
"	5 MP.	Sharp & Barran.
BRIDGEWATER....	1	J. A. Basker, Chemist, Fore Street.
BRIGHTON........	3½	Shelvey & Co., German Place.
"	3½	Brighton & South Coast Mineral Water Company, George Street.
"	2	W. R. Woodhouse, Bridge Street, Pentonville.
"	½	Goyne Stevens, Chemist, North Street.
BRISTOL	8	The Chemical Aërated Water Co., The Marsh.
"	6	Schweppe & Co., Queen's Square.
"	1	C. D. Barker & Co., West Park Corner, Clifton. Also Chaff Cutting, &c.
"	½	— Voysey.
"	½	Bristol & South Wales Aërated Water Co., Giant's Castle, St. Phillip's Bridge.
BUCKINGHAM	½	Jas. Bramson.
CARDIFF	2	H. L. Williams, Mellicant Street.
"	2	South Wales Aërated Water Co., Great Western Approach.
"	1	Thomas Elliott, Bute Mineral Water Works. Cutting Chaff.
CARLISLE	½	Jos. Todd, 47, Blackfriars Street.
"	½	Joseph Graham, 2, Church Street.
"	2	Hope & Bendell, Wine Merchants.
CASTLEFORD	½	Morrison & Townend, Dandelion Porter Manufacturers, Carlton Street.
CHATHAM........	½	Percy Legg. Also Chaff Cutting.
CHELTENHAM	½	Seagor & Co.
CHORLEY	3½	Robert Clayton.
CROYDON	3½	Packham & Co. Limited (Hedazon & Co.), Catherine Street.
DEPTFORD	3½	Geo. Banks, Church Street.
DERBY	½	W. Wilde, Robin Hood Inn.
"	5 MP.	Ford & Cope, Chemists.
DOVER	1	Souter & Co., Soda Water Works.
DUBLIN	6	O'Brien & Co., Henry Place.
"	6	Hamilton, Long & Co.
"	6	Byrne & McSweney.
"	6	Shanks & Co.
EALING	½	Hilton & Co., St. Mary's Road.
EAST GRINSTEAD	1	H. S. Martin, Chemist.
EDINBURGH	1	J. Robertson & Co., 35, George Street. Cost of gas, &c., for one year's running (daily) under £5.
......	½ (Vert.)	J. Todd, Edinburgh & Leith Aërated Water Company, Annandale Street.
"	½	W. Leitch, Picardy Place.
"	½	The British Public House Co., Northumberland Street Lane.
"	5 MP.	J. T. Leighton & Co., 20, Picardy Place.
FALKIRK	3½	R. Barr.
FARNHAM........	½	George Elliott, West Street. Also drives Saw.
FOLKESTONE	5 MP.	E. Souter.
GLASGOW	3½	J. Mackay & Co., 186, West Regent Street.
"	½	J. Farquhar, 7, Salt Market.
"	½	W. Brown, York Lane, York Street.
GOSPORT	8	Mumby & Co.
GRANTHAM	3½	W. Wysall. Also drives Stones and Crushing Roller. Cost of gas about 30/- per quarter.
GRAVESEND	1	C. H. Perry, Lord Street.
"	5 MP.	W. Hayward, 15, Milton Road.
GREENWICH	2	Lovibond & Son.
GREENOCK	½	Greenock Aërated Water Co.
GRAHAMSTONE ..	½	A. Scott, Springfield Lane.
GUILDFORD	½	F. Wheeler, Chemist, High Street.
HADLOW	½	Barnett & Shirwell.
HALIFAX	½	— Dyer, The Shay.
"	5 MP.	C. G. Hanson, New Bank.
HARROGATE......	3½	Mineral and Aërated Water Association.
HECKMONDWIKE..	½	W. Hendry, Tower Street.
HENLEY-ON-THAMES	2	Alfred Ive & Co.
HIGH WYCOMBE..	1	W. A. Bailey, 96, Oxford Street. Also Cutting Chaff, Boring Wood, &c.
HORSHAM	3½	H. Mitchell, West Street Brewery.
"	1	Harrington Scrase & Co.
HULL	16	Wm. Hay, 4, Regent's Terrace, Anlaby Road.
"	6	Wm. Hay, 4, Regent's Terrace, Anlaby Road.
ISLE OF MAN	½	T. M. Dodd, Castletown.
KESWICK	½	J. W. Townley, Chemist.
KIRKWALL	1	John Cursiter. Costs under 1/- per day of 10 hours with gas at 7/6 per thousand.
LANDPORT	1	Oldfield Bros., 337, Commercial Road.
"	5 MP.	Dance & Smith, Lake Road.
LEEDS............	2	J. Whitwan, St. Peter's Square.
"	1	Sarah Green, Clark Lane, Ellerby Lane.
"	1	Whitworth & Slater.
"	½	T. Brownfoot, Trafalgar Street. Drives a No. 2 Herman Lachapell (Paris) Mineral Water Plant. Costs under ½d. per hour for gas.
"	5 MP.	Queen's Hotel.
LEICESTER	3½	G. Paul, Grosvenor Street.
"	2	Jos. Allen, Dover Street.
"	1	J. Allbrighton, Southgate Street.
"	1	Samuel Cleaver, Junr., 4, Gladstone Street.
"	1	Leicester Coffee & Cocoa House Co., Highcross St.
"	2	T. Branston, Nichols Street.
LEITH............	2	J. & W. Currie, Aërated Water Manufacturers.
"	½	W. Petrie, 2, Citadel Street.
LIVERPOOL	3½	Jno. Lyon & Co., Lord Nelson Street.
"	3½	Per Furness & Co., Bankhall.
"	1	Liverpool Café Co.
"	½	Ambress & Hugh Oxley, 158, Hornby Street, Scotland Road.
"	5 MP.	Jas. Salisbury, Edge Lane Hotel.
"	5 MP.	Ed. Forrest, 53, High Street, Edge Hill.
LONDON..........	12	Chemists' Aërated and Mineral Water Company, 45, Siffard Street, N.
"	3½	Mountain, Horseleys & Co., Hop Exchange, Southwark, S.E.
"	3½	E. Geraut & Co., 1 and 2, Corporation Building, Farringdon Road, E.C.
"	3½	Roe & Marchant, Holland Street, Brixton.
"	3½	W. R. Lister & Clemow, 21, Catherine Street, Strand, W.C.
"	2	J. Husband, 184, High St., Stoke Newington, N.
"	2	H. Williams, 9, Vaughan Rd., Loughboro' Rd., S.E.
"	1	E. F. Newling, 28, Lewisham High Road, N.
"	1	Porter & Stevens, Tiger's Head Lee, S.E.
"	1	Thomas Hills, 7 & 8, Dean Terrace, Forest Hill, S.E.
"	1	Stiles & Co., 52 & 53, Well Street, Oxford St., W.
"	½	B. Zebach, 11, Bank's Buildings, Backing Rd., E.
"	½	Hiram Codd, 41, Gracechurch Street, E.C.
"	½	Edmond & Co., 8, Ainger Rd., Primrose Hill, N.W.

	HP.	
LONDON	½	W. P. Imber, 108, Redman's Rd., Stepney Green, E.
„	5 MP.	— Harben, 124, High Street, Peckham, S.W.
„	5 MP.	F. C. Faulkner, 16, Edwell St., Long Acre, W.C.
LONGTON	5 MP.	F. Barlow, Spring Garden Road.
„	5 MP.	H. Barlow, Chemist.
LOUTH	3½	East Brothers.
MAIDSTONE	2	Maskell & Son, St. Peter Street.
MANCHESTER	3½	B. Sykes, 30, Rosamond Street.
„	3½	Central Tea and Coffee House Co., Mosley Street.
„	2	— Dyson, Temperance Street.
„	1	Whitehead & Co., 81, Rusholme Road.
„	½	Joseph Wood, 23, Southall Street, Strangeways.
„	½	Stephen Chesters, Ashton Old Road.
„	½	S. Bradbury & Son, Ashton Old Road.
„	½	M. Davies, 58, Gt. Bridgewater Street, Gaythorn.
„	½	J. Pratt & Son, 58, Leigh St. East, Oldham Rd.
„	½	Dan Rylands, Blake Street, Stretford Road.
MITCHAM	1	J. W. Ferneley.
MONTROSE	½	D. Lackie, High Street.
NEWBURY (Berks).	1	Hickman & Sons.
NEWCASTLE-ON-TYNE	3½	John Powton, 43, Stowell Street.
„	2	G. Elland, 5, Cross Street.
„	2	William Rowe, Stowell Street.
„	2	Thomas Bradford & Co., Mineral Water Manufacturers, Scotswood Road.
„	2	R. Wightman, Pilgrim Street.
„	½	W. Glendenning, Granger Street.
„	½	R. Emmerson, Junr., 98, Scotswood Road.
NEWORTH	½	Caproon, Hankey & Co.
NEWPORT (Mon)..	½	H. L. Williams, Rodney Wharf.
NEWTON ABBOT ..	½	(Vert.) Ross & Co.
NORTHALLERTON .	½	W. Bell.
OBAN	1	D. McCall & Co.
OXFORD	1	Jones Brothers, Castle Street.
„	½	Oxford Wine Co., 3, St. Aidates.
„	½	J. Jessop, St. Giles.
„	5 MP.	H. G. Varney, 71, High Street.
PENRITH	½	J. B. Thwaites, Mineral Water Manufacturer. Costs under ½d. per hour for gas at 3/9 per 1,000.
PEMBROKE DOCK ..	2	S. B. Sketch, Bufferland.
PLYMOUTH	3½	R. Lake & Co., 45, Gibbon Street.
„	3½	Donneford & Son.
„	½	Whitmarsh & Son.
PORTSMOUTH	½	Webb & Salmon.
PRESTON	2	Preston Aërated Water Co.
RAMSGATE	3½	S. G. Philpott, High Street.
„	1	S. Daniel, Harbour Street.
READING	1	F. Tunbridge, 29, Castle Street.
REDDITCH	1	Smith & Co., Soda Water Manufacturers.
RICKMANSWORTH..	5 MP.	Franklin Bros., High Street.
ROCHESTER	½	R. Merrett, Cow Lane.
ROSS	½	Alton Court Brewery Co.
RUNCORN	½	Isaac Stubbs, Lowland Road.
SALISBURY	1	R. E. Hardy.
„	1	Henry Martin, 162, Castle Street.
SHEFFIELD	½	Herbert Holding, Twelve o'Clock Inn.
„	½	A. & C. Darwent, Swinton.
„	½	W. Oxley, 18, Ersham Street, Spittall Hill.
SHEERNESS	½	W. T. Dutnall, Richmond Street.
SHREWSBURY	½	J. Hughes, 16, New Park Street.
SITTINGBOURNE ..	½	W. D. & W. J. Jackson, Aërated Water Manufacturers.
SKIPTON	3½	Henry Willis, High St., Ale and Porter Merchant.
„	2	Spencer, Gill & Smith, High Street.
„	½	Wright Brothers, Raikes Road.
SMETHWICK	5 MP.	Malvern Mineral Water Co.
SOUTHEND	5 MP.	W. Hammond, London Road.
SOUTHPORT	1	Preston & Co., Stanley Street.
„	½	Southport Aërated Water Co. Limited, 58, Virginia St.
„	½	Eau de Soda Co.
SOUTH SHIELDS ..	2	Geo. Steele, 1, Beswick Street.
„ ..	2	Jas. Grieves, Ingham Street.
ST. IVES	3½	Jas. Wordsworth, St. Ives Manor House.
STRATFORD-ON-AVON	1	New & Son, Bridge Street.
SUNDERLAND	½	William Laing & Co., 254, High Street.
„	½	H. Carns, 11, Lambton Street.
„	½	T. Kirkeep, 22, Lambton Street.
SWINTON	2	Morris & Son.
TORQUAY	3½	Shapley & Austin, 2, Strand. Cost of gas about 1/- per day, working 10 hours regularly.
„	1	Hearder & Grimshaw.
TOTTENHAM	2	Wm. Brown, 1, Church Road.
„	½	Needham, Red House.
TULLAMORE	½	J. L. Stirling.
UCKFIELD	1	B. Salter, Chemist.
ULVERSTONE	½	— Hodgson, Fountain Street.
WALLINGFORD ..	½	E. Wells, Wallingford Brewery.
WEST HARTLEPOOL	½	Metcalf & Young, Whitby Street.
WHITBY	2	J. Stevenson.
WHITEHAVEN	2	Emerdale Aërated Water Co.
„	1	W. F. & H. Hunter.
WHITSTABLE (Kent)	½	— Coleman, Soda Water Works.
WIMBLEDON	½	C. Garcia & Co., Syrup Manufacturers.
WINDERMERE	½	J. Kendal.

BOTTLE WASHING.

	HP.	
BIRKENHEAD	2	Mackie & Gladstone, 88, Hamilton Street. Also Hoisting, Hay Cutting, &c.
BIRMINGHAM	6	Birmingham Coffee House Co., Bull Ring.
„	½	Barrett & Ellers, Johnson Street, Ladywood.
BLACKBURN	5 MP.	W. Smith, 9, Town Hall Street.
BRADFORD	2	Waller & Smith.
„	½	J. Lupton & Sons, 9, Cheapside.
BRISTOL	5 MP.	Dunlop, Mackie & Co.
GLASGOW	5 MP.	Sanderson & Morrison, 138, High Street.
HULL	½	T. Lindsey, Dagger Lane. Bottle Washing.
LEEDS	1	H. Coubrough & Co., Neville Street.
LEITH	5 MP.	W. J. Grieg, Bottler, Hillhousefield.
LIVERPOOL	2	Mackie & Gladstone, South Castle Street.
LONDON	3½	Dawkes & Co., Aubin Street, Waterloo Rd., S.E.
„	2	J. F. Biggs & Co., 76, Ludgate Hill, E.C.
„	½	Barrett's Screw Stopper Bottling Co., St. Pancras Station, N.
„	½	H. Barrett, 21, Charterhouse Buildings, Goswell Road, E.C.
„	½	H. J. Roydant & Co., 16, Effia Rd., Brixton, S.W.
„	5 MP.	John P. Barradale, 41, Lisson Grove, N.W.
MANCHESTER	½	Barrett's Screw Stopper Co., Central Station Arches, Watson Street, Peter Street.
NEWCASTLE-ON-TYNE	½	W. Glendenning, Granger Street. And Soda Water Machinery.
NORTH SHIELDS ..	1	Carr Bros. & Carr, Bottling Stores, Low Light Brewery.
QUEENSTOWN	½	F. Nolan, 17, Beech. And Grocers' Machinery.
SHEFFIELD	2	Duncan, Gilmore & Co., Queen Street.
„	1	Duncan, Gilmore & Co., Wine and Spirit Merchants.
STIRLING	8	D. & J. MacEwan. Also driving Hoists, Chaff Cutters, &c.
TORQUAY	1	Hearder & Grimshaw, Victoria Parade. Two Bottling Machines.
WOODBRIDGE	3½	H. Edwards & Son, Wine Merchants. Also Chaff Cutting.

NOTE.—*Many of the firms in the list of* "AERATED WATER MANUFACTURERS AND BREWERS" *also use their Engines for driving Bottle Washing Machines.*

Selection of Testimonials

FROM USERS OF

THE "OTTO" GAS ENGINE

FOR DRIVING

Electric Light Machinery.

CROSSLEY BROTHERS Limited, Engineers, MANCHESTER.

16-HP. ELECTRIC LIGHT INSTALLATION AT THE THEATRE ROYAL, BIRMINGHAM.

(Put down under the superintendence of Henry Lea, Esq., M.I.M.E., 38, Bennett's Hill, Birmingham.)

Engine, 16-HP. Dynamo 300 light Ferranti alternate current machine, with Siemens' Exciter. Speed, 900 revolutions per minute.

Lamps, 220. 110 volt Swan lamps, placed principally in auditorium, vestibules, and corridors. A few only used on stage.

Direct Lighting.

Light remarkably steady. Control of light from prompt side exclusively. No adjustments made in Engine room. Engine will run the full number of lamps and governs itself admirably. Ferranti dynamo is practically self-regulating. Hot bearings are unknown.

Arc light.—Small Siemen's dynamo and arc light occasionally used, driven from same Engine.

16-HP. ELECTRIC LIGHT INSTALLATION AT THE PRINCE OF WALES' THEATRE, BIRMINGHAM.

(Put down under the superintendence of Henry Lea, Esq., M.I.M.E., 38, Bennett's Hill, Birmingham.)

Engine, 16-HP. Dynamos and connections similar to those at the Theatre Royal.

Lamps, 200. 100 volt Swan lamps solely in auditorium and accessories.

Arc lighting—Burgin arc lighting machine, by Crompton & Co., and two Crompton-Crabbe arc lamps over porticos in Broad Street.

Results much the same as at the Theatre Royal. *(See above.)*

During recent alterations of the Stage, in which the roof was removed and raised, the arc lighting was diverted, and was found of great utility to enable the work to be carried on all night.

16-HP. DRAPERY & FURNISHING ESTABLISHMENT.

Angel Street and Castle Street, Sheffield, August 6th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 16-HP. "Otto" Gas Engine you supplied to me is regularly working my Electrical Installation, and I have not lost, by any fault of the Engine, more than a few hours during the last three-and-a-half years. It works two pairs of Siemens' Exciter and Dynamo Machines, viz., W 1, D 7, and W 2, D 6, which supply eighteen 400-candle power arc lamps, and 150 20-candle power incandescent lamps.

When working the larger pair of machines for lighting the inside of my premises about 600 feet of gas is consumed per hour, and when working the entire installation (which requires an actual force of fully 35 HP., exclusive of the amount used in the Engine itself), it consumes about 800 ft. of gas per hour, which is, I believe, a less cost than would be the cost of coal or coke for a steam engine of the size I should require; while I have not the dirt, heat, smoke, and danger to property, life, and limb, and attendance, which seem to be inseparable from steam engines.

I can also any time have my Engine started after a few minutes' warning. I may further add that the cost of repairs so far is almost *nil.*

I have great pleasure in sending the above information and expressing my general satisfaction. You are at liberty to make any use you think proper of this letter. I am, Gentlemen, yours truly,

G. H. HOVEY.

16-HP. DRAPERY & HOSIERY ESTABLISHMENT.

33 *to* 39, *Westborough, Scarborough, August 2nd,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—Your Engine, which is 16-HP., has been in use for about five years working a 200-Light Siemens' Dynamo. We have on the circuit 212 Edison-Swan lights, mainly of 16-candle power. On the whole, we think Gas Engines are well adapted for Electric Lighting, on account of their cleanliness and simplicity of working. One of our men, who had had no previous experience, has attended to it from the beginning.

Yours truly, W. ROWNTREE & SONS.

12-HP. *Borough Engineer's Office, Municipal Buildings, Leeds, August 4th,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to yours of the 30th ult., I have pleasure in handing you the following information, which you can use in any way you please:—

We have here two of your 12-HP. (nominal) Gas Engines driving two Dynamos for incandescent lighting in the Public Free Library, the lamps being driven direct from the dynamos.

We have at various times indicated the Engines, and find them to indicate 28 HP. each. The Engines are fitted with your self-starting apparatus, and we have lately made the necessary additions for coupling the two Engines, and find them to run well and very steadily together.

When driving the incandescent lamps the Engines run at their normal speed, but we have obtained very good results (for charging accumulators, &c.) when running at various speeds.

The dynamos are 200-light, "Phœnix" compound wound dynamos, each capable of developing 14,000 volts. When the lamps are running in the ordinary way each dynamo and Engine maintain 142 20-candle power lamps, with an out-put of about 10,000 watts 13·4 HP.

Any further information I shall be glad to supply.

Yours truly,

THOS. HEWSON, M.I.C.E.

12-HP. DRAPERY ESTABLISHMENT.

2, 4, 6, 10 & 10a, King's Road, and 5, 7, 9, 11, 13 & 15, Symons Street, Sloane Square, Chelsea, London, S.W., July 31st, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We use two of your "Otto" Gas Engines, 12-HP., and five Burgin's Patent Dynamos, driving 130 40-candle power Incandescent Lamps. Yours truly, PETER R. JONES.

P.S.—I may add that your Engines have given every satisfaction, and very probably I shall require another one before long.—P.J.

12-HP.

65 and 67, Ludgate Hill, London, March 11th, 1881.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We have much pleasure in testifying to the efficiency of the 12-HP. "Otto" Gas Engine that we are using as motive power for the Electric Light. The Engine is all that can be required both as to cleanliness and economy. Your truly,

SAMUEL BROTHERS.

9-HP. PROVISION MERCHANT.

137 & 139, Woodhouse Lane, Leeds, August 18th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to yours of 30th ult., the Gas Engine you supplied me with drives a Crompton dynamo of 100 lights, 20-candle power each, seventy of which are in regular use, and run perfectly steady and satisfactory in all respects. The Engine also drives at the same time two Sausage Machines, the light being equally steady when all are in use as when driving the dynamo only. Yours faithfully,

R. WOOD.

9-HP. ELECTRIC LIGHT INSTALLATION AT THE BIRMINGHAM ART GALLERY.

(Messrs. Chamberlain and Hookham, West Bromwich, Engineers.)

Engine, 9-HP. nominal, capable of indicating 18-HP.; actual indication, about 13-HP.

Dynamo, Chamberlain and Hookham's patent.

Lamps, one hundred 16-candle power nominal "Swan."

Remarks: The lamps are arranged in a novel manner, forming a single ring about 7 ft. diameter, and being backed up by silvered glass reflectors. They replace a sun burner which consumed 800 ft. of gas per hour, as compared with 270 ft. per hour consumed by the Gas Engine, and give at least three times as much light on the pictures.

(Signed) CHAMBERLAIN & HOOKHAM LIMITED,
West Bromwich.

TWIN 4-HP.

36, Victoria Street,
Works:—3, Sir Thomas's Buildings, Liverpool.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—*Re* our Twin Cylinder 4-HP. nominal, indicating 15 HP. This is driving on our premises two Phœnix Dynamos, which supply 102 20-candle power Edison-Swan lamps. Fifty-six of these are fitted on the premises of Messrs. Bennett Bros., Victoria Street, for the purpose of lighting their show windows; six are lighting a billiard table at Mr. Jas. Ashcroft's; the remainder being on our own premises. The above positions of lamps require extreme steadiness in driving, and the engine does the work admirably.

We are also quite satisfied that the cost of gas used is not half which would be burnt through same number of gas jets to give equal illumination.

Yours truly, PERRY & COX.

8-HP. *Oakworth House, Keighley, August 5th, 1886.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—Mr. Holden directs me to own receipt by him of your letter of 30th ult., and in reply thereto to give you the following particulars with respect to his Electric Light Apparatus.

He has two Dynamos, which are both driven (separately) by the 8-HP. "Otto" Gas Engine you supplied. One Dynamo is the Brush Patent, yielding light to his winter garden, 148 feet long, 90 feet wide, and 40 feet high, by means of six large arc lamps, of 2,000-candle power each. This Dynamo the Engine has to work while the light is required, and the light produced is quite satisfactory.

The other Dynamo is Crompton's Patent, and yields light to the mansion. The electricity from this machine, running when the arc lights are not in use, is stored in a battery of 110 accumulator cells, supplying 150 incandescent lamps, of 16 to 20-candle power each, which supply light to the hall, corridors, and rooms of the mansion.

I am, dear Sirs, yours truly, *p.* ISAAC HOLDEN,
JAMES FIRTH, *Secretary.*

8-HP. *Engineer's Department, St. James's Gate Brewery, Dublin, July 31st, 1886.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to yours of 30th inst., we have pleasure in giving you the information you ask, and have no objection to your publishing the same. Our "Otto" Gas Engine is a single one, 9-in. diameter, 16-in. stroke, and it works during the winter months only, driving two Dynamos, each Siemen's Ds machines. Each machine is connected to one of Siemen's arc lamps (smallest size), giving nominally 2,000-candle power each.

Yours truly, S. GEOGHEGAN.
p. G. H. S.

8-HP. *The Newport Alexandra Dock Company, Limited, Newport, Mon., August 4th, 1886.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your letter I beg to say we have two of your "Otto" Gas Engines, 8-HP. each, driving two Dynamo Machines, each revolving 720 revolutions per minute. Our lamps (arcs), three in number, are equal to 6,000-candle power each; but only one Engine will work one lamp at a time.

The Engines are working from dark to daylight, and have been in use about eight years, during which time we have had no trouble with them whatever; nothing but the usual repairs for ordinary wear and tear having been done to them. I am, dear Sirs, yours truly,

C. H. NOBLE.

8-HP. *Royal Institution of Great Britain, London, Nov. 12th, 1880.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I very willingly certify that the performance of the 8-HP. Gas Engine in the Royal Institution has been in the *highest degree satisfactory.*

My reply to your note has been deferred by my desire to learn from my colleague, Professor Dewar (who has had great experience of the Engine), his opinion of its merits. During a long series of investigations in which he has been engaged, and by which the engine has been very thoroughly tested, its performance has been all that could be desired.

Yours truly, JOHN TYNDALL.

8-HP. *South Kensington Museum, Science and Art Department, London, S.W., March 14th, 1881.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I am directed to acknowledge the receipt of your letter of the 10th inst., and in reply to inform you that the Gas Engine (8 HP.) therein referred to has given satisfaction.

I am, Gentlemen, your obedient servant,

G. F. DUNSCOMBE.

8-HP. *The "Van der Weyde Light" Studios, London and Paris, 182, Regent Street, March 15th, 1878.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to your request, that I should state how I like the 8-HP. Engine you put up for me some six months ago, I have great pleasure in being able to pronounce it a *brilliant success.* It has been driving my Electric apparatus at an average of ten hours a day ever since, and, instead of being the worse, seems to go the better for wear and tear.

Yours very truly,

HENRY VAN DER WEYDE.

8-HP. *114, 116, 118, and 120, Regent Street, London, W., March 15th, 1881.*

Messrs. Crossley Brothers, Limited.

Gentlemen,—We have pleasure in saying that the 8-HP. "Otto" Engine with which you supplied us in 1878 has given *great satisfaction.* It works one large Serrin Lamp and four Jablochoff Candles, needs little attention, and has a great regularity of speed, a very important point in Electric lighting.

Remaining, Gentlemen, yours faithfully,

H. J. NICOLL.

6-HP. *Opera House, Leicester.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 6-HP. "Otto" Gas Engine supplied to me by you is used for working Brush Dynamo, 6,000-candle power; six Arc Brush Lamps, 1,000-candle power each. It also works two lamps of the same kind (but not at the same time) at T. T. Paget's Bank, High Street. Works off fly-wheel direct on to dynamo. The Engine has been in use for 3½ years without a hitch of any description. If you wish you can publish this.

Yours, &c.,

ELLIOTT GALER,

per J. CLARKE, *Electrician.*

6-HP. *Gateshead Industrial Co-operative Society Limited, Jackson Street, Gateshead-on-Tyne, Aug. 10th, 1886.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to yours of the 7th inst., I beg to state that the Electric Lighting on our premises is worked by a 6-HP. "Otto" Gas Engine. We have seven large arc lamps, six inside and one outside. Nothing, in our opinion, could be more satisfactory than the way in which the Engine does its work.

Yours truly,

JAS. JOHNSON, *Manager.*

6-HP. *Hull, August 3rd, 1886.*

Messrs Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to your favour, we are using a Ferranti Dynamo, 55 volts, 150 ampères, 1,512 revolutions, and a Siemens' Exciter, in connection with the 6 HP. Engine you supplied us with, and find we can run sixty 20-candle power lamps to burn brilliantly.

Yours truly,

BARNETT & SCOTT, *Jewellers.*

4-HP. *Scotland Street Iron Works, Glasgow, August 18th, 1886.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—In reply to yours of 30th July, the 4-HP. "Otto" Gas Engine you fitted up at my house last winter has continued to give me full satisfaction. Its first duty was a 20-hour run without stop, which it did well. It drives a dynamo of Gramme type direct from fly-wheel, charging at the rate of 40 to 45 ampères, a storage battery and the approximate average consumption of gas is 100 cubic feet per hour. When lighting direct from dynamo, it keeps fifty lamps of 20-candle power in good glow. The mechanical detail of the Engine is admirably designed and executed.

I am, yours truly,

WILLIAM RENNY WATSON.

3½-HP. *28, George Square, Edinburgh, October 19th, 1878.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In answer to yours of the 17th, I can only say that so far as I have yet tried the 3½-HP. Gas Engine which you recently set up for me, it has worked to my entire satisfaction. It gives, from a Gramme Engine, *an exceedingly steady light,* quite as good as I used to obtain from sixty large Bunsen cells. It is very easy to work with, and its cost (as far as gas goes) is a mere trifle. I have not, however, had it in use long enough to be able to say whether it is easily kept in order. All I can as yet say on that point is that I have hitherto found no difficulty.

I am, Gentlemen, your obedient servant,

P. G. TAIT,

Professor of Natural Philosophy in the University of Edinburgh.

N.B.—Professor Tait has since put down a second Engine of 4-HP. (Twin) nominal.—C. B. Ltd.

3½-HP. *17 and 18, Bear Alley, Farringdon Street, London, August 4th, 1881.*

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—The 3½ HP. "Otto," purchased of you by Mr. Stewart, is used to drive the Siemens' Electric machine for photography, and we believe, answers its purpose admirably.

Yours truly,

A. S. CATTELL & CO.

3½-HP. *Knighton Spinneys, Leicester, October 23, 1886.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—My Engine is of 3½-HP., and drives an Elwell Parker Dynamo to my entire satisfaction. I use accumulators, and have about 80 lamps, 16 and 8 candle power; but 48 to 50 is about the average number used at one time.

Yours, &c.,

J. GODDARD, F.R.I.B.A.

2-HP. ELECTRIC LIGHT INSTALLATION AT MR. F. W. V. MITCHELL'S, EDGBASTON, BIRMINGHAM.

(Put down under the superintendence of Henry Lea, Esq., M.I.M.E., 38, Bennett's Hill, Birmingham.)

Engine, 2-HP. Dynamo, 2 unit shunt, with wrought iron magnets by Crompton & Co. Speed, 1,400 revolutions per minute.

Storage batteries, 24 E. P. S., 23 L. cells, of which 21 or 22 are usually connected, and the remainder kept charged as spares.

Total lamps now 30. 42 volt Swan lamps.

Some of these lamps are fixed in the billiard room of another residence about 150 yards away, in a parallel road, the leads being drawn into glazed pipes laid through the two gardens, the ends of which abut upon each other.

The gardener attends to the installation.

2-HP. ELECTRIC LIGHT INSTALLATION AT MR. A. C. MITCHELL'S, CHISELHURST.

(Put down under the superintendence of Henry Lea, Esq., M.I.M.E., 38, Bennett's Hill, Birmingham.)

Engine, 2-HP. Dynamo, 2 unit compound, by Crompton. Lamps, 38. 110 volt Swan lamp.

Specialties, an electro magnetic arrangement by H. Lea for stopping the Engine from a bedroom or landing, by pressing a button, whereby a portion of the current is made to shut off the gas.

Another specialty is a 6-light combination billiard pendant by R. W. Winfield & Co., in which, by an arrangement devised by H. Lea, the incandescent lamps can be swivelled in a vertical plane, so as to lie outside the cardboard shades, and the ordinary gas burners can then be lighted. In either case the source of light occupies the same position within the shade, which is an important matter. The change can be effected in a minute or two.

2-HP. *Broomfield, Derby, July 31st,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Sirs,—The Dynamo which my 2-HP. Engine drives is an Elwell Parker 8-in. compound wound, giving 30 ampères, 80 volts, speed *about* 1,500 per minute; the Engine runs at 170. There are two 54-in. fly-wheels on the engine, and the pulley on dynamo is 6-in., and is driven from one of the fly-wheels. There is a disc cast on the dynamo pulley, and by allowing a little slip in the belt the light is perfectly steady. I light *regularly* fourteen lamps. The most I have ever lighted at once is twenty-five, which number *did not take all the power.* The lamps are 80 volts, 20-candle power, made by Woodhouse and Rawson. The dynamo is supposed to give enough current at 1,460 revolutions per minute; but owing to the loss in cable, I have to run it at a rather higher speed. The lamps are 150 yards from the dynamo. The cable consists of fourteen No. 16 copper wires for 100 yards, and about fifty yards of seven No. 16 wires. Since I started this Engine on January 1st this year, I have never had the least trouble with either Engine or dynamo. In the winter I used to start the Engine after oiling all over, and leave it entirely alone for from six to eight hours, and when I stopped it I never found the bearings of either Engine or dynamo hot, or anything to indicate that they might not have been left even longer without attention., Yours truly,

C. L. SCHWIND.

1-HP. JEWELLER'S ESTABLISHMENT.

63 *and* 65, *Market Street, Lancaster.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—Our 1-HP. "Otto" drives a Gramme Dynamo, and fills eighteen 20-candle power incandescent lamps, lighting up our shop. We do not use accumulators, but drive direct; and by having a solid disc on shaft of dynamo, and a loose belt, we get a very steady light, entirely free from any pulsation. Yours, &c.,

BELL & ATKINSON.

½-HP. *(New) King Street, Belfast, August 5th,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—In reply to your inquiry respecting the Electric Light in my private house, the power is supplied by one of your ½-HP. (modern) Gas Engines, horizontal type, made about two years ago. The dynamo machine is one of my own construction, of modified Gramme pattern; shunt wound magnets, giving 54 volts at 1,450 revolutions. The armature is of small diameter. Running the lamps direct, we have had nine of 16-candle power and three of 10-candle power, all on at one time.

Since October I have been using accumulators, the E. P. S. type; they are most useful. We charge these up for ordinary use, and they supply current at times when the Engine is not running, besides supplementing the capacity for special occasions; as by charging up the battery during the day, we have had as many as sixteen lamps of 16-candle power and four lamps of 10-candle power, each lighted at the same time. The battery consists of 24 cells, having 11 plates in each, its storage capacity being 75 ampères. If I can give you any further information I shall be very glad.

I may state, in conclusion, that after two years' experience of the light in my house, I find the cost for gas used by the Engine, oil, waste, repairs, renewal of lamps, and other incidental expenses in connection with the Electric Light, is slightly less than an equal light obtained direct from the gas would amount to. Hence the interest on the first outlay is practically what the electric costs in *excess* of lighting by gas. There are many advantages in connection with the Electric Light which are so well known that it is not necessary to mention them here. I have not debited anything for attendance, as I look after the installation, so far as starting the Engine and dynamo, when necessary. The other members of the household find no difficulty in working the lamps and switches.

Faithfully yours,

J. H. GREENHILL.

½-HP. 557, *Wakefield Road, Bradford, July 31st,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have been running one of your ½-HP. Engines for working one of Roper's Electrical Machines, with incandescent lamps, seven 30-candle power each, or sometimes one Arc Lamp of 1,000-candle power. The Engine has run very steady, and at a cost of 1½d. per hour in gas. If this will do you any good, you may use it. I shall always recommend your Engine wherever I have the chance.

I am, Gentlemen, yours truly,

W. K. PYRAH.

½-HP. *Stockton-on-Tees, August 3rd,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—The Dynamo that our Gas Engine drives is one made by my son, P. B. Blair. It supplies current to seventeen 10-candle power Swan lamps, which work to their full power. There is a small fly-wheel on the dynamo, and the light is perfectly steady.

The Gas Engine is also used to blow a two-manual Pipe Organ of 16 stops, which it does very satisfactorily.

I remain, yours truly,

G. Y. BLAIR.

½-HP. ELECTRIC LIGHT INSTALLATION AT MR. HENRY LEA'S, EDGBASTON, BIRMINGHAM.

Engine, ½-HP., indicating 1¾ HP. at 200 revolutions.

Dynamo, 25-light compound by Chamberlain & Hookham. Speed, 2,000 revolutions per minute.

Lamps, 15. 46 volt Swan lamps.

Lighting formerly direct, now from storage cells, the series coils of the magnets being simply disconnected.

Cells, 24 E.P.S.; 11 L.

Special sliding switch for making all necessary alterations in connections by movement of one handle.

Housemaid oils, starts, and stops the machinery. In summer the Engine is run every third or fourth day. In winter every day.

¾-HP. Vertical. *Heather Bank, Bradford, August 2nd,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have pleasure in saying that my Engine drives a Dynamo made by Messrs. J. Roper & Co., of Bradford, and is running twelve to fifteen 20-candle power lamps of 50 volts each, and I am in every way satisfied with its performance.

Yours truly,

FREDK. ILLINGWORTH.

5-MP.

36, *Victoria Street,*
Works:—3, *Sir Thomas's Buildings, Liverpool.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—The 5-MP. Vertical Engine has been engaged since the opening of the Liverpool Exhibition in Driving a Phœnix Dynamo, giving 50 volts and 12 ampères. This charges secondary batteries and enables us to have 20 lamps running at night.

The same type of Engine is also satisfactorily driving eighteen Swan Lamps in the billiard pavilion erected by Mr. Jas. Ashcroft in the grounds of the Exhibition.

A Battery of 18 E. P. S. Cells is used in connection with this installation, and the Engine runs these without any trouble whatever.

Yours truly,
PERRY & COX.

BRIGHTON ELECTRIC RAILWAY.

(Magnus Volk, Esq., Engineer.)

Some little time ago we were favoured by Mr. Magnus Volk with the following brief but interesting particulars respecting the above railway. The railway, which is a quarter of a mile in length, and having a grade (going out) of 1 in 100, commenced work on August 4th, 1883. From this period up to September 29th, 1883. there were in all 24,000 persons conveyed in the cars—about 10 or 12 passengers a time. The power is obtained from an "Otto" Engine of 2 HP. (nominal), driving one of Siemens' D 5 Machines. The gas bill during the above-mentioned period, *i.e.*, August 4th to September 29th, 1883, in running the Engine (working 10 hours per day, and making six journeys per hour) amounted to £4 12s., including that used for the slide lights, and one burner used to light the arch; cost of gas; 3s. 3d. per thousand cubic feet. Mr. Volk expresses himself highly satisfied with the Engine.

Since the above was first published an Engine of greater power, *i.e.*, 12-HP. nominal, has been substituted, and the line extended to one mile in length. This Engine drives two cars seating thirty persons each; cost of gas at 3/3 per 1,000 cubic feet, 11d. per hour.

RYDE PIER ELECTRIC RAILWAY.

Gas Works, Ryde, Isle of Wight, October 22nd, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—This Railway has been in successful operation for eight months. The plant for working the ordinary tram-cars on the Ryde Pier Railway, about half a mile in length, was put down by Messrs. Siemens Brothers, of London; the prime motor being a 12-HP. "Otto" Gas Engine, fitted with self-starter, anti-fluctuator, and all the latest improvements by your Company. The Engine is connected by a leather link-belt to a Siemens' Dynamo, revolving at the rate of about 1,000 times per minute, and gives an electrical power of 60 ampères, 120 volts. These, together with the 100-light Cowan's dry gas meter, &c., are handsomely finished and enclosed in an ornamental engine-house, glazed all round with plate-glass, forming a strikingly elegant structure, open to the inspection of the public near the Pier gates. From the dynamo the current is conveyed by cable to the positive conductor of inverted channel iron, running alongside the railway, and supported at a height of 12 inches by insulated standards attached to the sleepers. The ordinary rails are used for the return current. They are made of steel, and joined by iron connections electrically welded to them. A motor is fixed under one of the cars, and an arm, carrying a spring-contact, extends from this to the positive conductor. Each train consists of two ordinary tram-carts capable of carrying from 13 to 15 tons, including the carriages, and travels from 10 to 12 miles per hour. Each journey is effected in 2½ minutes at a cost of less than 1d. for gas. On the occasion of the last Bank Holiday the Engine was kept running for 12 hours, and carried 3,400 passengers, with a consumption of 2,800 cubic feet of gas. The Engine is working better than ever, requiring only *cleanliness* and careful lubrication.

I believe this installation of the electric transmission of power is unique, whilst the cost of working is less than horse power, and the work actually done more than double.

Yours faithfully,
GEORGE GARNETT, M. Inst. C.E.

PRESS EXTRACTS.

DOMESTIC ELECTRIC LIGHTING.

The following account of a complete system of domestic electric lighting is given in *Engineering*:—

Lauriston House, Bromley, the residence of Mr. Swan, is lighted throughout with electricity, and forms one of the most interesting private installations yet made. It is remarkable for its completeness, every room and closet being lighted by the current—even the coal cellars and the gate lamps. The lights are all commanded by small switches, suitably placed so that a person entering a room, say a bedroom or a closet, can light it up before going, and darken it on leaving again. The switches for this purpose are placed near the doors, either outside or just within. Again, if a light is wanted at the toilet table or writing desk, it can be had in a moment by touching the proper switch. One of the beds has a reading lamp just over the pillows for an invalid who desires to read, and the switch is ready to his hand. The gate lamps are controlled by switches in the engine-house. The drawing-room is lighted by three very elegant chandeliers made by Farady. They are of brasswork, and each holds six lamps shaded with blue glass cups. The lamps are controlled by switches, one for each chandelier, fitted into the wall. Besides this there are six wall bracket lamps with crystal reflectors behind. Both here and in the dining-room, indeed throughout the whole house, the lamps are fitted up with great taste, and at the same time economy. In the dining-room the chandeliers and brackets are by Elkington, the globes being of the new crinkled glass, which has a very pretty effect like rough ice. The filaments in all cases, except where naked lights are used in the cellars, are quite shaded from the eye by the ground glass or crinkled globes. In the drawing-room this effect is produced by having the bulbs themselves of ground glass. The dining-room table is further lighted by two brass standard lamps which are placed on it when required, and connected by wires through the tablecloth, table, and floor. These connections are made by bodkins running through the tablecloth into the table. Moreover, a large Japanese calabash filled with roses and used as a centrepiece has several lamps hid amongst the flowers; and these are lighted up in the same way, producing a very pretty effect, the lamps resembling yellow roses. An artificial lemon tree has its fruit lighted internally in the same way. By means of a small Thompson motor Mr. Swan also employs the current from a lamp at will to drive a sewing machine or coffee mill. Light for candles, or fire for the cigar is also obtained from the lamp's current by means of a small device invented by Mr. J. E. H. Gordon. This consists of an ebonite handle, with a disc guard, like a dagger haft, and having in front of the disc, where the blade should be, a spiral of bare platinum wire surrounding a plug of fireclay. When the current from a lamp is sent through this wire by means of insulated wires running through the haft, the platinum gets heated up and light can be obtained from it. There are between sixty and seventy lights on Mr. Swan's premises, including two in the engine-house. They are supplied by two "Otto" Gas Engines, each of ½-HP. nominal, but capable of developing 2-HP. Each drives a Siemen's continuous current dynamo of the smallest size, and thirty Faure-Sellon-Volkmar accumulators are charged for an hour before the lighting begins. These accumulators serve to supply extra lamps when wanted, the two dynamos only supplying thirty lamps when running on them alone. The accumulators can be kept partially charged by a bye circuit while the machines are running. They maintain the extra lamps required on special occasions, and also yield occasional lights during day. The Engines consume 75 cubic feet of gas per hour, and this expended in gas lighting would give thirty gas jets of 15-candle power; but the electric lights are rather over 15 candles (they are 20-candle lamps), and the light is far more pure, agreeable, and healthy.

N.B.—The plant has since been enlarged, and a 3½-HP. "Otto" Engine substituted.—C. B. Ltd.

ELECTRIC LIGHTING.

The adaptability of electricity to all purposes of domestic lighting has just received the fullest illustration at the house of Lord Randolph Churchill, in Connaught-place. In every part of the house, from top to bottom, wherever gas is ordinarily used, the Electric Light has been introduced with the most satisfactory and literally brilliant effect. There are 105 "Swan" incandescent lamps distributed through the building, supplied from an "Otto" Gas Engine of 3½-HP., working in conjunction with 35 Sellon-Volkmar accumulators. When the latter are fully charged they are competent to supply most of the lamps in the house for 10 or 12 hours without the aid of the Engine. The machine for generating the electricity is a Crompton-Bürgin dynamo machine, of the self-regulating type, so that the whole or any number of lights may be turned on or off at pleasure. The Engine and machine are placed in the basement, which extends a short distance under the road. No inconvenience is experienced from their working, and their propinquity would scarcely be suspected in either dining or drawing-room. A large portion of the brackets, standards, and other fittings have been specially designed to suit the electric light, but a chandelier and a couple of candelabra have been adapted from their previous uses. In the study and library are reading lamps, which can be moved about with much greater facility than oil, gas, or candle; while the lights in the boudoir, shaded with opal glass, produce an effect which no other illuminating power could rival. Without giving further details, it may be said generally that the lights are adapted throughout the house to the different requirements of the various rooms, at the entrance to which a small switch is fixed by which the electric power is turned on or off at pleasure. All the wires are very carefully insulated, and in no case obtrude upon the sight, while safety fuses provide against overheating. The work has been carried out by the Crompton-Winfield Association on behalf of the Incandescent Electric Lighting Company, which has been formed for the purpose of supplying the Electric Light from central stations, and also of enabling private occupiers to set up or "instal," as it is technically termed, the entire machinery and apparatus for themselves.—*Morning Post.*

N.B.—This plant has since been enlarged, and a 6-HP. "Otto" substituted.—C. B. Ltd.

ELECTRIC LIGHTING IN NEWCASTLE.

We have to-day to record a highly interesting and successful installation of electric lighting at the residence of W. H. Holmes, Esq., Wellburn, Jesmond, which has been carried out by Messrs. J. H. Holmes & Co., electrical engineers, 67, Westgate Road, Newcastle, in a manner that would be a credit to any firm in the electrical business. The installation consists of 40 incandescent lights. The lamps are made by the Swan Co. The power is supplied by one of Crossley's ½-horse Gas Engines, driving one of Siemens' S D 5 Dynamo machines, supplemented by 22 Faure-Sellon-Volkmar secondary batteries, each consisting of 16 lead plates 10 by 12 inches. The entrance hall is lighted by two 12-candle lamps in an ordinary coloured glass case with brass frames, and the interior hall is lighted in a similar way. The library is lighted by five 12-candle lamps, with their bulbs ground so as not to dazzle the eyes; they being arranged in an electrolier, and the effect is piquant and cheerful. In the same way the drawing-room is lighted by ten 12-candle lamps in two beautiful circles, one five inches above the other with gay Venetian glass flowers of delicate colour hanging over each, the dining-room more soberly with five 20-candle obscured moons. On the landing of the staircase there was a single 20-candle lamp in a rich flower of Venetian glass, and each of the bedrooms was immediately lit up as you entered; the dressing-rooms opening into them did not require this arrangement, you could see your way to go and turn on the old gas tap that now turned on the electric light.

We cannot speak too highly of this new method of lighting, nor of the taste and skill with which it has been carried out; but there is one important point we must mention, which to our mind outweighs even its beauty and convenience, and that is the sanitary improvement. There you have an absolutely unpolluted atmosphere to breathe, where plants will thrive and human beings be healthy, where ceilings will not be blackened, books and pictures destroyed, and curtains dirtied.

Surely this is a move in the right direction, which all who can should follow. The *engine room* was not utterly without interest, for here, too, cleanliness and order reigned. There was our old slave the gas toiling away at his engine, and the dynamo humming converting motion into electricity, and the rows of jars where it is converted into chemical action, to be given off again when wanted as electricity. On the switchboard where the delicate instrument for indicating the pressure and the current, the volt-meter registering the 45 volts of pressure that the lamps require, and the ammeter, the nine or ten ampères of current that were flowing from the dynamo, and the same from the secondary batteries along the parallel lines of wires and through the lamps between them, making the beautiful illuminations that we had just witnessed.—*Newcastle Examiner, Saturday, Sept. 7th,* 1884.

List of Users of the "OTTO" GAS ENGINE for Electric Lighting (ONLY).

For Engines driving Dynamos for Electro Plating, and for Experimental Purposes, see separate List.

Town.	Address	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
		HP.						
Aberdeen	Professor C. Niven, The College	3½	....	....	....	....	....	....
"	Sir W. S. Lewis, J.P., The Mordy	2	....	....	....	....	....	....
Alresford	H. Wood, Esq., Arlebury	4	....	....	....	....	....	Accumulators.
Ashton-under-Lyne	Abel Buckley, Esq., Ryecroft Hall	4	1	Victoria Incandescent Brush Electric Light Company	....	80	60 volt, 20-candle power	Accumulators.
Barrow-in-Furness	W. Postlethwaite, Grocer, Dulse Street	3½	....	....	....	....	....	Also used for driving grocer's machinery
Beaminster ..	John H. Fussell, Esq., Dannemora Cottage	½	1	Siemens S D 5	—	14	20-candle power, Woodhouse & Rawson	Also used for pumping, &c.

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
Belfast	Belfast Electric Appliances Company Limited	HP. 1	1	Newton dynamo	1	—	1,000-candle power arc lamp	....
,, ...	J. H. Greenhill, Esq., King St.	½	1	Dynamo of own make; "Gramme" pattern, shunt wound	—	12/20	Nine 16-candle power & three 10-candle power, or with accumulators sixteen 16-candle power & four 10-candle power	Battery of 24 cells, 11 plates in each, storage capacity, 75 lamp hours.
Birmingham ..	Theatre Royal, *per* Henry Lea, Esq., C.E.	16	2	300-light Ferranti alternate current, with Siemens exciter; speed, 900 revolutions	—	220	100 volt Swan lamps ..	In theatre auditorium, vestibule, and corridor, and a few on stage.
		—	1	Small Siemens dynamo	1	—	(used occasionally)....	....
..	Prince of Wales Theatre, *per* Henry Lea, Esq., C.E.	16	2	300-light Ferranti alternate current, with Siemens exciter; speed, 900 revolutions	—	200	100 volt Swan lamps ..	In theatre auditorium, vestibule, and corridor, and a few on stage.
		—	1	Crompton & Co.'s Burgin arc-light dynamo	2	—	"Crompton-Crabbe"..	Over porticos in Broad St.
..	The Art Gallery..............	9	1	7½ in. by 9 in. (8 unit nominal), Chamberlain and Hookham patent dynamo	—	120	20-candle power Swan lamps	Lights taken direct from dynamo.
,, ..	Lewis & Co., Bull Street	9	2	Jablochoff & Richardson's	14	—	2,000-candle power each	Arc lighting.
,, ..	G. H. Kenrick, Esq., Whetstone, Somerset Road, Edgbaston	7	1	6 in. by 7½ in. (5 unit nominal), Chamberlain and Hookham patent dynamo	—	55	20-candle power Swan lamps	Driving into accumulators, *i.e.*, set of twenty-six 23-light, E. P. S. Co.'s storage batteries.
,, ..	Smith & Chamberlain, New Bartholomew Street	6	....	....	—	—	....	....
,, ..	H. Chamberlain, Esq., Penryn, Somerset Road, Edgbaston	4	1	6 in. by 7½ in. (5 unit nominal), Chamberlain and Hookham patent dynamo	—	92	20-candle power Swan lamps	Driving into accumulators, *i.e.*, double set of 28 cells each, 23-light, storage batteries.
,, ..	G. E. Bellis, Esq., The Dell, Kingsnorton	4	1	Chamberlain & Hookham	—	—	....	....
,, ..	W. A. Albright, Esq., Mariemont, Edgbaston	2	1	2 unit Crompton	—	25	16 and 18 candle power lamps	....
,, ..	F. W. V. Mitchell, Esq., Hagley Road, Edgbaston, *per* H. Lea, Esq.	2	1	2 unit, shunt wound, with wrought iron magnets, Crompton & Co.; speed, 1,400 revolutions.	—	30	42 volt Swan lamps ..	Storage batteries, 24 E. P. S. & Co.'s 23-light cells.
..	Henry Lea, Esq., 38, Bennett's Hill	½	1	25-light compound dynamo, by Chamberlain & Hookham; speed 2,000 revolutions	—	15	46 volt Swan lamps ..	Storage batteries, 24 E. P. S. & Co.'s 11-light cells.
Bowdon	F. W. Crossley, Esq., Fairlie..	2	1	8-in. Elwell Parker dynamo	—	20	45 volt, 20-candle power lamps	Accumulators.
,, ...	W. J. Crossley, Esq., Glenfield	2	1	8-in. Elwell Parker dynamo	—	40	45 volt, 20-candle power lamps	Accumulators.
Braintree	— Courtauld, Esq., Bocking Place	3½	1	Elwell Parker	—	62	16 and 10 candle power lamps	Accumulators.
Bradford	G. Thorpe & Co., Drapers, Tyrol Street	16	1	J. Roper & Co.'s dynamo	15	—	1,000-candle power arc	....
,, ...	F. Illingworth, Esq., Heather Bank	¼	1	J. Roper & Co., Bradford	—	12/15	20-candle power, 50 volts	....
,, ...	W. R. Pyrah, Esq., 557, Wakefield Road	½	1	J. Roper & Co., Bradford	1	or 7	Of 1,000 and 30 candle power respectively	....
Brandon (Norfolk)	W. A. Tysen-Amhurst, Didlington Hall	12	....	....	—	—	....	Accumulators.
Brighton......	Alderman Mayall, 91, King's Road	6	1	British Electric Light Co.'s dynamo	2	—	1,400-candle power....	Direct for photography.
,, ...	Volk's Electric Railway	12	....	....	—	—	....	Driving dynamo for Electric Railway

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
Bristol	Sir J. H. Greville Smythe, Bart., Ashton Court	HP. 6 twin	1	....	—	250	20 50-candle power.... 210 20- " .... 20 10- "	The lights are never all on at the same time.
"	Elliot Armstrong, Esq., Dardham Down	½	1	Elwell Parker 6-in. dynamo; speed, 1,750 revs.	—	10 to 12	20-candle power, Woodhouse & Rawson lamps	Accumulators.
"	J. W. Simpson, Esq...........	½	....	....	—	—	....	....
Bromley	J. W. Swan, Esq., Lauriston House	3½	1	....	—	—	Swan lamps, 55 volts, 44 ampères, 60 cubic feet of gas per hour	(*See Press Extract, p.* 5)
Chislehurst ..	A. C. Mitchell, Esq., Lime Villas, *per* H. Lea, Esq., C.E.	2	1	2 unit compound machine, by Crompton	—	38	110 volt Swan lamps ..	For billiard room, &c.
Church........	James Kerr, Esq., Dunkenhalgh, Rishton	3½	1	Siemens S B 7	—	92	100 volt Swan lamps ..	52 E. P. S. Co.'s accumulators.
Darwen	C. P. Huntingdon, Esq., Astley Bank	3½	1	Victoria..............	—	100	20-candle power	About 40 to 50 running at a time.
Derby	C. L. Schwind, Esq., Broomfield	2	1	Elwell Parker 8-in. compound wound, 30 ampères, 80 volts, speed 1,500	—	25	20-candle power, 80 volts, Woodhouse and Rawson	....
Dewsbury	Ledbetter & Co., Market Place	9	1	2 unit compound Crompton	—	56	16-candle power Edison Swan lamps	Lighting grocer's establishment
Didsbury......	H. P. Holt, Esq., The Cedars..	1½	1	2 unit shunt Crompton dynamo	—	} 80	} 20-candle power Swan, 50 volts	Charging 28 E. P. S. accumulators.
"	H. P. Holt, Esq., The Cedars..	1	1	2 unit shunt Crompton dynamo	—			Charging 28 Elwell Parker accumulators.
Dublin	E. Burk, Esq., Gortmore... ..	6 twin	2	Elwell Parker	—	—	....	Accumulators.
"	*Irish Times* Office	12	1	Siemens alternating dynamo	—	—	....	Driven direct.
"	A. Guinness, Sons & Co.	8	2	Siemens D3 machines	2	—	2,000-candle power each	....
"	Trinity College	3½	1	Gramme..............	1	—	....	....
"	Alliance Gas Company	3½	1	Gramme..............	1	—	....	....
"	J. Edmundson & Co., Capel Street	2	1	Elwell Parker shunt wound, 1 unit size	—	20	16-candle power	For shop windows and a model drawing room.
"	Royal College of Science	½	1	....	—	10	16-candle power	Accumulators.
Ealing	Andrew Common, Esq., 63, Eaton Lane	½	1	Siemens..............	—	—	....	Direct, and through accumulators. Used also for turning lathes for optical glass manufactory.
Edinburgh	Professor Tait, The College....	3½	...	....	—	—	....	....
"	Professor Ewart..	½	....	....	—	—	....	Lighting, and for experimental purposes.
....	W. D. Hart, The Observatory, Castle Hill	½	{ 1	Gramme machine, 11½ ampères, 25 volts	1	or 9	1,010-candle power and 15-candle power respectively	} Only one machine in use at a time.
			1	Gülcher Co. 10 ampères, 50 volts	—	10	20-candle power each	
Elstree	H. H. Gibbs, Esq., Aldenham House	9	1	Victoria Brush........	—	—	Edison & Swan	Accumulators. This Engine is driven by Dowson economic gas.
Gateshead	Co-operative Society, Jackson Street	6	1	J. H. Holmes & Co.'s "Castle" dynamo	7	—	1,500-candle power each	Six lamps inside and one outside.
"	W. Clarke, Esq., The Hermitage	2	1	Siemens..............	—	20	20-candle power	Accumulators.

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of		Lamps.	Remarks.
					Arc.	Inc.	Candle Power & Make.	
Glasgow	Muir & Mavor, 134, St. Vincent Street	HP. 8	1	Burgin Crompton	—	70	16-candle power	....
"	W. Rennie Watson, Esq., Woodside Terrace	4	1	Gramme type	—	50	20-candle power (driving direct)	Also used with accumulators.
"	J. Stephen, Esq., Donier House, Patrick	3½	1	Faraday dynamo......	—	30	16-candle power	Or, with a set of thirty accumulators, will fill sixty 16-candle power lamps.
"	W. Shireffs, 249A, West George Street	½	....	....	—	—	....	....
Halifax	L. J. Crossley, Esq.	6 twin	1	....	—	120	50 to 10 candle power incandescent	Accumulators. (Also used for other work.)
"	C. Marcheth, Esq., Sleaford House, Stafford Road	½	....	....	—	—	....	....
Hatfield	Marquis of Salisbury..........	16	1	Siemens..............	—	250	Edison & Swan	Driven direct.
Hanley	McIlroy Brothers, Drapers, Lamb Street	6	1	Elwell Parker	5	—	Four 500-candle power, two 1,000-candle power	....
Henley-on-Thames	R. Ovey, Esq., Badgemore	6	....	....	—	—	....	Accumulators.
Hull	Thomas Wilson, Sons & Co. Limited	12	1	Siemens 100 volt	—	130	16-candle power	Lighting offices. (Also used for driving woodworking machinery.)
"	Barnett & Scott, Jewellers	6	1	Ferranti dynamo, 55 volts, 150 ampères, 1,512 revolutions	—	60	20-candle power	Lighting jeweller's shop.
"	Bristowe & Co., Grocers	....	1	Siemens dynamo......	1	—	2,000-candle power....	Lighting outside of shop
"	Jno. Coalman, 65, Sandringham Street	5-HP.	1	....	—	6	20-candle power	Direct.
Keighley......	I. Holden, Esq., Oakworth House	8	2	Crompton	—	150	16 to 20 candle power..	Accumulators. (Inside mansion.)
				Brush	6	—	2,000-candle power....	Winter Gardens, 148 ft. by 90 ft.
Lancaster	Thomas Storey, Esq., Westfield House	6	1	Siemens S.D. 2, 60-light	—	100	16-candle power	Works in connection with accumulators.
"	Bell & Atkinson, Silversmiths..	1	1	"Gramme"	—	18	20-candle power	Lights taken direct from dynamo.
Leeds	Leeds Corporation Municipal Buildings, Free Library	12	1	200-light Phœnix compound wound, 14,000 watts power	—	142	20-candle power	Direct for Municipal Buildings, and into accumulators (when not working incandescent lamps) to supply light for 8 arc lamps in Town Hall.
		12	1	200-light Phœnix compound wound, 14,000 watts power	—	142	20-candle power	
"	R. Wood, Butcher, &c.........	9	1	Crompton dynamo	—	100	20-candle power	Also used for other work.
Leicester	Opera House	6	1	6,000-candle power Brush dynamo	6	—	Arc "Brush" lamps of 1000-candle power each	Also lights up Messrs. Paget's Bank with two 1000-candle power arc lamps when not used in theatre.
"	F. Goddard, Esq., F.R.I.B.A., Knighton Spinneys	3½	1	Elwell Parker	—	87	16 and 8-candle power	Accumulators. Average of about 50 lamps in use
Lincoln	Jas. Usher & Son, Cornhill....	2	1	J. H. Holmes & Co.'s "Castle" dynamo	—	35	16-candle power	Lighting up jeweller's shop and house.
Littlehampton	Nicholas O'Reilly, Esq., Shelton House	8	1	....	—	75	20-candle power	Direct.
Liverpool	Perry & Cox, 36, Victoria Street	4 twin	2	Phœnix dynamos	—	102	20-candle power (Edison Swans)	56 lamps at Messrs. Bennett Bros., Victoria St., six at Messrs. Ashcroft's, lighting billiard table, & rest on own premises.

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
LIVERPOOL	Perry & Cox, 36, Victoria Street	HP. 5-MP.	....	Combined with Phœnix dynamo, 50 volts, 12 ampères	—	6	20-candle power	Accumulators.
LLANDUDNO	T. Edge, Photographer, Gloddeth Street	3½	1	Crompton's "Burgin-Crompton"	2	—	3,000-candle power each	For photographic copying.
LONDON	Willis's Rooms, King Street, St. James's, S.W.	16	1	Siemens	—	170	16-candle power incandescent	Driven direct.
,, ...	The Royal Hotel, Blackfriars, E.C.	16	1	Siemens	6	126	Arcs, 600-candle power	Driven direct.
,, ...	General Post Office, Savings Bank Department, Queen Victoria Street, E.C.	16	2	Maxim Weston	—	400	10-candle power and upwards, Maxim Weston	Driven direct.
......	General Post Office, Savings Bank Department, Queen Victoria Street, E.C.	16	2	Maxim Weston	—	400	10-candle power and upwards, Maxim Weston	Driven direct.
......	General Post Office, Savings Bank Department, Queen Victoria Street, E.C.	16	2	Maxim Weston	—	400	10-candle power and upwards, Maxim Weston	Driven direct.
,, ...	Pavilion Music Hall, Piccadilly Circus, W.	16	1	Edison Company......	—	—	Edison & Swan	Regulators.
,, ...	Pavilion Music Hall, Piccadilly Circus, W.	16	1	Edison Company......	—	—	Edison & Swan	Regulators
,, ... {	National Provincial Bank, E.C.	14	2	Edison Hopkinson dynamos	—	200	20-candle power	Direct.
	National Provincial Bank, E.C.	14	2	Edison Hopkinson dynamos	—	200	20-candle power	Direct.
,, ...	Royal Institution, Albermarle Street, W.	6 TWIN	1	Crompton 8 unit......	—	140	....	Accumulators. Drives dynamo for laboratory purposes also.
,, ...	Cochrane & Sons, Westminster Chambers, Victoria St., S.W.	6 TWIN	1	Crompton	5	—	3,000-candle power each	During day time drives saw mill.
,, ...	Meisenbach Company Limited, Tulse Hill	6 TWIN	1	Crompton 15 unit	4	—	10,000-candle power each	Direct.
,, ...		6 TWIN	....	Anglo-American Brush Electric Light Co. Ld.	—	—	....	....
......	W. A. Higgs & Co., 30, High Street, Islington, N.	12	....	Maxim Weston	10	20	(Incandescent lights, 16-candle power)	Direct.
,, ...	Museum of Geology, South Kensington, S.W.	12	1	No. 7 Brush machine, Gramme type	13	—	....	....
,, ...	Peter Jones, 2, 4 & 6, King's Road, Chelsea	12	} 5	Crompton 4 unit machines	—	140	16-candle power	....
,, ...	Peter Jones, 2, 4 & 6, King's Road, Chelsea	12						
,, ...	Technical College, Finsbury Tabernacle Walk, E.C.	12	1	Edison	—	180	16-candle power Edison	Direct.
,, ...	E. Bieber, Esq., Champion Hill, S.E.	12	2	Siemens..............	—	150	16-candle power Edison	Accumulators.
,, ...	The "Falstaff," Eastcheap, E.C. (restaurant)	12	1	Siemens..............	—	60/100	20-candle power Edison	Accumulators.
,, ...	"Hatchett's" Hotel, Piccadilly, W.	12	1	Edison	—	130	Edison & Swan 16-candle power	Direct.
,, ...	"Hatchett's" Hotel, Piccadilly, W.	12	1	Edison	—	130	Edison & Swan 16-candle power	Direct.
,, ...	Samuel Brothers, 65, Ludgate Hill, E.C.	12	1	Jablochoff....	20	—	....	....
,, ...	Sir E. C. Guinness, Bart., Grosvenor Place	12	1	.... {	—	150 and 200	} 16-candle power Swan lamps	150 direct. Accumulators for 200 more.
,, ...	Chas. H. Wilson, Esq., M.P., Grosvenor Square	12	....	....	—	—	....	Accumulators.
,, ...	The Athenæum Club	12	....	Edison Swan Company	—	—	....	....
,, ...	The Athenæum Club	12	....	Edison Swan Company	—	—	....	....

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
London	A. Gibbs & Son, Bishopsgate, E.C.	HP. 12	1	Brush	—	150	20-candle power lamps, by Laing & Fox	E. P. S. Co.'s accumulators.
"	Temple Library, The Temple, E.C.	12	....	Edison	—	—	....	Direct.
"	Dowager Duchess of Montrose, Belgrave Square	9	....	....	—	—	....	Accumulators.
"	The Alhambra Theatre, Leicester Square, W.C.	9	1	Edison Company......	—	80	Edison & Swan	Direct.
"	North British and Mercantile Assurance Company	9	....	....	—	—	....	....
"	Right Hon. Lord Wolverton ..	8	....	....	—	—	....	Accumulators.
"	J. B. Lamb & Co.	8	....	....	—	—	....	....
"	H. Van der Weyde, 182, Regent Street, W.	8	2	1 Siemens .... 1 Gramme............	1	40	Incandescents, 10 & 20 candle power; arc, 6,000-candle power	Photographing direct.
"	The Stereoscopic Company, 110, Regent Street, W.	8	4	1 Siemens............ 2 Gramme Jablochoff.. 1 Gramme Jablochoff..	1 4 1	— — —	....	Used in winter, at night, for photographing direct
"	H. J. Nicoll, Esq., 45, Warwick Street, W.	8	1	Elwell Parker	--	30	16-candle power	Running day time, charging cells.
"	The Royal Society, Burlington House, Piccadilly	8	....	....	—	—	....	E. P. S. Co.'s accumulators.
"	J. Ackermann, Esq., 6, Queen's Square, W.C.	8	1	Gramme..............	1	—	10,000-candle power ..	Photographing.
"	W. Griggs, Esq., Elm House, Hanover Street, Peckham	8	2	Siemens	1	20	Arc, 5,000-candle power; incandescent, 20-candle power	Accumulators.
"	Society of Arts, John Street, Adelphi	8	1	Siemens	—	60	18-candle power	Accumulators.
"	W. S. Gilbert, Esq., 19, Harrington Gardens, S.W.	8	1	Crompton 8 unit	—	100	....	Accumulators.
"	Faraday & Son, 3, Berners Street, Oxford Street, W.	8	1	Siemens	—	20	Swan 16-candle power	Drives lathes and electric light through accumulators.
"	Goringe & Co., 49 and 59, Buckingham Palace Rd., S.W.	8	1	Edison	—	111	Edison & Swan 16-candle power	Direct.
"	Hammond & Co., 463, Oxford Street	8	....	....	—	—	....	....
"	L. Mond, Esq., 20, Avenue Road, Regent's Park	8	1	Elwell Parker	—	100	Bernstein lamps, average 16-candle power	Accumulators.
"	Dicks & Co., 296, High Holborn, W.C.	8	1	Andrews	—	65	16-candle power Edison	Direct. Also drives boot and shoe machinery.
"	Woodbury Permanent Photo Printing Company	8	1	Crompton	—	—	....	Photographic work.
"	L. B. & S. Coast Railway, Victoria Station, S.W.	8	1	Siemens	—	—	....	Charging cells for the Brighton express train Pullman car.
"	A. & G. Taylor Victoria Works, Forest Hill	8	2	Siemens	4	54	Incandescent lamps, 20-candle power; two arcs 2,000, two arcs 1,000	Direct.
"	— Littleton, Esq., Westwood House, Sydenham	8	....	....	—	—	....	....

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
London	T. Lansell, Esq., Ferndale, Nightingale Lane, S.W.	HP. 8	1	....	—	90/100	Swan 20-candle power	Direct.
,, ...	Pavilion Music Hall, Piccadilly Circus, W.	8	1	Edison Company......	—	—	Edison and Swan......	Regulators.
,, ...	R. Woodley, 248, Burdett Read, E.	7	1	....	—	20	16-candle power Swan Edison	Froude's accumulators for electric light. Also drives engineers' tools
,, ...	J. Aird, Esq., 19, Hyde Park Terrace	7	1	Edison	—	—	....	....
,, ...	R. Woodley, 248, Burdett Road, E.	7	1	Edison Swan	—	—	....	....
,, ...	A. Lee, 98, King's Road. Camden Road	7	1	Own make	—	20	Swan lamps	Direct. Drives lathes, &c., also.
,, ...	A. S. Mallett, Esq., 68, Wardour Street	7	1	....	—	—	....	....
,, ...	Bank of Australia	7	....	....	—	—	....	....
,, ...	J. Simonsen & Co., Dowgate Hill, E.C.	6	....	....	—	—	....	....
,, ...	City Guilds College, Cowper Street, E.C.	6	....	....	—	—	....	....
,, ...	R. Hammond, Esq., Hildrop, Highgate	6	1	....	—	—	....	....
,, ...	G. H. Lee, Esq., West Lodge, Attenborough Gardens, Clapham Common, S.W.	6	1	Own make	—	—	....	....
,, ...	Lord Randolph Churchill, 2, Connaught Place	6	1	Crompton	1	105	....	....
,, ...	School of Shorthand, 27, Chancery Lane, W.C.	6	2	....	—	58	1 arc lamp and Gatehouse incandescent	Direct.
,, ...	Chancery Lane Safe Deposit, 61, Chancery Lane	6	1	Elwell Parker	—	53	20-candle Swan Edison	Direct.
,, ...	Rosing Bros. & Co., 10, Basinghall Street, E.C.	6	1	Paterson & Cooper....	6	60to70	16-candle Swan	Direct.
,, ...	J. Pierce, 84, Farringdon Street	6	1	Stanley Davis	—	—	1,000-candle power Clarke & Power	Direct.
,, ...	Great Eastern Railway Co., Liverpool Street Station, E.C.	6	1	Edison	—	46	20-candle power......	Direct.
,, ...	Asprey & Sons, 166, New Bond Street, W.	4	1	....	—	40	20-candle power	26 accumulator cells.
,, ...	Fairbrother, Ellis, Clarke & Co., 29, Fleet Street, E.C.	4	1	Latimer Clark	—	56	....	Accumulators.
,, ...	— Stewart, Esq., Cowcross St.	4	1	....	—	—	....	....
,, ...	Hon. P. J. Locke-King, 38, Dover Street, Piccadilly, W.	4 }	1	Greenwood & Batley ..	—	{ 190 to 230	} 20-candle power Swan	Accumulators.
,, ...	Hon. P. J. Locke-King, 38, Dover Street, Piccadilly, W.	4 }						
,, ...	W. F. Thomas, Esq., 75, Strand, W.C.	4	1	Jablochoff...........	—	40to45	20-candle power Swan	Direct.
,, ...	Bank of Rio de Janeiro, St. Helen's Place, E.C.	4	....	....	—	—	....	....
,, ...	Professor Crookes, Kensington Park Gardens, S.W.	3½	1	....	—	—	....	....
,, ...	R. E. Crompton, Esq., 23, Porchester Gardens	3½	1	Crompton 2 unit	—	69	....	Accumulators.
,, ...	J. S. Sellon, Esq., Sydenham..	3½	1	Victoria	—	107	16-candle power	Accumulators.
,, ...	J. Turner & Co., 185, Edgware Road, W.	3½	1	Gramme..............	1	—	....	Direct.
,, ...	Sir R. E. Webster, Hornton Lodge, Kensington, W.	3½	1	Crompton..	—	35	Swan	....

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
		HP.						
London	Haywards & Co., 166, Oxford Street, W.	3½	1	Paterson & Cooper....	—	120	10 and 16 on circuit, and about 25 through accumulators	Accumulators.
"	East India Dock House, Billeter Street, E.C.	3½	1	Crompton 2 unit	—	40	....	Accumulators.
"	H. B. Merton, 3, Palace Houses, Bayswater	3½	1	Crompton 4 unit	—	83	Varying from 52 largest to 31 smaller	E. P. S. Co.'s accumulators.
"	Bank of New South Wales, Broad Street, E.C.	3½	....	....	—	—	....	....
"	A. M. Singer, Esq., 30A, St. James Street, W.	3½	1	Victoria	—	45	20-candle power Woodhouse and Rawson	Elwell & Parker's accumulators.
"	C. Dent, Brook Street, W.	3½	1	Elwell Parker	—	50	20-candle power	E. P. S. Co.'s accumulators.
"	Johnson, Matthey & Co., 78, Hatton Garden	3½	1	Victoria	—	100	16-candle power Swan	Accumulators.
"	Laing, Wharton & Down, 8 & 9, Holborn Viaduct, E.C.	2	1	Crompton	—	30	20-candle power Swan..	Direct.
"	H. Seehbohm, Esq., 22, Courtfield Gardens, W.	2	1	Elwell Parker	—	52	10-candle power Edison	Accumulators.
"	Hugh Watt, Esq., M.P., 119, St. George's Road, Pimlico	2	1	Maxim Weston	—	30	Maxim Weston	Direct.
"	Spink & Son, Gracechurch St., E.C.	2	1	Consolidated Company	—	36	16-candle power Edison	....
"	Eastern Telegraph Company, 11, Old Broad Street	2	1	Siemens	—	25	16-candle power	Direct.
"	Charles Elam, Esq., M.D., 75, Harley Street, Cavendish Sq.	2	1	Goolden & Trollin....	—	—	....	Accumulators.
"	H. Harben, Esq., Sleaford Lodge, Fellows Road, N.W.	2	....	....	—	—	....	....
"	Foster & Braithwaite, 27, Austin Friars, E.C.	1	1	Railway Electrical Co.	—	20	16-candle power	....
"	F. D. Banister, Esq., 117, Denmark Hill	1	1	....	—	—	Incandescent lamps	Direct.
"	J. B. Braithwaite, Esq., 18, Highbury New Park	1	1	Victoria	—	—	....	Accumulators.
"	— Turnbull, Esq., Sydenham ..	1	1	....	—	—	....	....
"	Burroughs & Watts, 19, Soho Square, W.	1	1	....	—	—	....	Accumulators.
"	Electric Apparatus Co. Limited, 58, Queen Victoria Street	1	1	Siemens	1	30	Incandescent lamps, 16 candle power	Accumulators.
"	C. H. Stearne, Esq., Selwood, Mayo Road, Forest Hill	½	1	....	—	—	....	....
"	C. H. Stearne, Esq., Selwood, Mayó Road, Forest Hill	½	1	....	—	—	....	....
"	T. Penn, Esq., Grove House, Lewisham	½	1	Own make............	--	15	15-candle power	Direct.
"	J. C. Fuller & Son, 47, Finsbury Pavement, E.C.	½	....	....	—	—	....	....
"	J. Schweppe & Co., 51, Berners Street, Oxford Street	½	1	Siemens	—	12 to 15	Mostly 10-candle power	....
"	Keyser & Co., 21, Cornhill, E.C.	½	1	Elwell Parker	—	20	Woodhouse & Rawson	Elwell Parker accumulators.
"	J. Edmondson & Co., 19, Great George Street	½	1	....	—	—	....	Accumulators.
"	Capt. H. C. Holden, 20, Redcliffe Square, S.W.	5-MP.	1	Combined with Jones's patent dynamo	—	6	Edison Swan, 20-candle power	Friction gear ....
Lowestoft	W. Youngman, 64, High Street	4	....	....	—	—	....	....
Manchester ..	Art Gallery	16	1	Elwell Parker 110 volts	—	520 (both)	20-candle power	Direct.
" ..	Art Gallery	16	1	Elwell Parker 110 volts	—			Direct.

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
Manchester *	Manchester & Salford Bank, Mosley Street	HP. 8	1	Elwell Parker	—	75	20-candle power, 100 volt	Direct.
,, ..	Edison Electric Light Co., St. Mary's Gate	8	1	Elwell Parker	—	70/80	16-candle power	Direct. Not worked to full power
,, ..	Mather & Platt, Engineers, Salford	8	1	Mather & Platt's No. 4 Manchester compound wound	—	120	20-candle power	Direct.
,, ..	Crossley Bros. Limited, Openshaw	6TWIN	1	Elwell Parker	—	50	20-candle power	Direct. Lighting offices. Also drives smithy fan, working with Dowson economic gas.
,, ..	Bruderer & Co., Princess Street	6TWIN	1	Elwell Parker 12-in. ..	—	150	16-candle power Edison	Direct.
,, ..	Charles Mosley, Esq., Grangethorpe	6	1	Elwell Parker 10-in. ..	—	120	20-candle power	Elwell Parker accumulators.
,, ..	Bridge Wine Company........	6	1	Elwell Parker 10-in. ..	—	50	20-candle power	Direct.
,, ..	Samuel Armitage, Esq., Chaseley House, Pendleton	3½	1	Elwell Parker	—	100	20-candle power	Accumulators.
,, ..	Jas. Horrocks, Esq., Broad Oak Park, Worsley	2	1	2 unit Crompton dynamo, of fifty lamps 60 volts power	—	20	16-candle power	Driving into accumulators.
,, ..	Alcock & Co. (late A. Brothers), Photographers, St. Ann's Square	2VERT	1	2 unit Crompton dynamo	1	—	4,000-candle power....	For photographic copying.
,, ..	V. K. Armitage, Esq., Crimble Lodge, Swinton Park	2	1	Elwell Parker's 8-in. dynamo	—	50	20-candle power	Driving into set of No. 12 Elwell Parker accumulators.
,, ..	H. Gartside, Photographer, Cannon Street	2	1	Siemens dynamo......	1	—	....	For photographic copying.
,, ..	Edison Electric Light Co., St. Mary's Gate	½	1	6-in. Elwell Parker dynamo	—	12	20-candle power	Direct.
,, ..	Owens College................	½	1	Gramme of the M. type	—	7	20-candle power	(For projection.)
Newcastle-on-Tyne	R. Robinson & Co., Clavering Place	12	1	Siemens D2	—	55	16-candle power, 60 volts	Driving into accumulators. Also drives printing machines at same time.
,, ..	Mawson & Swan, Mosley St. ..	8	....	....	—	—	....	....
,, ..	Captain Noble, Jesemond Dene House	7	2	Victoria B2 dynamos ..	—	75	16-candle power	Driving into accumulators.
,, ..	Charles Mitchell, Esq., Jesmond Tower	6TWIN	2	Siemens 100-light dynamo	—	230	16-candle power	Driving into accumulators.
,, ..	Co-operative Society	4TWIN	....	....	—	—	....	....
,, ..	Thomas Pumphrey, Esq., Cloth Market	2	1	J. H. Holmes & Co.'s "Castle" dynamo	—	35	16-candle power	Driving into accumulators. Also drives grocery machinery.
,, ..	C. H. Ginningham, Esq., 153, Park Road	½	....	....	—	—	....	....
,, ..	W. H. Holmes, Esq., Jesmond Road	½	1	Siemens S. D5	—	15to20	16-candle power	Storage batteries.
Newport (Mon.)	Newport Dock Co., Alexandra Docks	8	1	Siemens 6,000-candle dynamo	1	—	6,000-candle power....	For dock purposes. In use eight years. Run from dusk till daylight.
		8	1	Siemens 6,000-candle dynamo	1	—	6,000-candle power....	
Norbiton	Right Hon. Lord Wolverton, Warren House	9	....	....	—	—	....	Accumulators.
Oxford........	Oxford Union Society	16	3	Pilsen Joel	5	210	One dynamo for arc, two for incandescent	....
,, ...	Dr. B. Sanderson, 50, Banbury Road	2	1	Gramme dynamo, by Soutier, Lemonier and Co., Paris, 20 ampères	1	—	Siemens	Also drives other machinery.
,, ...	R. E.	5-HP.	1	Gramme shunt wound, 40/50 volts, 5/6 ampères	—	6	16-candle power, 40 volts	Charges twenty of the smallest E. P. S. accumulators.

(* *See also* Ashton, Bowdon, Didsbury, *and* Poynton.)

Town.	Address.	Size of Engine.	No. of Dynamos.	Make of Dynamo.	No. of Arc.	No. of Inc.	Lamps. Candle Power & Make.	Remarks.
Plymouth	Plymouth Pier Co.	HP. 16	....	....	—	—	....	....
"	Lord Revelstoke, Mewbland House	12	....	....	—	—	....	Accumulators.
Portsea	— Antill, Esq., Queen Street ..	8	....	Gramme	—	—	....	....
Poynton	Mrs. Turner, Barlow Fold	6	1	10-in. Elwell Parker ..	—	130	112 16-candle power, 45 volts; 12 5-candle power, 45 volts; 6 50-candle power, 45 volts	Charges 28 No. 12 Elwell Parker accumulators.
Preston	T. Townley Parker, Esq., Bamber Bridge	5	1	Elwell Parker	—	—	....	....
ReigateHeath (Surrey)	H. G. Ohrly, Esq., Sandells ..	½	....	5 unit	—	80	20-candle power	Direct and through accumulators.
Renfrew	Sir Archibald Campbell, Bart., Blythswood	12	....	....	—	—	....	....
Ryde (I. of W.)	Ryde Pier Company	12	1	Siemens	—	—	....	Driving Electric Railway.
St. Helens	Thomas Beecham, Esq., Pill Manufacturer	16	1	....	—	—	....	Lighting up works.
"	Thomas Beecham, Esq., Pill Manufacturer	4	1	....	—	—	....	Lighting up private residence at Huyton, near Liverpool
Scarborough ..	W. Rowntree, Son & Co., Drapers	16	1	Siemens 200-light machine	—	212	Edison Swan, 16-candle power	Lighting up large drapery establishment. In use about six years.
" ..	Colonel Steble, Ramsdale Bank, Belmont Road	7	....	....	—	—	....	....
Sheffield	G. H. Hovey, Draper, Angel Street	16	4	Two Pairs of Siemens exciters and dynamo machines, viz., W1, D7, and W2, D6	18 —	— 150	400-candle power arc lamps, and 20-candle power incandescent lamps	Lighting up large drapery establishment, and is also used for other purposes.
"	Vickers & Co., Steel Works, Attercliffe	16	2	Crompton's dynamos ..	6	40	....	Used chiefly for other purposes.
South Shields	F. M. Laing, Royal Hotel	6	....	....	—	—	....	....
Stockton-on-Tees	G. Y. Blair, Esq.	½	1	Dynamo by P. B. Blair, Esq.	—	17	10-candle power	Also drives two-manual organ, sixteen stops.
Sunderland ..	The Earl of Durham, Lambton Drops	12	....	....	—	—	....	....
Swansea	Craig-a-Nos Castle (Madame Adelina Patti)	6	1	Paterson-Cooper	—	80	Incandescent lamps ..	Lighting up the Castle.
Taunton	Rev. F. J. Smith	½	....	....	—	—	....	....
Totnes	A. M. Singer, Esq., Redworth	9	1	....	—	—	....	....
Tunbridge Wells	Rev. R. J. Thornton, Dulcote ..	2	1	Elwell Parker	—	20	20-candle power	Accumulators.
Wigan	W. D. Brown, Grocer, &c.	8	....	....	—	—	....	....
Walsall	John Shannon & Son	12	1	Crompton	—	150	20-candle power	Direct, and through accumulators.
WestBromwich	Free Press Company	8	1	Chamberlain & Hookham	—	—	....	Accumulators.

CROSSLEY'S "OTTO" GAS ENGINE

6,000 SOLD

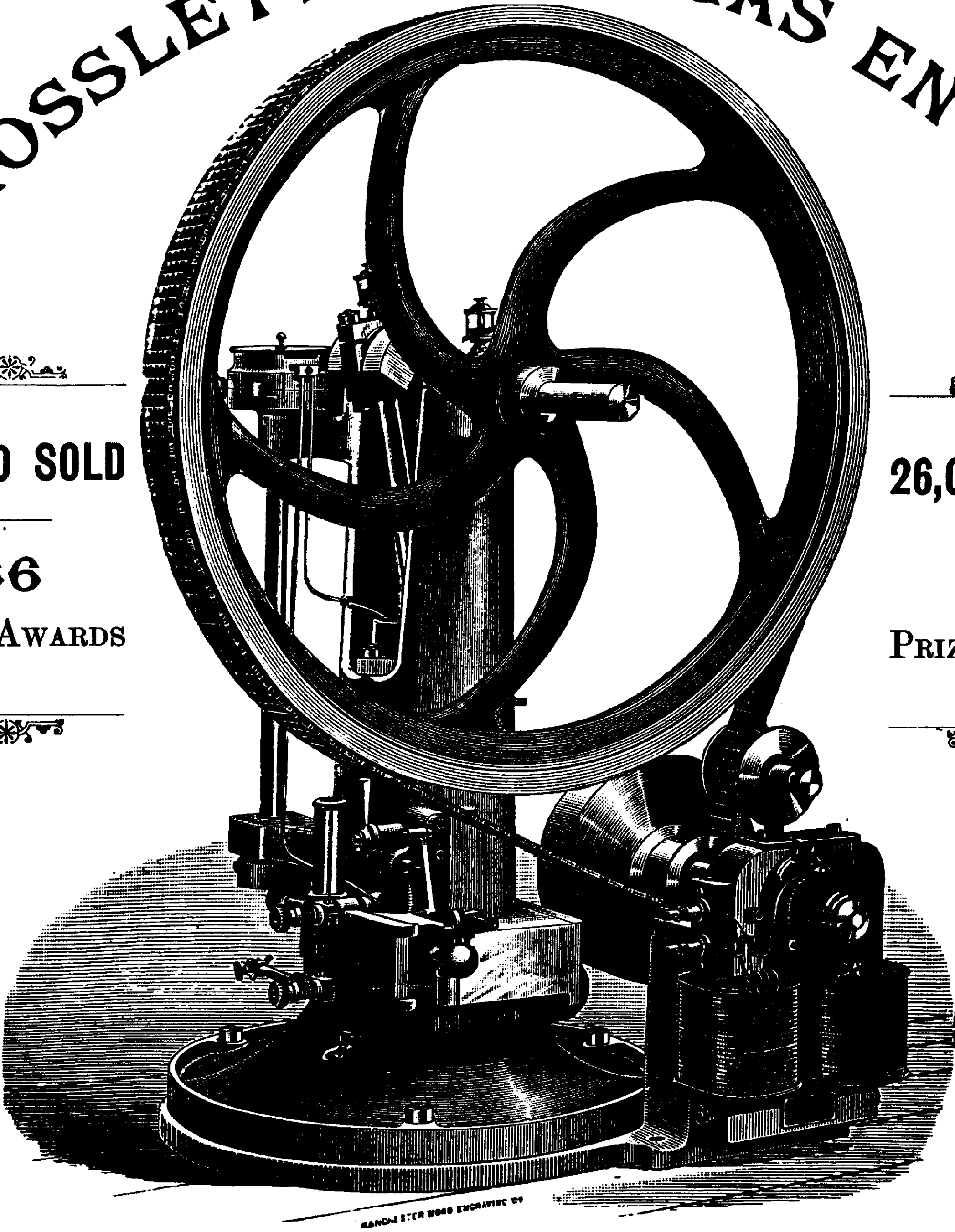
66

RIZE AWARDS

26,000 SOLD

66

PRIZE AWARDS



Represents 1½-HP. VERTICAL, OTTO" GAS ENGINE combined with Dynamo.

ROSSLEY BROS. LIMITED, OPENSHAW, MANCHESTER.

D. 1/88. CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

List of a few Users

OF

CROSSLEY'S "OTTO" GAS ENGINE

FOR

GENERAL PUMPING PURPOSES.

CROSSLEY BROTHERS LIMITED, Engineers, OPENSHAW, MANCHESTER.

	HP.	
ABBERLEY HALL, *near Stourport*	3½	John Jones, Esq. Domestic Supply.
ABERYSTWITH	3½	J. Roberts, The Brewery. Deep Well Pump.
ALFRETON	12	Jas. Oakes & Co., Iron Works. Nine Hydraulic Pumps and other work.
"	4	Blackwell Colliery Company.
ALLOA	1	Captain Young.
ASCOT	1	The Hon. R. H. Mead. Domestic Supply.
"	1	C. D. Kemp Welch, Esq., Red House, Leigham Avenue, Broadlands.
ASHFORD	5-HP.	J. Sterling, Esq., Locomotive Superintendent, South Eastern Railway.
ASHTEAD	3½	W. Lucas, Esq., Ashtead Park. Domestic Supply.
ASHTON	8	— Buckley.
AYLESBURY	7	Baron Rothschild. (Also two 3½-HP. Engines at Leighton Buzzard.)
BALLYWATER (Co. Down)	½	John Mulholland, Esq., M.P., Ballywater Park. Domestic Supply.
BARNET	½	W. J. Cowles, Esq.
BARRHEAD	1	William Stirratt, Engineer.
BARTON-UNDER-UNDERWOOD	½	(Vert.) John R. Walker, Esq., The Knoll. Domestic Supply.
BASFORD, *near Nottingham*	8	Brixtowe Skin Works.
BATH	½	Gilliard Spence.
BATTLE	8	H. & R. Noakes, Tanners. Pumping and Grinding Bark.
BEDFORD	1½	F. C. Fuller, Lark Street Brewery.
"	5-HP.	— Harter, Esq., Cranfield Court, near Bedford.
BELFAST	12	Brookfield Linen Company Limited. Hydraulic Press Pumps.
"	7	Ewing, Son & Co., Donegall Square, South. Hydraulic Press Pumps.
"	6	R. D. Harrison, Esq., Holywood House. Domestic Supply and Farm Work.
"	3½	J. & R. Young, Wellington Place. Hydraulic Press Pumps.
"	3½	McCrum, Watson & Co. Hydraulic Press Pumps.
BELFAST	3½	William Kirk & Partners. Hydraulic Press Pumps.
"	1	James Barbour, Esq. (Coombe, Barbour & Co.)
"	1	County Down Flax Spinning Company. Press Pumps.
BIRMINGHAM	16	Clifford & Son. Hydraulic Pumps for Accumulator.
"	6	M. A. Eaves, Holland Street. Hydraulic Pumps for stamping.
"	1	Thomas Hall, Esq., Warley Hall. Domestic Supply.
BLACKBURN	2	Freeman & Co., Brewers.
BLACKPOOL	3½	Dr. W. H. Cocker, The Aquarium.
"	½	Prince of Wales Baths. Pumping Sea Water.
BLAIRGOWRIE	3½	James Ogilvie, Brewer.
BOLTON	3½	J. & J. Mather, Lard Merchants. And Hoisting.
BOSTON	½	Samuel Waddington, Fellmonger and Leather Dresser. Pumps 1,000 galls. per hour, at a cost of one penny.
"	2	J. H. Bury, Brewer.
BRADFORD	12	D. Midgeley & Co. Press Pumping.
"	8	James Lumby & Co., Swaine Street. Press Pumping and other work.
"	6	Quitzow & Co., Merchants. Press Pumping and other work.
"	6	Delius & Co., East Parade. Press Pumping and other work.
"	6	— Tafel.
"	6	— Homer & Craven.
"	3½	R. Taylor, Leeds Road. Press Pumping and other work.
"	3½	C. G. Steinthal & Co., Currer Street. Press Pumping and other work.
"	3½	J. Tordorf & Son, Brewers, Thornton. Pumping and other work.
"	3½	Young, Burt & Co., 5, Hall Ings. Hydraulic Press Pumping.
"	3½	— Sale.
"	3½	— Ahrons.
"	3½	— Higgins.

	H.P.	
BRADFORD	2	A. Marsden & Co., 38, Chapel Street, Leeds Road. And other work.
"	2	J. O. & J. Wood, Brewers, Thornton. And other work.
"	2	E. Wall & Co., 25, Canal Road. Hydraulic Press Pumping.
BRECHIN	8	James Ferguson & Sons, Distillers.
BRIGHOUSE	2	North Cheshire Brewery Company. Pumping.
BRISTOL	16	H. H. & S. Budgett & Co., Wholesale Grocers, Nelson Street. Hydraulic Pumps and General Grocers' Machinery.
"	12	H. H. & S. Budgett & Co., Wholesale Grocers, Nelson Street. Hydraulic Pumps for Lift.
"	8	Bristol Distillery Company, Cheese Lane. Centrifugal and other Pumps.
"	6	Baker, Baker & Co., Wine Street. Hydraulic Pumps for Hoist
"	1	T. Baker, Esq., Walcroft House, Durdham Down. Domestic Supply.
"	½	Blind Asylum.
BROMLEY	2	E. Hambro, Esq., Hoyes Place. Domestic Supply.
BROUGH	½	Jas. Reckett, Esq., Swanland Manor. Domestic Supply.
BURTON-ON-TRENT	12	J. Thompson & Sons, Brewers.
BURTON SALMON	½	John Davies, Victoria Brewery.
BURY	4	Walmsley House. Domestic Supply.
CAMBRIDGE	1	W. Norboy, Brewer, Sturton Street.
"	5-HP.	— Humphreys, Esq. Pumping on a Church Estate at Newnham.
CANTERBURY	6	W. Howard. And other work.
"	1	Drury & Biggleston, High Street.
"	½	S. Beer, Brewer.
"	½	George Beer, Brewer.
CARDIFF	7	Taff Vale Railway Company. Hydraulic Pumps.
CARGILL	2	Dowager Lady Lansdowne. Domestic Supply.
CARLISLE	½	Joseph Graham, Caldergate.
CARMARTHEN	2	Great Western Railway Company. Hydraulic Pumps.
CATERHAM JUNCTION	2	— Cooper, Esq., Hooley House. Domestic Supply.
CHATHAM	3½	Charles Arkcoll & Co., Lion Brewery.
CHELMSFORD	8	Charles Portway, Esq.
CHELTENHAM	1	W. H. Freeman, Esq., Thirlstain Hall Domestic Supply.
"	1	John Lea, Esq., Elmhurst. Domestic Supply.
"	5-HP.	Geo. Meek, Victoria Brewery, St. Pauls.
CLONMEL	3½	J. Murphy & Co. Set of Three-throw Pumps, raising water 40 feet from an Abyssinian tube well.
COLDSTREAM	1	Earl of Home, The Hirsel.
COTTINGHAM, *near Hull*	5-HP.	D. Wilson, Esq., M.P., Park House. Domestic Supply.
COVENTRY	½	Chas. Browett, Esq., Westfield. Domestic Supply.
CUCKFIELD	½	S. Knight.
DALKEITH	8	Lord Elphinstone. Pumping water at Carberry Tower. Water conveyed 340 yards to filtering tanks; thence to double-barrelled gun-metal pump to Queen Mary's Mount. Water rises 320 feet in column, 138 lbs. pressure to sq. in.
DARLINGTON	3½	G. J. Scurfield, Esq., Hurworth-on-Tees. Domestic Supply.
DEAL	1	H. Page, Esq., Walmer Court. Domestic Supply.
DENBIGH	½	Dr. Turnour, Grove House. Domestic Supply.
DERBY	½	All Saints College. Domestic Supply.
DOVER	6	Dover Brewery Company.
DROGHEDA	1½	L. J. Healey.
DUBLIN	3½	George Roe & Co. Limited, Thomas Street. Distillery.
"	3½	Great Southern and Western Railway, Inchicore.
"	2	Great Southern and Western Railway, Inchicore.
"	1	Great Southern and Western Railway, Kingsbridge.
DUDLEY	6	Dudley Tramway Company.
"	1	W. Bassano, Esq., Haden Cross Old Hill. Domestic Supply.
DUFFIELD	5-HP.	Hon. F. S. O'Grady, Duffield Park. Domestic Supply.
DUNDEE	16	Harbour Trust. Hydraulic Machinery.
"	8	Forbes & Christie, Victoria Road. Packing Pumps (four Plungers) and other work.
"	6	J. & W. Smith, Commercial Street. Hydraulic Pumps and other machinery.
DUNFERMLINE	3½	R. E. Walker, Reid & Co., Linen Manufacturers.
EAST DEREHAM	6	Smith & Sons, Maltsters. And Hoisting.
EAST GRINSTEAD	3½	E. C. Blount, Esq., Imberholme Manor. Domestic Supply.
"	½	J. Tooth, Esq., St. Margaret's Home. Domestic Supply.
EAST HARNHAM	3½	Henry Rogers. Pumping and Chalk Grinding.
"	1	Henry Rogers. Pumping and Chalk Grinding.
ECCLESHILL (Yorks.)	3½	J. Mitchell, Esq., The Park. Domestic Supply. Has also a 1-HP. Engine for other work.
EDINBURGH	8	Thomas Nelson & Sons, Publishers. Hydraulic Pumps and other machinery.
"	8	Simon Henderson, 181, Fountain Bridge. Pumps and Baking Machinery.
"	6	G. Harrison & Co., Chambers Street. Hydraulic Press Pumps and other machinery.
"	6	Younger & Co., Brewers.
"	4	A. Usher & Co., Bonded Warehouse. Pumping Spirits and other work.
"	1	R. M. Brechin & Co., Aquarium.
EGHAM (Surrey)	2	Sir W. N. Field.
"	½	G. Raphael, Englefield Green. Domestic Supply.
"	½	G. Thomas, Park House. Domestic Supply.
ENFIELD	½	Royal Engineers.
EPSOM	3½	Royal Medical College, Epsom Downs.
FAIRFIELD	½	R. H. Kay & Co.
FAVERSHAM	3½	H. Woolright, Esq., Berkley Lodge. Domestic Supply.
"	2	A. W. Fulcher, Esq., Lyndall Park. Domestic Supply.
FOLKESTONE	3½	E. Dawes, Esq., Mount Ephraim. Domestic Supply.
GALWAY	3½	H. St. Persee, Nuns Island Distillery.
GLASGOW	16	Govan Dry Dock Company.
"	8	Edwards, Cunliffe, Wilson & Co. Pumps for Press Packing.
"	6	McHaffie & Alexander, Buchanan St. Hydraulic Pumps for Press.

	HP.	
Glasgow	2	J. Greenless, St. Vincent Boating Loch.
,,	2	A. & J. Faill, Craig Park. Pumping Water out of Quarry.
,,	1	Stevenson, Taylor & Co., Wine and Spirit Merchants. Pumping Whisky.
Gloucester	12	Gloucester County Asylum. Pumps, Laundry, and other Machinery. Working with **Dowson Economic Gas.**
,,	12	Gloucester County Asylum. Pumps, Laundry, and other Machinery. Working with **Dowson Economic Gas.**
Gravesend	½	— Mallinson, Esq., Cumberland House. Domestic Supply.
Grimsby	6	Great Grimsby Tramways Company. Pumping, Chaff Cutting, and Corn Crushing.
Guernsey	½	J. B. Gardner, Royal Hotel. Domestic Supply, Laundry, and other work.
Gunton	½	Dent & Hillier.
Haddington	3½	Mr. Binnie, Brewer.
Hadleigh (Suffolk)	3½	— Wilson, Maltster. And Hoisting
Hale, *near Liverpool*	5-HP.	Col. Blackburn, The Hall. Domestic Supply.
Hampton Wick	1	Mark H. Robinson, Esq., Emberfield.
Handboro'	2	James Mason, Esq., Eyeshall Hall, near Witney. Domestic Supply.
Harrogate	3½	R. Stobart, Esq., Spellow Hill. Domestic Supply.
Hatfield (Herts)	6	T. W. Carlisle, Esq., Ponsbourne Park. Domestic Supply.
,,	½	J. Camp, Esq. Domestic Supply.
Haworth-on-Tees	3½	Colonel Scurfield. Domestic Supply.
Hayward's Heath	½	*Per* J. Warner & Sons.
,,	½	*Per* J. Warner & Sons.
Heckmondwike	3½	Whitworth Brothers, Brewers.
Hemel Hempstead	2	A. Longman, Esq., Shendish. Domestic Supply.
Henley-on-Thames	8	M. R. Noble, Esq., Park Place. Domestic Supply.
,,	6	J. Brennan, Esq., Badgemore. And Electric Lighting.
,,	1	R. Crosier, Esq., Thamesfield. Domestic Supply.
,,	1	Colonel Makins, M.P., Rotherfield Court. Domestic Supply.
Hertford	2	Robert Smith, Esq., Goldings. Pumping Sewage.
,,	2	Dr. Elim, Leahoe. Domestic Supply.
Hessle	2	— Saunders, Granby Hotel.
,,	½	F. B. Grotrian, Esq., M.P., CragView. Domestic Supply.
,,	½	R. F. Jamieson, Esq. Domestic Supply.
,,	½	Henry Barkworth, Esq.
,,	5-HP.	— Carver, Esq.
,,	5-HP.	— Birkenshaw, Esq.
,,	5-HP.	G. E. Bohn, C.E.
Higham, *near Rochester*	1	Pickersgill Cunliffe, Esq., Great Hermitage. Domestic Supply.
Hitchin	2	J. Gatward & Son, Swan Ironworks.
,,	½	W. Ransome, Esq., Fairfield. Domestic Supply.
Huddersfield	8	Bentley & Shaw, Lockwood Brewery. Pumps and Elevators.
,,	½	(Vert.) Bentley & Shaw, Lockwood Brewery.
Hull	16	Kingston Cotton Mill Company. Pumps and for Press Packing.
,,	16	South End Graving Dry Dock Company.
Hull	16	W. Hay, Chemist. Two Setts Pumps.
,,	8	Hull and Barnsley Railway. Accumulators for Swing Bridge.
,,	3½	C. J. Christie.
,,	½	Thomas Linsley, 7, Dagger Lane.
,,	½	F. Jamieson, Eastella. Domestic Supply.
Hurstpierpoint	½	(Vert.) G. B. Woodruff, Esq., Oaklands Park. Domestic Supply.
Hyde	3½	Equitable Co-operative Society. Press Pumps.
Ilford	5-HP.	A. S. Watford, Esq., Cranbrook Hall. Domestic Supply.
Keston	1	G. Fox, Esq. Domestic Supply.
Kilkenny	2	Power & Son, High Street.
Kilmarnock	3½	Sir W. H. Houldsworth Bart., M.P., Coodham. Domestic Supply.
Kingsbridge	1	Great Southern and Western Railway Company.
Kingston-on-Thames (Herts)	1	Mark H. Robinson, Esq., Emberfield, Hamptonwick. Domestic Supply.
Leatherhead	1	Henry Courage, Esq., The Red House. Domestic Supply.
,,	1	Richard Sturgess, Esq., The Grove. Domestic Supply.
Ledbury	½	C. M. Edwards, Brewer. Pumping and Hoisting.
Leeds	12	Buckley & Sons, Greek Street. Presses and other machinery.
,,	8	Schunck Souchay & Co., St. George Street. Press Pumps.
,,	3½	Zossenheim & Co., York Place. Pumping and Hoisting.
,,	2	Wright Brothers, Brewers, Durham Street. Hoisting, Pumping, and Malting.
Leicester	3½	John Taylor, Belgrave Gate. Pumping, Malt Crushing, &c.
,,	2	Lord Stamford, Bradgate House. Domestic Supply.
,,	½	— Parkinson, Selby Street. Lift and Force Pump.
Leighton Buzzard	3½	Baron Leopold de Rothschild, Ascot House. Domestic Supply.
,,	3½	Baron Leopold de Rothschild, Ascot House. Domestic Supply. (Also 7-HP. at Aylesbury.)
Leith	3½	R. H. Thomson & Co., 130, Constitution Street. Hoisting, Pumping, and Mill Work.
,,	½	A. Saunderson.
Lichfield	½	Lichfield Brewery Company.
Lindfield (Sussex)	½	W. Sturdy, Esq., Pax Hill Park. Domestic Supply.
Liverpool	16	Baerlein & Co. Pumps for Hydraulic Press.
,,	8	Commercial Paper Stock Company Limited, 23, Cherry Lane. Hydraulic Pumps.
,,	6	Henry Hayes & Co., Henry Street. Press Pumps.
Liversedge	2	Rouse & Nelson, Maltsters.
Llandilo	1	Thomas Thomas & Sons, Curriers.
London	16	Junior Army and Navy Stores, Regent Street.
,,	16	Pickford & Co., Castle Wood St. Fire Pumps.
,,	16	London Oil Storage Company.
,,	12	East and West India Dock Company. Crutched Friars. Pumping at Crutched Friars Warehouse.
,,	8	E. S. Torrey, 27, Britannia Street, Hoxton. Hydraulic Press Pump.

	HP.	
London	8	*Per* Hunter & English, Bow Road, E.
"	8	Rev. Thomas Seddon, Archbishop's Court.
"	8	American Elevator Co. Pumps for Hydraulic Elevators.
"	8	Rylands & Sons Limited, Wood St. Hydraulic Machine.
"	8	New Co-operative Stores, Rupert St. Hydraulic Hoist.
"	6	Compressed Tea Company, 129, Whitechapel. Compressing Tea by Hydraulic Press.
"	6	The Equitable Assurance Company, Cheapside, E.C. Accumulators for Hydraulic Hoist.
"	6	Thurber & Co., 9, Fenchurch Avenue, E.C. Accumulators for Hydraulic Hoist.
"	6	Walker & Co., 2, Old Swan Lane, Upper Thames Street. Hydraulic Pumps.
"	6	J. Dickinson & Co., 65, Old Bailey, E.C. Hydraulic Lift.
"	6	H. Hayes & Co., Henry Street. Hydraulic Pumps in connection with Lifts.
"	6	East London Cemetery Company.
"	4	F. Puckeridge & Nephew, Mount Pleasant Lane, Clapton.
"	4	Gwynne & Co., Essex Street Works, Strand, W.C.
"	3½	Rylands & Sons, London Wall, E.C.
"	3½	*Per* T. Tilley & Sons, 15, Wallbrook, E.C.
"	3½	Josiah Pewtress, 104, Cannon Street. Pumps.
"	3½	A. W. R. & N. Potts, 22, Southwark Buildings. Pumping in Vinegar Works.
"	3½	Alderman McArthur, M.P., Silk Street.
"	3½	City of London Brewery, Upper Thames Street.
"	3½	Sargood, Son & Ewen, Bunhill Row. Two Cranes and Pumping for Hydraulic Lift.
"	2	North London Hospital for Consumption, Hampstead.
"	2	Smallpox Hospital, Highgate.
"	2	Children's Hospital, South Hackney.
"	2	St. Catherine College, White Hart Lane, Tottenham.
"	2	R. L. Crikks, Esq., Oxford Mansions, W.
"	2	Proprietors of Mansion House Buildings, 42, Victoria Street.
"	2	T. Middleton & Co., Loman Street, Southwark.
"	2	G. Edwards & Son, 1 & 2, Poultry. Hydraulic Hoist.
"	2	T. Tilley, 12, Wallbrook, E.C.
"	2	Army and Navy Toilet Club, 24, Queen Victoria Street, E.C. Pumping, &c.
"	2	Mure, Warner & Co., Hampstead Brewery.
"	2	Metropolitan Board of Works, Deptford Pumping Station.
"	2	The Dover Oil Seed Crushing Company, Limehouse, E. Pumping Oil.
"	1	W. Brown, Church Road, Tottenham.
"	1	G. Lansell, Esq., Nightingale Lane, Wandsworth.
"	1	Proprietors of York Mansions, Earl's Court, S.W. Working Lift.
"	1	J. Warner & Sons, Jewin Street.
"	1	J. Warner & Sons, Crescent Foundry, Cripplegate.
"	1	London & South Western Railway Company, Waterloo Bridge Station.

	HP.	
London	1	Crosse & Blackwell, Brewery Road, Caledonian Road.
"	1	J. Tylor & Sons, 2, Newgate Street.
"	1	Taylor & Sons, Newgate Street.
"	1	J. Warner & Sons, Jewin Street.
"	1	J. Warner & Sons, Crescent Foundry, Cripplegate.
"	1	Hardware Agency Company, Hands, Bethnal Green Road. Hydraulic Machinery.
"	1	Crosse & Blackwell, Brewery Road, Caledonian Road.
"	1	Wells & Co., 26, Queen Victoria Street, E.C.
"	1	T. Middleton & Co., Loman Street, S.E.
"	1	T. Middleton & Co., Loman Street, S.E.
"	½	*Per* J. Warner & Sons, Crescent Foundry, Cripplegate.
"	½	Post Office Savings Bank, Queen Victoria Street.
"	½	E. Mackness, Esq., 23, Maiden Lane, E.C.
"	½	Children's Hospital, South Hackney.
"	½	Reliance Insurance Company, King William Street. Hydraulic Machinery.
"	½	Army and Navy Provision Market, Regent St.
"	½	E. Mackness, Meatcock Court, 44, Strand, W.C.
"	5-MP.	*Per* R. Waygood & Co., Falmouth Road, Great Dover Street, S.E.
Lowestoft	1	W. Youngman.
Ludlow	3½	J. W. East, Mineral Water Manufacturer. Pumping and other work.
"	2	H. Lloyd, Corve Street, Maltster.
"	½	Mrs. Foster, Moor Park. Domestic Supply.
Lutterworth (Leicestershire)	1	David Bromilow, Esq., Bitteswell Hall. Domestic Supply.
Maidstone	2	Lady Caroline Neville. Domestic Supply.
"	2	*Per* Taylor & Neate, Foley House.
Malton	6	Malton Farmers' Manure Co. And other work.
Manchester	16	S. Albrecht & Co., Aytoun Street. Pumps for Hydraulic Presses.
"	16	Buckley & Co., 113, Princess Street.
"	16	Brüderer & Co., Princess Street. Hydraulic Press Pumps.
"	16	D. Midgeley & Co. Hydraulic Press Pumps.
"	14	Ligeune, Shimmell & Co., 32, Bloom Street. Hydraulic Press Pumps.
"	12	Crossley Bros. Limited, Openshaw. Combined Engine and Pumps for Hydraulic Cranes, &c.
"	12	Novelli & Co., Chorlton Street. Driving Packing Pumps and Hoists.
"	12	Sidebottom & Hardie, Lower Mosley Street. Driving Packing Pumps and Hoists.
"	12	Liebert & Co., Dolefield, Driving Packing Pumps and Hoists.
"	12	Joseph Hinmers, 8, South Street. Pumps for Press Packing.
"	12	Koecher & Co., Dickinson Street. Pumps for Press Packing.
"	12	Edwards, Cunliffe, Wilson & Co., Byrom Street. Packing Press Pumps and Hoisting.
"	12	J. H. Mort & Co., Bloom Street. Pumps for Press Packing.
"	12	Waeny, Hill & Co., John Dalton Street. Pumps for Press Packing.
"	12	T. Bostock & Co., Bloom Street. Pumps for Press Packing.

	HP.	
MANCHESTER	12	— Bianco.
"	12	— Bellhouse.
"	12	Julius Lesser & Co., Gartside Street. Press Packing.
"	12	Zill & Schwabe, Strangeways. Press Packing.
"	12	Valentine, Dutton & Co., Cooper Street. Press Packing.
"	12	J. Jackson & Co., 75, George Street. Press Packing.
"	12	J. R. Hampson & Sons, South Parade. Hydraulic Press Pumps.
"	12	Shakespear Shaw, Brazennose Street. Hoisting Jiggers, Hoisting and Packing Presses.
"	12	J. Lilley & Co., Minshull Street, Fetter Lane. Hoisting and Packing Presses.
"	12	W. L. Norbury, Major Street. Working Six-Crank Hydraulic Pumps for Presses and Bale Lift and Geared Hoist.
"	12	A. K. Dyson & Co., 38, George Street. Press Pump.
"	12	Fallows & Keymer, Faulkner St. Press Pump.
"	12	Heymansen & Martienson, Lever Street. Press Pump.
"	9	McLeod Brothers, China Lane, Piccadilly. Hydraulic Press Pumps.
"	8	Bell Bros. & Co., Stevenson Square. Press Packing for Export.
"	8	J. G. Thomas, Dickinson St. Press Pumps, &c.
"	7	A. Dux & Co., 11, Grosvenor Street, Piccadilly.
"	6	Middleton, Chiswell & Jones, 2, Chorlton Street, Portland Street.
"	3½	Salomonson & Co., Bloom Street. Hoisting and Pumping.
"	3½	George Everatt, Tib Street.
"	3½	W. & J. Openshaw, High Street. Hoisting, Pumping, Hydraulic Presses, &c.
"	3½	J. A. Turner & Co., 53, Peter Street. Bale Press, &c., Hoist.
"	3½	J. Beaumont, Pump Street, Oldham Road. Press Pumps, &c.
"	3½	Hamilton, Brothers & Co., Minshull Street.
"	3½	John Hough, Charlotte Street. Hoisting and Pumping.
"	3½	Ellinger & Co., 8, Minshull Street.
"	2	L. & Y. Railway Co., Newton Heath, Miles Platting. Pumping for Locomotives.
"	1	R. Haworth & Co., High Street.
MANNINGTREE	3½	W. Brooks & Sons, Mistley.
MARLBOROUGH	½	Benjamin Hillier.
MEERSTHAM	1	W. Gardner, Esq., Rockshaw. Domestic Supply. (With Mansfield Oil Gas.)
MICHELDEVER	12	Portal & Co. (Bank of England Note Paper Works.) Hydraulic Press Pump, and other Work.
MICKLEDOVER	1	A. Wallworth, Esq. Domestic Supply.
NAVERBY	1	R. H. C. Neville, Esq., Wellingore Hall. Domestic Supply.
NEWBURY (Berks)	3½	Hawkins & Co., The Maltings. Pumping and Hoisting.
NEWCASTLE-ON TYNE	3½	Campbell & Erskine, Brewers, Westgate Road. And other machinery.
"	½	J. W. Pease, Esq., Pendover. Domestic Supply.
NEWMARKET	½	Duchess of Montrose, Sefton Lodge. Domestic Supply.
"	½	W. W. Fyfe & Co.
NORTHAMPTON	8	Actyner Doubleday, 81, Carrington Street, Bridge. Accumulators.
"	1	Convent of Notre Dame. Domestic Supply and other work.
NORTH SHIELDS	8	North Eastern Railway Co., Goods Station. Hydraulic Machinery.
NORWICH	1	— Farmer. Hydraulic Hoist.
"	1	J. H. Sperling, Esq., Catton House. Domestic Supply.
NOTTINGHAM	2	C. H. & A. H. Clarke, Lace Manufacturers. Hydraulic Press.
"	1	— Egginton. Pumps for Hydraulic Press.
ORPINGTON	3½	C. W. A. Dickenson, Esq., Park Street. Domestic Supply.
ORWELL PARK (Suffolk)	2	Colonel Tomlin. Domestic Supply.
OSWESTRY	½	Enoch Evans, Brewer.
OXFORD	3½	Radley College. Domestic Supply.
PARSONSTOWN	½	W. W. Stott, Esq.
PERTH	3½	Dowager Marchioness of Lansdowne, Mickle-owar House. Domestic Supply.
"	½	William Muir, Esq., Lynwood House, Scone. Domestic Supply.
PLYMOUTH	6	Pitt, Son & King, 58, Southside Street.
PORTSMOUTH	6	Vosper & Co., Engineers.
RAINHILL	2	Rainhill Asylum. Domestic Supply.
RATHDOWNEY	6	R. Perry & Sons Limited, Brewery.
RAWDON, *near Leeds*	1	M. Bottomley, Esq., Woodleigh Hall. Domestic Supply.
READING	1	Edward Margrett, Kennett Iron Works, King's Road.
"	2	F. Shoolbred, Esq., Pangebourne. Domestic Supply.
REDHILL	3½	Joshua Fielding, Esq., Nutfield Priory. Domestic Supply.
REIGATE HEATH	½	H. G. Ohrly, Esq., Sandells. Domestic Supply and Electric Light.
REPTON, *near Burton-on-Trent*	½ (Vert.)	J. W. S. Peach. Domestic Supply.
"	½	John Shaw, Repton School.
RETFORD (Notts)	½	H. & F. Binley.
RICHMOND	1	D. Watney & Co., Brewers. Pumping in Brewery.
RICKSMANSWORTH (Herts)	2	J. W. Birch, Esq. Domestic Supply.
"	½	John Iles, Esq., The Cedars. Domestic Supply.
ROMFORD	12	E. C. Allan.
ROMSEY (Hants)	2	Tardrew Brothers, Porter's Bridge. Grinding Chalk and Pumping.
ROTHERHAM	½	H. Jones, Esq., Oakwood Grange. Domestic Supply.
RYDE (I. of W.)	3½	Ryde Pier and Railway Co. Centrifugal Pumps.
"	3½	Ryde Pier and Railway Co. Centrifugal Pumps.
"	1½	T. G. Duffett, Iron Brewery.
"	½ (Vert.)	John Rylands, Esq., Longford House. Domestic Supply. Engine combined with Pumps.
SAFFRON WALDEN	3½	Friends' School. Domestic Supply.
"	½	Mistresses' College. Domestic Supply.

	HP.	
SALISBURY	3½	Henry Rogers, East Harnham. Three Chalk Mixing Mills, three Pumps.
,,	1	E. Hall & Son, 56, Castle Street.
,,	1	Dr. Finch, Esq., Fisherton House Asylum. Domestic Supply.
SALTBURN	6	Sir W. J. Pease, Bart. Accumulators for Inclined Tramway.
SCARBOROUGH	3½	Queen's Parade Tramway Company.
SEAFORD	½	Convalescent Hospital. Domestic Supply.
SEVENOAKS	2	T. L. Devitt, Esq., Godden Green. Domestic Supply.
,,	2	— Hudson, Esq., Godden Green. Domestic Supply.
,,	2	Lord Sackville, Knole Park.
,,	1	F. A. Forbes, Esq., Godden Green. Domestic Supply.
SHEFFIELD	2	E. Hall, Esq., Alberydale Park. Domestic Supply.
,,	½	Joshua Tysack, Esq. Domestic Supply.
SHENLEY (Herts)	2	J. H. Sanders, Esq., Porters Park. Domestic Supply.
SHREWSBURY	3½	Mr. Mullard, Maltster.
,,	2	J. Watson, Esq., Berwick House. Domestic Supply.
,,	2	W. J. Mason, Esq., New School Buildings. Domestic Supply.
SOUTHALL	8	St. Mary's Orphanage. Domestic Supply.
,,	1	Feltham School. Domestic Supply.
SOUTHAMPTON	3½	William Vaudry, Esq., Langmore Manor, Ealing. Domestic Supply.
,,	½	R. Moss, Esq., M.P., Western Lodge. Domestic Supply.
SOUTH SHIELDS	6	R. Henderson, Brewer, Thomas Street.
ST. ANDREWS	1	Peter Stewart, Public Baths.
,,	½	Scottish Fishery Board.

	HP.	
ST. HELIERS (Jersey)	1	A. F. Payne, Eastern Railway. Accumulators.
STONEHOUSE (Devon)	½	— Vesper, Brewer.
STOWMARKET	2	E. Green & Son, Ale Stores.
STRATFORD-ON-AVON	1	S. Saunders, Esq., Bearley. Domestic Supply.
STROUD (Glo'ster)	½	Alfred Miller, Gloucester Street.
STUDLEY		— Walker, Esq., Studley Castle. Domestic Supply.
SUTTON VALENCE	½	Rev. G. L. Bennett's School. Domestic Supply.
SWANAGE	8	G. Burt, Esq., Purburt House. Domestic Supply.
TAMWORTH	1	A. B. Foster, Esq., Canwell Hall. Domestic Supply.
TIVERTON (Devon)	1	Pass & Cornish, Engineers.
TORQUAY	1	J. Kitson, Esq., Shipay Park. Domestic Supply.
TROWBRIDGE	7	F. McClean, Esq., Rusthall House. Domestic Supply.
UCKFIELD	1	B. Salter, Chemist. And other work.
WAKEFIELD	2	Saunderson & Sons, Maltsters.
,,	2	Saunderson & Sons, Maltsters.
,,	2	Saunderson & Sons, Maltsters.
WALTHAM ABBEY	2	Royal Gunpowder Factory.
WARMINSTER	2	Carson & Toone, Wiltshire Foundry.
WEST DRAYTON	½	S. E. Taylor, Esq., The Coppins. Pumping Sewage.
WHITCHURCH	½	J. Foster, Esq., Coombe Lodge. Domestic Supply.
WIGTON	1	John Dalton, Tanner, &c.
WINCHESTER	2	Winchester Modern School. Domestic Supply.
WOODBRIDGE (Suffolk)	2	Lord Rendlesham. Domestic Supply.
WOMBWELL	3½	Manchester, Sheffield, and Lincolnshire Railway Company. Accumulators.
WORKINGTON, *via Penrith*	2	Iredale Brothers, High Brewery.
YORK	3½	Rountree, Hill & Co.

CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

LIST OF USERS

OF

CROSSLEY'S "OTTO" GAS ENGINE

FOR

Domestic Purposes, Pumping, Laundry Work, &c.

For Engines in use for Electric Lighting, Farm Work, Organ Blowing, Chaff Cutting, &c. Amateurs' Workshops, &c., see separate List.

	HP.	
Abberley Hall, *near Stourport* ..	3½	John Jones, Esq.
Alloa	1	Captain Young.
Ascot	1	The Hon. R. H. Mead.
,, ...	1	C. D. Kemp Welch, Esq., Red House, Leigham Avenue, Broadlands.
Ashford..........	5-MP.	J. Sterling, Esq., Locomotive Superintendent, South Eastern Railway.
Ashtead........ .	3½	W. Lucas, Esq., Ashtead Park.
Ashton	4	A. Buckley, Esq.
Aylesbury........	7	Baron Rothschild. (Also two 3½-HP. Engines at Leighton Buzzard.)
Ballywater (Co. Down)......	½	John Mulholland, Esq., M.P., Ballywater Park.
Barnet	½	W. J. Cowles, Esq.
Barton-under-Underwood	¾	(Vert.) John R. Walker, Esq., The Knoll.
Bath	½	Gilliard Spence.
Bedford..........	5-MP.	— Harter, Esq., Cranfield Court, near Bedford.
Belfast	6	R. D. Harrison, Esq., Holywood House. And Farm Work.
,, ...	1	James Barbour, Esq. (Coombe, Barbour & Co.)
Birmingham	1	Thomas Hall, Esq., Warley Hall.
Blackpool........	3½	Dr. W. H. Cocker, The Aquarium.
,, ...	½	Prince of Wales Baths. Pumping Sea Water.
Bristol	1	T. Baker, Esq., Walcroft House, Durdham Down.
,, ...	½	Blind Asylum.
Bromley..........	2	E. Hambro, Esq., Hoyes Place.
Brough	½	James Reckett, Esq., Swanland Manor.
Burton Salmon ..	½	John Davies, Victoria Brewery.
Bury	4	Walmsley House.
Cambridge	5-MP.	— Humphreys, Esq. Pumping on a Church Estate at Newnham.
Cargill	2	Dowager Lady Lansdowne.
Carlisle	½	Joseph Graham, Caldergate.
Caterham Junction	2	— Cooper, Esq., Hooley House.
Cheltenham	1	W. H. Freeman, Esq., Thirlstain Hall.
,, ...	1	John Lea, Esq., Elmhurst.
Coldstream......	1	Earl of Home, The Hirsel.
Cottingham, *near Hull*............	5-MP.	D. Wilson, Esq., M.P., Park House.
Coventry	½	Charles Browett, Esq., Westfield.
Cuckfield........	½	S. Knight.

	HP.	
Dalkeith	8	Lord Elphinstone. Pumping Water at Carberry Tower. Water conveyed 340 yards to filtering tanks; thence to double-barrelled gun-metal pump to Queen Mary's Mount. Water rises 320 feet in column, 138 lbs. pressure to sq. in.
Darlington	3½	G. J. Scurfield, Esq., Hurworth-on-Tees.
Deal	1	H. Page, Esq., Walmer Court.
Denbigh	¾	Dr. Turnour, Grove House. (Organ Blowing.)
Derby	½	All Saint's College.
Dudley	1	W. Bassano, Esq., Haden Cross Old Hill.
Duffield	5-MP.	Hon. F. S. O'Grady, Duffield Park.
East Grinstead..	3½	E. C. Blount, Esq., Inberholme Manor.
,, ..	½	J. Tooth, Esq., St. Margaret's Home.
Eccleshill (Yorks.)	3½	J. Mitchell, Esq., The Park. (Has also a 1-HP. Engine for other Work.)
Egham (Surrey) ..	2	Sir W. N. Field.
,, ...	½	G. Raphael, Englefield Green.
,, ...	½	G. Thomas, Park House.
Epsom	3½	Royal Medical College, Epsom Downs.
Faversham	3½	H. Woolright, Esq., Berkley Lodge.
,, ...	2	A. W. Fulcher, Esq., Lyndall Park.
Folkestone	3½	E. Dawes, Esq., Mount Ephraim.
Gloucester	12	Gloucester County Asylum. Pumps, Laundry, and other Machinery. Working with **Dowson Economic Gas.**
......	12	Gloucester County Asylum. Pumps, Laundry, and other Machinery. Working with **Dowson Economic Gas.**
Gravesend	½	— Mallinson, Esq., Cumberland House.
Hale, *nr. Liverpool*.	5-MP.	Colonel Blackburn, The Hall.
Hampton Wick ..	1	Mark H. Robinson, Esq., Emberfield.
Handboro'........	2	James Mason, Esq., Eyeshall Hall, near Witney.
Harrogate	3½	R. Stobart, Esq., Spellow Hill.
Hatfield (Herts)..	6	T. W. Carlisle, Esq. Ponsbourne Park. (Farm Work, &c.)
,, ...	½	J. Camp, Esq.
Haworth-on-Tees	3½	Colonel Scurfield.
Hayward's Heath	½	*Per* J. Warner & Sons.
,, ...	½	*Per* J. Warner & Sons.
Hemel Hempstead	2	A. Longman, Esq., Shendish.
Henley-on-Thames	8	M. R. Noble, Esq., Park Place.
,, ...	6	J. Brennan, Esq., Badgemore. And Electric Lighting.

LIST OF USERS.

	HP.	
HENLEY-ON-THAMES	1	R. Crozier, Esq., Thamesfield.
,,	1	Colonel Makins, M.P., Rotherfield Court.
HERTFORD	2	Robert Smith, Esq., Goldings. Pumping Sewage.
,,	2	Dr. Elim, Leahoe.
HESSLE	½	F. B. Grotrian, Esq., M.P., Crag View.
,,	½	R. F. Jamieson, Esq.
,,	½	Henry Barkworth, Esq.
,,	5-HP.	G. E. Bohn, C.E.
HIGHAM, *near Rochester*	1	Pickersgull Cunliffe, Esq., Great Hermitage.
HITCHIN	½	W. Ransome, Esq., Fairfield.
HULL	½	F. Jamieson, Eastella.
HURSTPIERPOINT	¾	(Vert.) G. B. Woodruff, Esq., Oaklands Park.
ILFORD	5-HP.	A. S. Watford, Esq., Cranbrook Hall.
KESTON	1	G. Fox, Esq.
KILMARNOCK	3½	Sir W. H. Houldsworth, Bart., M.P., Coodham.
KINGSTON-ON-THAMES (Herts)	1	Mark H. Robinson, Esq., Emberfield, Hampton Wick.
LEATHERHEAD	1	Henry Courage, Esq., The Red House.
,,	1	Richard Sturgess, Esq., The Grove.
LEICESTER	2	Lord Stamford, Bradgate House.
LEIGHTON BUZZARD	3½	Baron Leopold de Rothschild, Ascot House.
,,	3½	Baron Leopold de Rothschild, Ascot House. (Also 7-HP. at Aylesbury.)
LINDFIELD (Sussex)	½	W. Sturdy, Esq., Pax Hill Park.
LONDON	8	Rev. Thomas Seddon, Archbishop's Court.
,,	2	North London Hospital for Consumption, Hampstead.
,,	2	Smallpox Hospital, Highgate.
,,	2	Children's Hospital, South Hackney.
,,	2	St. Catherine's College, White Hart Lane, Tottenham.
,,	2	R. L. Crikks, Esq., Oxford Mansions, W.
,,	1	G. Lansell, Esq., Nightingale Lane, Wandsworth.
,,	½	E. Mackness, Esq., 23, Maiden Lane, E.C.
,,	½	Children's Hospital, South Hackney.
LUDLOW	½	Mrs. Foster, Moor Park.
LUTTERWORTH (Leicestershire)	1	David Bromilow, Esq., Bitteswell Hall.
MAIDSTONE	2	Lady Caroline Neville.
,,	2	Foley House. (*Per* Taylor & Neate.)
MEERSTHAM	1	W. Gardner, Esq., Rockshaw. (With Mansfield Oil Gas.)
MICKLEDOVER	1	A. Wallworth, Esq.
NAVERBY	1	R. H. C. Neville, Esq., Wellingore Hall.
NEWCASTLE-ON-TYNE	½	J. W. Pease, Esq., Pendover.
NEWMARKET	½	Duchess of Montrose, Sefton Lodge.
,,	½	W. W. Fyfe & Co.
NORTHAMPTON	1	Convent of Notre Dame. And other Work.
NORWICH	1	J. H. Sperling, Esq., Catton House.
ORPINGTON	3½	C. W. A. Dickinson, Esq., Park Street.
ORWELL PARK (Suffolk)	2	Colonel Tomlin.
OXFORD	3½	Radley College.
PARSONSTOWN	½	W. W. Stott, Esq.
PERTH	3½	Dowager Marchioness of Lansdowne, Mickle-ower House.
,,	½	William Muir, Esq., Lynwood House, Scone.
RAINHILL	2	Rainhill Asylum.
RAWDON, *near Leeds*	1	M. Bottomley, Esq., Woodleigh Hall.
READING	2	F. Shoolbred, Esq., Pangebourne.
REDHILL	3½	Joshua Fielding, Esq., Nutfield Priory.
REIGATE HEATH	½	H. G. Ohrly, Esq., Sandells. And Electric Light.
REPTON, *near Burton-on-Trent*	½	(Vert.) J. W. S. Peach.
,,	½	John Shaw, Repton School.
RICKMANSWORTH (Herts)	2	J. W. Birch, Esq.
,,	½	John Iles, Esq., The Cedars.
ROTHERHAM	½	H. Jones, Esq., Oakwood Grange.
RYDE (I. of W.)	½	(Vert.) John Rylands, Esq., Longford House. Engine combined with Pumps.
SAFFRON WALDEN	3½	Friends' School.
,,	½	Mistresses' College.
SALISBURY	1	Dr. Finch, Esq., Fisherton House Asylum.
SEAFORD	½	Convalescent Hospital.
SEVENOAKS	2	T. L. Devitt, Esq., Godden Green.
,,	2	— Hudson, Esq., Godden Green.
,,	2	Lord Sackville, Knole Park.
,,	1	F. A. Forbes, Esq., Godden Green.
SHEFFIELD	2	E. Hall, Esq., Alberydale Park.
,,	½	Joshua Tysack, Esq.
SHENLEY (Herts)	2	J. H. Sanders, Esq., Porters Park.
SHREWSBURY	2	J. Watson, Esq., Berwick House.
,,	2	W. J. Mason, Esq., New School Buildings.
SOUTHALL	8	St. Mary's Orphanage.
,,	1	Feltham School.
SOUTHAMPTON	3½	William Vaudry, Esq., Langmoor Manor, Ealing.
,,	½	R. Moss, Esq., M.P., Western Lodge.
STRATFORD-ON-AVON	1	S. Saunders, Esq., Bearley.
STUDLEY		— Walker, Esq., Studley Castle.
SUTTON VALENCE	½	Rev. G. L. Bennett's School.
SWANAGE	8	G. Burt, Esq., Purburt House.
TAMWORTH	1	A. B. Foster, Esq., Canwell Hall.
TORQUAY	1	J. Kitson, Esq., Shipay Park.
TROWBRIDGE	7	F. McClean, Esq., Rusthall House.
WEST DRAYTON	½	S. E. Taylor, Esq., The Coppins. Pumping Sewage.
WHITCHURCH	½	J. Foster, Esq., Coombe Lodge.
WINCHESTER	2	Winchester Modern School.
WOODBRIDGE (Suff.)	2	Lord Rendlesham.

LAUNDRY WORK.

(See also "Domestic Purposes.")

	HP.	
BIRMINGHAM	2	(Vert.) Birmingham Coffee House Company, Cobden Hotel.
BLACKPOOL	½	Prince of Wales' Baths.
BROOKWOOD, *near Woking*	½	C. Beale, Esq., Brookwood Asylum.
GLOUCESTER	12	Gloucester Lunatic Asylum.
HARROGATE	3½	George Donson, Esq.
HENLEY-ON-THAMES	5-HP.	W. H. Smith, Esq., M.P., Greenlands.
LLANDERFEL	½	H. Robertson, Esq., M.P., Pale, Corwen.
LONDON	12	Lambeth Infirmary, Brook Street, Kennington.
,,	8	*Per* W. Blenkinson, Son & Co., 56a, Murray Street, N.
,,	3½	Belsize Park Laundry, Fair Hazell Gardens, Belsize Park.
,,	3½	St. Mary's Orphanage, North Hyde, Hounslow.
,,	3½	E. C. Orr & Haswell, 5, 6 and 7, Jewin Crescent.
,,	3½	The Royal Patriotic Asylum, Wandsworth, S.W.
,,	2	North London Hospital for Consumptives, North Vernon, Hampstead. Pumping.
,,	2	Smallpox Hospital, Highgate Hill, N. Pumping.
,,	2	Smallpox Hospital, Highgate Hill, N. Pumping.
,,	2	*Per* T. Bradford & Co., High Holborn, W.C.
,,	1	W. Ward, 7, Mayall Road, Brixton, S.W.
,,	1	G. W. Whitehead, Park Road, Acton, W.
LONDON	¾	(Vert.) National Hospital for the Paralysed and Epileptic, Queen's Square, Bloomsbury.
,,	½	North Eastern Hospital for Children, Hackney Road, E.
,,	½	The Brown Institution, Wandsworth Road, S.W.
,,	½	W. Williamson & Co., 133, High Holborn, W.C.
LYTHAM	3½	Clifton Arms Hotel Company Limited.
MANCHESTER	4	Penitentiary, Great Islington Street.
,,	3½	Royal Infirmary.
,,	1	Royal Eye Hospital.
NEW BRIGHTON	3½	French Laundry Company, Egerton Street.
NEWCASTLE-ON-TYNE	2	C. T. Maling, 14, Ellison Place.
NORTHAMPTON	1	Convent of Notre Dame.
RAWDON, *near Leeds*	1	M. Bottomley, Esq., Woodleigh Hall.
REDHILL	6	St. Annes School.
RICHMOND	8	Royal Laundry, Blythswood.
RIPON	¾	R. Kearsley, Esq., Highfield.
SAFFRON WALDEN	3½	Friends' School.
SHANKLIN (I. of W.)	2	Thomas Harvey, Esq., The Cliffe.
SOUTHPORT	½	Chadwick's School.
WORTLEY, *near Leeds*	2	Mr. Marsden.

CROSSLEY BROTHERS LIMITED, Engineers, OPENSHAW, MANCHESTER.

2,000. 12/87. CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

3½ J. Boyd & Son, Strangeways. Hoisting.
3½ Isaac Marsden, Cable Street. Hoisting.
3½ Schwann, Modera & Co., 117, Portland Street. Hoisting.
3½ Dacca Twist Company, Great Bridgewater Street. Hoisting.
3½ Salomonson & Co., Bloom Street. Hoisting and Pumping.
3½ John Hough, Charlotte Street. Hoisting and Pumping.
3½ Hamilton Brothers & Co., Minshull Street. Hoisting.
3½ Milnes Brothers, Faulkner Street. Warehouse Hoist.
3½ Jones Brothers & Co., York Street. Hoisting.
3½ Richardson, Tee, Rycroft & Co., Portland Street. Hoisting.
3½ D. Matheson & Co., Peter Street. Hoisting.
3½ W. A. Louis, 15, Major Street. Hoisting.
3½ Ellinger & Co., 8, Minshull Street. Lapping Machines, &c.
3½ Waddington & Ramsbottom, Nicholas Croft. Hoisting.
3½ W. & J. Openshaw, High Street. Hoisting, Pumping, Hydraulic Presses, &c.
3½ J. A. Turner & Co., 53, Peter Street. Driving 5 Winding Frames, 1 Bale Press, and Hoist.
3½ J. Hoyle & Son, Mosley Street. Hoisting.
3½ Arnold, Constable & Co., Lower Mosley Street. Hoisting.
3½ G. Hodgkinson & Sons, 13, Major Street. General Hoists.
3½ McIntyre, Hogg & Co., 16, Newton Street. Sewing Machines.
3½ Portland Street Manufacturing Company. Sewing Machines.
3½ Gemmell & Harter, 16, Charlotte Street. Hoisting.
3½ Tootal, Broadhurst & Co., Ogden Street Works, Cornbrook. Sewing Machines.
3½ F. Collier & Co., 33, High Street. Hoisting.
3½ Brown & Murray, 6a, Pump Street, London Rd. Sewing Machines.
3½ Robert Proctor, Deansgate. Hoisting.
3½ J. Royle & Co., Dantzic Street. Hoisting.
3½ J. & N. Phillips & Co., Turner Street. Hoisting.
3½ Jas. Beaumont, Pump St., Oldham Rd. Hoisting and Press Packing.
2 Greg Brothers & Co., Chancery Lane. Hoisting.
2 Fox & Kay, 17, Cannon Street. Hoisting.
2 Atcherley & Lund, Corporation Street. Hoisting.
2 Harding, Son & Co., New Brown Street. Hoisting.
2 Wrigley & Son, 29, John Dalton Street. Hoisting.
2 Ralph Harrison & Sons, Waste Dealers, Salford. Hoisting.
2 G. W. Simpole, Rag Dealer, Sutton Street. Hoisting Bags of Rags.
2 Fothergill & Harvey, 31, Cooper Street.
2 Robert Pattison, Pump Street. Hoisting.
2 Samuel Ogden, 7, New Cannon Street. Band Knives.
1½ Charles Newsome, 64, Jersey Street.
1 R. Haworth & Co., High Street. Lapping Machines.
1 William Shaw, 68, Dantzic Street. Hoisting.
1 J. H. Garside & Co., 36, Fountain Street.
½ T. H. Rigby & Co., 2, Parker Street, Manchester. Band Knife.
½ J. G. Tiller, 38, Bloom Street. Two Lapping Machines.
½ J. Dyson, Portland Street. Hoisting.
½ R. Johnson, 35, Tib Street. Cloth Cutting.
½ (Vert.) James McLaren, 28, Portland Street.
½ (Vert.) Joseph Bleackley & Son, 105, Port Street. Lapping Machines.
5-HP. Beaver Packing House, Dickinson Street. Lapping Machinery.

N.B.—The above List does not comprise the whole of the Engines at work in Manchester, but only those engaged in the work above mentioned.

CROSSLEY BROS. LIMITED,

OPENSHAW, MANCHESTER.

LIST OF

CROSSLEY'S "OTTO" GAS ENGINES

IN USE BY

Local Boards and other Public Bodies

FOR

PUMPING, FOG SIGNALLING, &c.

TOWN.	HP.	NAME OF USER AND REMARKS.
ABBOTTS LANGLEY	6	Waterworks—A. F. Phillips, Esq., Engineer. (Combined with Crossley's pumps, 6in. by 8in. Pumps 4,000 galls. per hour about 300 feet high.)
"	6	Waterworks. (Duplicate of above.)
ACTON	6	Bedford Park Sewage Works. (Working chain sewage pump.)
"	3½	Bedford Park Sewage Works. (Working chain sewage pump.)
AILSA CRAIG	8	Syren Fog Signalling.
"	8	
"	8	
"	8	
"	8	
ALFRETON	3½	Waterworks; Rural Sanitary Authority, Mansfield Union.
"	3½	Waterworks; Rural Sanitary Authority, Mansfield Union.
ANDOVER	8	Waterworks. (One set of three-throw 9-in. deep well pumps, doing about 12,000 galls. per hour 90 feet high).
ANFIELD, *near Liverpool*	1	Gas Company.
BALLYMENA	6	Sewage Works.
BARNSLEY	8	Hull and Barnsley Railway Co. (Accumulators for raising swing bridge.)
BEESTON	6	Sewage Works.
"	6	Sewage Works.
BELFAST	12	Harbour Commissioners, Clarendon Dock. (Pumps for hydraulic turning of bridge.)
BESCOT	6	Sewage Farm.
BIRMINGHAM	12	Waterworks, Aston Station. (This corporation have also two 12-HP. Engines at their gas works, pumping into accumulators.)
"	3½	Kingshorton Union.
BRISTOL	12	Waterworks, St. George's. (Combined with Crossley's 7-in. by 9-in. pumps.)
"	12	Waterworks, St. George's. (Duplicate of above.)
"	8	Dock Commissioners, Princess Street Bridge. (Pumps for hydraulic turning of bridge.)
BROADSTAIRS	8	Waterworks. (One set of three-throw pumps, 5 in. by 14 in., pumping 5,041 galls. 195 feet.
CARDIFF	7	Taff Vale Railway Company. (3-in. and 4½-in. pumps, three rams, delivering 20 galls. of water per minute, at 400 lbs. per inch pressure.)
CARNFORTH	1	Gas Company.
CHELMSFORD	8	Waterworks. (Combined with two pumps, 8 in. and 10 in., doing 10,000 galls. per hour 100 feet high.
CHESHAM	6	Waterworks. (Pumping with one set of pumps 7,500 galls. per hour, or 15,000 galls. with two sets of pumps. Height of lift, 104 feet.)
"	6	Waterworks. (As stand-bye to above.)
COLNEY HATCH	6	County Lunatic Asylum. (Combined with Crossley's pumps, doing 14,000 galls. per hour 28 feet high.)
CORK	8	Harbour Commissioners, Anglesea Bridge. (Pumps for hydraulic turning of bridge.)
DEVIZES	3½	Wilts County Asylum. (With Crossley's pumps combined.)
DISS	3½	Local Board.
DUBLIN	16	General Post office. (For pneumatic tube system.)
"	16	General Post Office. (Duplicate of above.)
"	8	Commissioners of Irish Lighthouses, Howth Bailey. (Fog signalling.)
"	8	Commissioners of Irish Lighthouses, Howth Bailey. (Duplicate of above.)
DUNDEE	16	Harbour Trust. (Hydraulic machinery.)
EALING	2	Local Board.
EAST STONEHOUSE	½	Local Board. (Filling water carts.)
EAST GRINSTEAD	6	Local Board. (One set of three-throw pumps, 5 in. by 15 in., doing 2,400 galls. per hour 180 feet high.)
"	1	Local Board. (Sewage Works.)
JARROW-ON-TYNE	1	South Shields Gas Company.
KIMBOLTON	2	Sanitary Authorities.
KIRKLEATHAM	2	Local Board. (One set of three-throw 5-in. pumps combined with engine.)
KNUTSFORD	3½	Local Board.
LINCOLN	6	Waterworks.
LITTLEHAMPTON	2	Local Board. (Pumping sea water for street purposes.)
LONDON	12	Regent's Canal. (Rotary pump; 300,000 galls. per hour 8 feet high.)
"	8	Submarine Telegraph Co. (Pneumatic tube system.)
"	8	Submarine Telegraph Co. (Pneumatic tube system.)
"	2	Hampstead Hospital.
"	2	Westminster Union. (Combined with Crossley's pumps, 4 in. by 6 in., delivering 2,000 galls. of water 62 feet high per hour.)
"	½	Children's Hospital, South Hackney.
MANCHESTER	8	London and North-Western Railway Passenger Hoist, London Road. (With pumps combined, for accumulators.)
MITCHAM	6	Infirmary.
MORLEY	8	Waterworks.
NEWPORT PAGNELL	4	Local Board.
"	4	Local Board.
NORTH SHIELDS	8	North-Eastern Railway Company. (Pumping into accumulators.)
NORTHAMPTON	6	Sewage Works. (Pumping 18,000 galls. per hour 100 feet high.)
"	6	Sewage Works. (Duplicate of above.)
OXFORD	1	New Botley Sewage Works. (Pumping 3,000 galls. per hour. Crossley's pumps.)
"	1	New Botley Sewage Works. (Duplicate of the other.)
PORTSEA ISLE	4	Union Workhouse. (Set of three-throw pumps, delivering 1,303 galls. 18 feet high per hour.)
PORTSMOUTH	8	Dry Dock. (Centrifugal pumps, lifting 20,000 galls. per hour 15 feet high.)
"	4	Stainshaw Sewage Works. (*See* STAINSHAW.)
"	2	Semaphore Tower. (Driving Crossley's pumps, doing 6,000 galls. per hour 50 feet high.)
"	2	Waterworks.
RAINHILL	2	Rainhill Asylum.
REDHILL	6	St. Anne's School.
SALISBURY	6	Local Board—C. E. Bothams, Esq., Surveyor. (At New Sewage Works, Fisherton, dealing with 3,000,000 galls. daily; driving centrifugal pumps, strainers, &c. **Engine driven by the Dowson Economic Gas process.**)
"	6	Local Board. (Duplicate of above.)
SALTBURN-BY-SEA	6	Improvement Commissioners. (With Crossley's pumps combined. Pumping water for raising inclined tramway.)
SCARBOROUGH	3½	Scarborough Cliff Company. (Pumping water for inclined tramcar lift.)
STAINSHAW	4	Sewage Works. (Set of three-throw pumps, 9 in. by 18 in., 16,000 galls. per hour 27 feet high.)
"	4	Sewage Works. (Duplicate of above.)
STRATFORD-ON-AVON	6	Sewage Works. (Set of two-throw pumps, 10 in. by 12½ in., doing 21,000 galls. per hour 23 feet high.)
"	6	Sewage Works. (Duplicate of above.)
"	6	Sewage Works. (Duplicate of above.)
STEVENAGE	9	Local Board. (**Working with the Dowson Patent Economic Gas**, driving three-throw pumps, lifting 7,500 galls. of water per hour 200 feet high.
ST. ALBANS	12	Local Board. (Combined with Crossley's pumps, 10in. by 12½in., 13,000 galls. per hour 250 feet high.)
SUTTON VALENCE	2	Waterworks. (One set of three-throw pumps, 4 in. by 9½ in., 2,600 galls. per hour 105 feet high.)

Enfield	6	Local Board. (Combined with Crossley's pumps, 7 in. by 9 in., doing about 8,800 galls. per hour.)
"	½	Royal Engineers.
Epsom	3½	Local Board. (One set of three-throw pumps, 3 in. by 10 in., doing 2,000 galls. 25½ feet high per hour.)
Finchley	12	Local Board. (One set of three-throw pumps, 11 in. diameter, 15 in. stroke, lifting 420 galls. of sewage per minute 70 feet high. **Working with the Dowson Economic Gas.**)
"	12	Local Board. (Duplicate of the above.)
Glasgow	16	Trustees of the Clyde Navigation. (Pumping at Govan Dock.)
"	6	Trustees of Clyde Lighthouse, Cumbrae Island. (For fog signals.)
Gloucester	12	First Gloucester County Asylum. (**Engine worked by Dowson Economic Gas process.**)
"	12	First Gloucester County Asylum. (Duplicate of above.)
Godalming	16	Frith Hill, Godalming and Farncombe Water Co. (Pumping 7,000 galls. per hour. Height of lift: 187 feet into reservoir; 262 feet into tower; total, 449 feet. Cost per week of 86 hours, £1 14s. 10d. **Working with Dowson's Patent Economic Gas.**)
Guildford	12	Waterworks. (Two sets of 6-in. three-throw pumps, delivering 8,000 galls. per hour 300 feet high, and 5,000 galls. per hour 165 feet high; total, 13,000.)
Halifax	12	Lancashire and Yorkshire Railway Co. (Accumulator work.)
Hanwell	3½	Local Board. (Drives two stirrers, and pumps 7,200 galls. per hour 20 feet high with centrifugal pump.)
Hastings	6	Rural Sanitary Authority. (Set of three-throw pumps, delivering 4,000 galls. of water 280 feet high per hour.)
Hornsey	2	Local Board. (Double-acting vertical pump, 6 in. by 12 in.; suction, 4 in.; delivery, 6 in.; lifting power per stroke, 2·33 galls. sewage; height of lift, 23 feet; average amount of sewage per hour, 6,020 galls. [can do 7,000 galls.] Gas consumption, about 40 feet per hour.)
"	2	Local Board. (Duplicate of above.)
Holt	3½	Gas and Water Company.
Hull	12	Kingston Gas Company.
Ilford	6	Sewage Works. (Rotary pumps, delivering 18,000 galls. of sewage 28 feet high per hour Gas consumed about 160 cubic feet per hour.)
"	6	Sewage Works. (Duplicate of above.)
Isle of Man	3½	Langness Point Fog Signalling. (Worked with Keith's oil gas.)
"	3½	Langness Point Fog Signalling. (Duplicate of above.)
Swanage	8	Waterworks. (One set of three-throw pumps, 5 in. by 5 in., 5,637 galls. 150 feet high.)
"	8	Waterworks. (Duplicate of above.)
Toward Point	1	Lighthouse. (Ringing danger bell.)
Tunbridge	9	Local Board. (Deep well pump, lifting 12,000 galls per hour 150 feet high.)
"	9	Local Board. (Duplicate of the above.)
Tunbridge Wells	1	Sewage Works.
"	1	Waterworks.
Tynemouth	8	North-Eastern Railway. (Pumping into accumulators.)
Uppingham	2	Gas Company.
Wallingford	6	Waterworks. (One set of two-throw pumps, 6 in. by 18 in., doing 6,500 galls. per hour 70 feet high.)
"	6	Waterworks. (Duplicate of above.)
Waltham Abbey	2	Royal Gunpowder Factory.
Watford	1	Levesden Asylum.
Wednesbury	16	Sewage Works. (Combined with air pumps, delivering 2,400 cubic feet of air, at 30 lbs. pressure, per hour.)
"	16	Sewage Works. (Duplicate of above.)
Wellington (Somerset)	9	Waterworks. (Set of three-throw pumps, 7 in. by 4½ in., doing 7 500 galls. per hour 139 feet high. **Engine driven by the Dowson Patent Economic Gas Process.**)
"	9	Waterworks. (Duplicate of above.)
West Malling	½	Waterworks. (Pumps, 6 in. by 12 in.; about 3,000 galls. per hour.)
"	½	Waterworks. (Duplicate of above.)
Westminster	2	Westminster Union. (With Crossley's pumps combined.)
Whitstable	12	Waterworks. (Set of three-throw pumps, 8 in. by 17 in., doing 6,497 galls. 190 feet high.)
Wimbledon	3½	Drainage Board Waterworks. (Set of bucket and plunger pumps, raising 10,500 galls. 33 feet high per hour. Gas consumed, one cubic foot for each 112 galls. lifted.
"	3½	Drainage Board Waterworks. (Duplicate of above.)
Woolwich	2	Becton Sewage Works. (Drives three-throw 4-in. pump for sewage.)
Yarmouth	8	Local Board. (With Crossley's 12-in. by 15-in. pumps combined. Pumping sea water for flushing mains and streets.)
"	6	Sewage Works.
Yeadon	6	Waterworks.
York	2	Skeldergate Bridge Committee. (Pumping for bridge.)

The above List comprises only Engines at work in this country.

For List of Users of Engines Pumping on Private Estates and for Trade Purposes, see separate List.

For Engines in use at Gas Works, Pumping for Scrubbers and Works' Purposes, Exhausting, &c., see separate List.

CROSSLEY BROS. LIMITED,

"Otto" Gas Engine Works,

OPENSHAW, MANCHESTER.

10—7.87

CUTHBERTSON & BLACK, MANCHESTER.

List of a Few Users of

THE "OTTO" GAS ENGINE

FOR

MECHANICAL VENTILATING.

TOWN.	HP.	NAME OF USER.
ABERDEEN	3½	Rosemount Public School. (48-in. Blackman fan.)
,,	3½	King Street Public School. (48-in. Blackman fan.)
ACCRINGTON	1½ VERT.	New Jerusalem Schools. (Blackman fan.)
BIRKENHEAD	2	Thomson, Townsend & Son. (Blackman fan.)
,,	2	Sessions Court.
BIRMINGHAM	1½	New Board Schools, Barford Street.
BRADFORD	12	Fox & Whitley. (Root's blower and Blackman's air propeller, for wool-sorters' room.)
BRISTOL	12	Merchant Ventures School. (Bacon's system.)
,,	—	W. D. & H. O. Wills, Tobacco Manufacturers. (Blackman fan.)
CLIFTON	3½	University College.
CLAVERHOUSE *near Dundee*	3½	Boase & Co. (Blackman air propeller.)
DUBLIN	—	"Irish Times" office.
DUNDEE	3½	Harris's Academy. (Blackman fan.)
,,	2	High School for Girls. (48-in. Blackman fan.)
,,	2	Dundee University College, Medical Department. (Cunningham's system.)
,,	1	High School. (Cunningham's system.)
EDINBURGH	½	Edinburgh University, Chemical Department. (Blackman fan.)
FINCHLEY (East and West)	½	Board Schools. (Blackman fan.)
FORMBY	½	Dr. Gill's Retreat. (Haden's system.)
GATESHEAD	—	J. Robinson & Co., Bacon Curers. (Blackman fan.)
GLASGOW	2	Hillhead School. (Alleyn's system.)
HOLLINWOOD	2	S. Oldroyd & Sons, Glue Works.
LEEDS	—	J. Barran & Sons, Cloth Manufacturers. (Blackman fan.)
,,	5-HP.	Midland Railway Company's Queen's Hotel. (Driving Blackman fan.)
LIVERPOOL	2	University College, Chemical Department.
LONDON	—	Hazell, Watson & Viney, Printers, Hatton Garden, E.C. (Blackman fan.)
,,	—	Civil Service Bread Association Limited, Horseferry Road, Westminster.
,,	—	W. Cate, Printer, Bouverie St., E.C. (Blackman fan.)
,,	—	Howard & Jones, Printers, Bury Street, St. Mary Axe, E.C. (Blackman fan.)
,,	—	Nissen & Arnold, Printers, Fenchurch Street, E.C. (Blackman fan.)
,,	—	Standidge & Co., Printers, White Street, E.C. (Blackman fan.)
,,	—	Bemrose & Son, Printers, Old Bailey, E.C. (Blackman fan.)
LONDON	—	T. J. Whiting, Printer, South Place, E.C. (Blackman fan.)
,,	—	W. Augener, Printer, Little Windmill Street, E.C. (Blackman fan.)
,,	—	Straker Brothers & Co., Printers, Camomile Street, E.C. (Blackman fan.)
,,	—	A. Kingdon & Co., Printers, Moorfields, E.C. (Blackman fan.)
,,	—	Bowles & Son, Printers, George Street, Mansion House, E.C. (Blackman fan.)
,,	—	Walbrook & Co., Printers, Whitefriars Street, E.C. (Blackman fan.)
,,	—	Blades, East & Blades, Printers, Leonard Street, E.C. (Blackman fan.)
,,	—	W. Straker, Printer, Ludgate Hill, E.C. (Blackman fan.)
,,	—	Marchant, Singer & Co., Printers, St. Mary Axe, E.C. (Blackman fan.)
,,	—	Brooke, Bond & Co., Tea Merchants, High Street, Whitechapel, E. (Blackman fan.)
,,	—	Reed Brothers, Beer Bottlers, Kentish Town Road, N.W. (Blackman fan.)
,,	—	J. L. Bacon & Co., Engineers, Upper Gloucester Place, N.W. (Blackman fan.)
,,	—	J. T. Farwig & Co., Queen St., E.C. (Blackman fan.)
,,	—	J. Shoolbred & Co., Upholsterers, Tottenham Court Road, W. (Blackman fan.)
,,	—	Army and Navy Toilet Club, Queen Victoria Street, E.C. (Blackman fan.)
MALTON	—	Malton Farmers' Manure Co. (Blackman fan.)
MANCHESTER	1½	Owens College.
,,	1½	Owens College.
,,	—	Chorlton & Knowles, Printers. (Blackman fan.)
,,	—	Bodega Wine Co., Cross Street. (Blackman fan.)
NEWCASTLE-ON-TYNE	—	Sir W. G. Armstrong & Co., Engineers. (Blackman fan.)
,,	—	Wholesale Co-operative Society. (Blackman fan.)
PENDLETON	—	Co-operative Society. (Blackman fan.)
PENTONVILLE	—	Dunn & Hewett, Confectioners. (Blackman fan.)
RICHMOND	—	H. Morris, Baker, 21, George Street. (Blackman air propeller.)
SHEFFIELD	2	Town Hall.
ST. HELENS	2	Pilkington & Co. (Haden's system.)
WAKEFIELD	3½	Her Majesty's Prison.
WORCESTER	—	Worcester Porcelain Company. (Blackman fan.)

NOTE.—*Where the size of Engine is not given, the Fan forms only one of the many machines driven by the Engine.*

CROSSLEY BROS. LIMITED, OPENSHAW, MANCHESTER.

CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

List of a Few Gas Companies

USING

CROSSLEY'S "OTTO" GAS ENGINE.

	HP.	
Aberavon	½	Gas and Water Works. Exhausting.
Anfield, *near Liverpool*........	1	Gas Company. Exhausting.
Armagh	3½	Gas Works. Exhausting and Pumping.
Ashton	4	Gas Company.
Atherstone......	3½	Gas Company.
Barnsley	3½	Wombwell Local Board of Health. Gas Exhausting and Pumps.
"	1	Old Mill Gas Works. Driving Scrubber.
Bath	6	Gas Works. Exhausting.
Beccles	1	Gas Works. Exhausting and Pumping.
Beckton..........	2	Gas Light and Coke Company.
Berwick-on-Tweed..........	1	Gas Company. Pumping.
Bessbrook	1	Bessbrook Spinning Company Limited. Exhausting Gas.
Beverley	6	Gas Works. Pumping and Scrubber.
Birmingham	12	Birmingham Corporation, Windsor Street Gas Works. Pumping. (This Corporation have also several other Engines in their various departments.)
"	12	Birmingham Corporation, &c.
Bishops Stortford	3½	Gas Company, Gas Works. Exhauster, &c.
Blackpool........	1	Gas Works, Kirkham, near Blackpool. Pumping.
Bolton	3½	Gas Company.
Bowness..........	½	Windermere District Gas Company. Exhausting.
Bradford	2	Clayton Gas Company. Gas Exhausting.
Brentford	16	Gas Company, High Street. Gas Exhausting.
Brigg	1	The Gas Company Limited. Driving 2,200 Gwynne and Beale's Exhauster, Pumping and Distributing Water for Tower Scrubber.
Bristol	8	The Gas Light and Coke Company. Gas Works.
Broadstairs......	3½	Gas Works. Drives a 5,000 Gwynne and Beale's Exhauster. (Also 8-HP. in Water Supply Department.)
Carlow	1	Gas Company. Exhausting.
Carnforth	1	Gas Company. Pumping, Exhausting, &c.
Chelmsford	8	Gas Works. Pumping.
Cheltenham	6	Gas Company, Tewkesbury Road. Machine Tools in Repairing Shop.
Chester	3½	Gas Works. Machine Shop.
Clayton, *near Bradford*........	2	Clayton West Gas Company. Gas Exhausting.
Clevedon	2 (Vert.)	Gas Works. Exhausting and Pumping.
Clonmel..........	5-HP.	Gas Company.
Doncaster	6	Gas Works. Hoisting.
Driffield	1	Driffield Gas Company. Gas Exhausting and Pumping.
Dublin	8	Alliance Gas Company. Pumping.
"	6	Alliance Gas Company. Ammoniacal Liquor Pumps.
"	3½	Alliance Gas Company. Driving Dynamo.
"	2	Alliance Gas Company.
"	1	Alliance Gas Company.
Dundalk	3½	Dundalk Gas Company. Exhausting Retorts and Pumping Water to Scrubbers, &c.
East Grinstead..	7	Gas Works.
Edinburgh........	½	Gas Company. Turning Lathes.
Evesham	3½	Gas Company. Exhausting and Pumping.
Exeter	3½	Willey & Co., Gas Works.
Fareham	3½	Fareham Gas Company. Driving 5,300 Beale's
Leith	3½	Edinburgh and Leith Gas Company. Driving Lathes, &c., in Mechanics' Shop.
Leominster	3½	Leominster Gas and Coke Company. Drives a 5,000 Beale's Exhauster and Pumps.
Limerick	12	Gas Works. Two Siemen's Electric Upright Machines, and one D. 6-Dynamo supplying two Arc lights of 6,000 candle-power, for lighting docks.
Llangollen	½	Gas Company.
London	8	Phœnix Gas Company, Vauxhall.
"	8	Gas Light and Coke Company's Works, Horseferry Road.
"	8	Commercial Gas Company, Stepney.
"	3½	Hunter & English. Gas Exhausting and Hoisting.
"	2	Crystal Palace District Gas Company, Lower Sydenham. Coke Breaking.
"	2	South Metropolitan Gas Works, 589, Old Kent Road. Coke Breaking.
"	2	Crystal Palace District Gas Company, Lower Sydenham.
"	2	London Gas Works, Nine Elms.
"	2	Commercial Gas Company, Stepney.
"	2	Metropolitan Gas Works, Old Kent Road.
"	1	Metropolitan Gas Works, Old Kent Road.
"	1	Crystal Palace District Gas Company, Lower Sydenham.
"	1	South Metropolitan Gas Works, 582, Old Kent Road.
"	1	London, Brighton, and South Coast Railway Company's Gas Works, Cold Blow, New Cross.
"	1	London, Brighton, and South Coast Railway Company's Gas Works, Cold Blow, New Cross. Driving Rotary Exhaust.
"	1	London Gas Company, Fulham.
Longridge (Preston)	1	Gas Company. Exhauster, Scrubber, and Tar Pump.
Looe (Cornwall) ..	1	Gas Company.
Loughborough ..	2	Gas Company.
Ludlow	2	Ludlow Union Gas Works. Exhausting.
Lurgan	3½	Lurgan Gas Company. Exhauster and 2 Pumps.
Lytham	2	Improvement Commissioners. Gas Works.
Maidstone	3½	Gas Company. Driving Lathe.
Malton	3½	Malton Gas Company. Driving Double-Cylinde Gas Exhauster, and Pumping Water.
Matlock	1	Gas Company. Exhausting.
Matlock Bridge	1	Gas Company. Exhausting.
Melksham........	½	Gas Company. Exhausting.
Middleton	½	Gas Company. Washer, &c.
Middlewich	1	Gas Light Company. Pumping and Exhausting.
Mitcham (Surrey)..	2	Holborn Union Gas Works.
Musselburgh and Portobello	3½	Gas Company. Pumps, &c.
Musselburgh	3½	Gas Company. Exhausting and Pumping.
Newhaven........	5-HP.	Gas and Coke Company.
Newton Abbott..	3½	Newton Gas and Coke Company. Driving Beale's Exhauster, &c.
Nuneaton........	8	Gas Works. Exhausting and Pumping.
Oldham	2	Gas Company, Greaves Street.

Fareham	3½	Fareham Gas Company. Driving 5,300 Beale's Exhauster and working a pair of Ammoniacal Liquor Pumps.
Fareham	3½	Gas Company. Exhausting.
Farringdon	1	Gas Works. Driving Exhauster, &c.
Galway	3½	Gas Light and Coke Company. Exhausting.
Guildford	8	Gas Company.
Halifax	8	Gas Company. Exhausting.
„	1	Gas Company. Breaking Coke, &c.
Handsworth Woodhouse	½	Gas Company. Exhausting and Pumping.
Harrogate	½	Gas Company.
Hartlepool	3½	Gas Company.
„	1	Gas Company.
„	5-MP.	Gas Company.
Hastings	2	Gas Company. Coke Breaking.
Haworth, *near Keighley*	2	Gas Company. Works a 10,000 Gas Exhauster and Pumps for Tar and Liquor.
Hessel, *near Hull*	1	Gas Company. Exhausting.
Hexham	2	Gas Company. Exhauster and two Pumps.
Hinckley	3½	Hinckley Gas Company. Exhausters, Pumping, and Coke Crushing; works day and night.
Holyhead	5-MP.	Gas Company.
Huddersfield	7	Gas Works.
„	3½	Corporation Gas Works, Mold Green. Exhauster.
Hull	12	Kingston Gas Co. Exhausting and Pumping.
„	½	British Gas Company.
Huntingdon	2	Gas Works. Exhausting, Pumping Water, and Drawing Dempster's Patent Scrubbers.
Isle of Man	6	Gas Company.
Jersey	1	Gas Light Company.
Keighley	6	Gas Company. Exhausting.
Keswick	1	Gas Works. Exhausting.
Kington (Herts)	1	Gas Works.
Kirkham	½	Gas Company.
Knaresborough	4	Gas Works.
Leamington	3½	Leamington Priors Gas Company. 50,000 per hour Exhauster for Ventilating Foul Lime Purifier, Chaff Cutting, Crushing Oats, Mortar Mill.
Leatherhead	2	Gas Company.
Leeds	6	Gas Company. (Wortley Depôt).
„	6	Gas Company. (Wortley Depôt).
„	6	Gas Company. (Kirkstall Depôt).
„	6	Gas Company. (Kirkstall Depôt).
„	6	Gas Company. (Sheepscar Depôt).
Leicester	½	The Gas Works, Aylestone Road. Pumping.
Leith	6	Edinburgh and Leith Gas Company, 11, Baltic Street. Driving Scrubber.
Oldham	2	Gas Company, Greaves Street.
Oswestry	6	Gas Company. Pumping, Exhausting and Scrubbing.
Paignton	3½	Torquay Gas Works. Pumping.
Parsonstown	½	Gas Company. Pumping.
Portobello	3½	Gas Company. Exhausting, &c.
Portishead	½	Gas Works.
Preston	2	Gas Works.
„	½	Gas Works. Coke Crushing.
Redhill	3½	Gas Works. Exhausting.
Rhyl	1	Gas Company. Driving Scrubbers.
Rochester	3½	Gas Company. Coke Crushing and Tools.
Romsey (Herts)	½	(Vert.) Gas Company. Exhausting and Pumping.
Rotherham	2	Gas Company. Coke Crushing.
Ryde	5-MP.	Gas Company.
Sheffield	8	Gas Company.
„	8	Gas Company.
„	½	Gas Company.
Shipley	3½	Gas Works. Coke Breaking.
Sleaford	3½	The Sleaford Gas Company. 7,000 per hour Beale's Exhauster, through a Fison's Regulator, also Liquor and Waste Pumps.
Sligo	1	Gas Company.
Southall	3½	Gas Company. Scrubbers, &c.
South Shields	½	Gas Company. Pumping, &c.
Sutton-in-Ashfield	2	Gas Works. Exhausting.
Sydenham	1	Crystal Palace District Gas Company.
Tavistock	2	Gas Company. Exhausting.
Thorpe, *near Huddersfield*	1	Norton Brothers. Regulator at Gas Works, Supplying their Mills and Village.
Wantage	1	Wantage Gas Works. Exhauster.
Wellington	½	Fox Brothers & Co., Cloth Manufacturers. Used in their Gas Works for Exhausting.
West Hartlepool	1	Gas and Water Company. Exhauster, Tar Pump, &c.
Weston-super-Mare	2	Gas Company. Scrubber, &c.
Whitchurch	3½	Whitchurch and Hoddington Gas Light and Coke Company.
Whitstable (Kent)	3½	The Whitstable Gas Company. Exhausting.
Wigton (Cumberland)	½	(Vert.) Gas Company. Exhauster and Force Pump.
Winsford	1	Over and Wharton Gas Company.
Wolverton	3½	London and North Western Railway Company. Exhausting.
Wombwell, *near Barnsley*	3½	Gas Company. Exhausting.
Woodbridge	½	Gas Company. Pumping.
Uppingham	2	Gas Works. Exhausting and Pumping.
Yeovil	3½	Gas Works.

CROSSLEY BROTHERS LIMITED,

Engineers,

OPENSHAW, MANCHESTER.

2,000. 16/11/87.

Cuthbertson & Black, Manchester

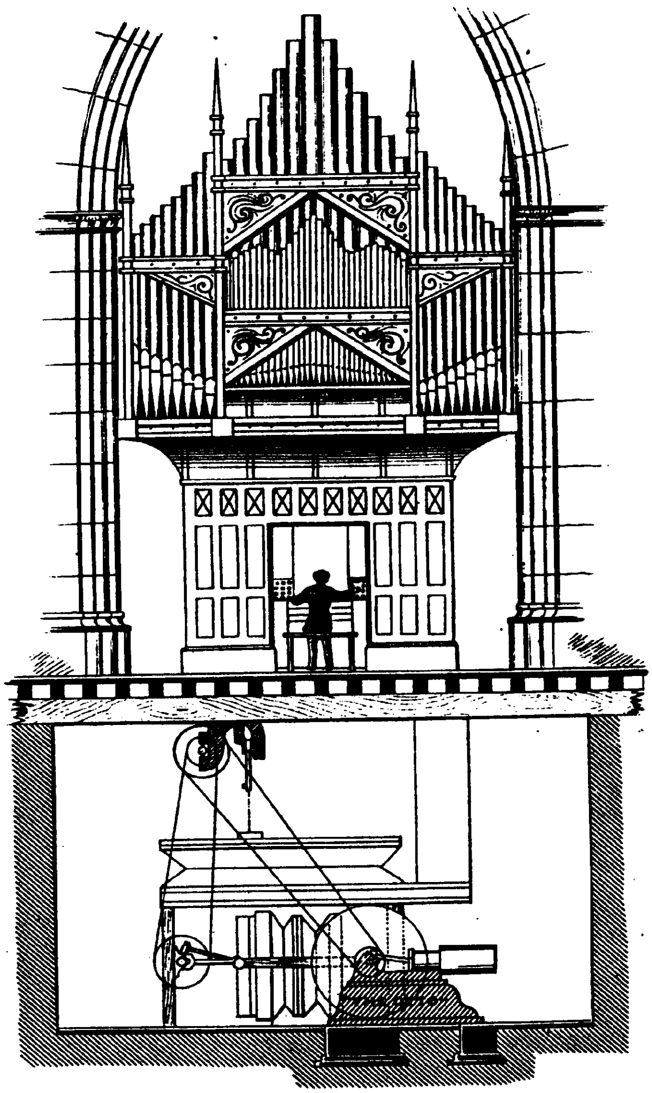
Selection of Testimonials

FROM USERS OF

CROSSLEY'S "OTTO" GAS ENGINE

FOR

ORGAN BLOWING.



THE Plan above shows an "OTTO" Engine adapted for Organ Blowing. The Engine is connected by very simple gearing to the ordinary organ feeders, and an automatic apparatus is supplied which stops the feeders when the wind chest is full, and starts them when the wind chest top has fallen about three inches. The Engine and feeders may be placed in any desired position. Instead of the feeders a single cast-iron blowing machine can be supplied if preferred.

TESTIMONIALS.

3½-HP.

ST. GILES' CATHEDRAL, EDINBURGH.

George Street, Edinburgh, 15th September, 1884.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We have much pleasure in bearing testimony to the efficient working of the "OTTO" Gas Engine as supplied by your firm for use in St. Giles' Cathedral, Edinburgh. The difficulty in bringing the wind from the engine-house to the Organ, without in any way interfering with the architectural structure, was considerable, and we must compliment you on the result.

The Organist of St. Giles' reports that the wind, for steadiness of pressure and supply, is perfect; and when it is taken into consideration that it is required for a Four-manual Organ, with pneumatic action and 32 feet pedal stops, it is evident that the "OTTO" is admirably adapted for such purposes. (Signed) McGIBBON & ROSS, Architects.

This Instrument consists of 4 complete manuals, CC to A, 58 notes, and a Pedal Organ, CCCC to F, 30 notes, 60 sounding stops, 11 couplers, and 17 composition pedals (3,694 pipes) as follows :—

Great Organ,	16	stops,	1,228	pipes.
Swell	,,	16	,,	1,148	,,
Choir	,,	11	,,	638	,,
Solo	,,	6	,,	290	,,
Pedal	,,	11	,,	390	,,
Couplers		11	,,		

The bellows (9 pairs) are worked by a 3½-HP. "OTTO" Gas Engine.

3½-HP.

ST. PAUL'S CATHEDRAL, LONDON.

Particulars of ORGAN driven by 3½-HP. "OTTO" Gas Engine.

The Organ consists of 4 complete manuals, having a compass of 58 notes, and a pedal clavier of 30 notes. Pneumatic levers are applied to 3 of the manuals, and to the pedals, and also to the draw-stop action and combination pistons. The system of pneumatic tubes, invented by the builder, Mr. Henry Willis, connects the pipes on the two sides of the chancel. The number of pipes is 3,172, distributed among 52 sounding stops, of which 7 are of 16 feet pitch, and 2 of 32 feet. All the stops are of complete compass. The Gas Engine drives two pairs of Willis' patent cylindrical feeders, two of which supply the high pressure wind, two the ordinary pressure. The Gas Engine is very economical, and gives entire satisfaction.

JOHN STAINER,
M.A., Mus. Doc., F.C.O., R.A.M., C.L.H.

3½-HP.

SALISBURY CATHEDRAL.

Particulars of ORGAN driven by 3½-HP. "OTTO" Gas Engine.—Four manuals, 55 speaking stops. *Makers:* Henry Willis & Sons, Camden Town, London.

The "OTTO" Engine for blowing the Organ in Salisbury Cathedral works splendidly and gives every satisfaction. It is placed outside the east wall of the north transept, the bellows and blowing apparatus being in the isle of the transept. CHARLES F. SOUTH,
Organist and Choirmaster, Salisbury Cathedral.

3½-HP.

HY. WOOLWRIGHT, Esq., BERKELEY LODGE, FAVERSHAM.

Particulars of ORGAN driven by 3½-HP. "OTTO" Gas Engine.—Fourteen stops with couplers, swell, &c. It occupies end of the room, 20 feet mahogany front, with imitation pipes. *Maker:* Rushworth, of Liverpool.

Bellows are about 170 feet from Engine, worked by a horizontal shaft with cranks. The Engine works them very easily and with perfect regularity, without any loss of speed that I can discover—and without check—no hitch at any time. H. WOOLWRIGHT.

2-HP.

WESTMINSTER ABBEY, LONDON.

Extract from *Engineer*, August 21st, 1885. Commenting on the rebuilding of this Organ *Engineer* says—

"For some time the question of blowing and blowing power remained undecided, but eventually it was determined to construct a special vault in the cloister green, which could contain the blowing feeders, and also a Gas Engine to drive the same; and arrangements were made for taking the wind into the Abbey by means of underground pipes of large size passing from the vault to the reservoirs within the Organ itself. A distance of about 60 feet separates the bellows in the cloister vault from the reservoirs in the Organ. The vault is below ground, and is lighted by a skylight in the green above. The feeders and bellows at various pressures are driven by an "OTTO" Gas Engine of nominal 2-HP., but which works at a higher power if necessary. The pulleys are driven by toothed wheels with chain gear, which prevents any slipping as in the case of belts. A wooden partition divides the Engine from the feeders. In order to maintain an equal temperature of air driven through the Organ, and so keep the Organ in good time—the feeders draw the atmosphere from the Abbey itself through the space left between the iron tubes and the brick shaft containing them, so that the air in the building is of exactly the same temperature as that passing through the pipes. This arrangement has been found to act admirably. The Engine can be started in a few seconds on receipt of a signal from the organist, who is provided with a speaking tube, and the distance of course insures perfect silence, the blowing action being absolutely inaudible in the Abbey. The stops may be scheduled as follows :—

Great Organ, CC to A, 13.	Choir Organ, CC to A, 11.
Swell ,, ,, ,, 14.	Solo ,, ,, ,, 8.
Pedal ,, CCCC to F, 10.	Couplers. 16

2-HP.

HOLY TRINITY CHURCH, SOUTHPORT.

Particulars of ORGAN driven by 2-HP. "OTTO" Gas Engine.—Four manuals and pedals, 49 speaking stops, and 10 couplers; pedal Organ of 8 stops, 3,338 pipes. *Makers:* Foster & Andrews, Hull.

The Engine is applied to Organ by fast and loose pulleys to a three-throw crank. Exceedingly valuable. Does the work of three blowers at a twentieth of the cost. I have great pleasure in stating how satisfied we are with it.

HENRY HUDSON,
F.C.O., L. Mus. L.R.A.M., London.

2-HP.

ST. PETER'S CHURCH, EATON SQUARE, LONDON.

Particulars of ORGAN driven by 2-HP. "OTTO" Gas Engine.—*Makers:* Lewis & Co.

Great Organ,	19 stops,	wind pressure	3½ inches,	3 reeds at 7 inches.
Swell	,, 14	,,	,,	,,	,, super & sub-couplers.
Choir	,, 12	,,	,,	2½	,,
Pedal	,, 6	,,	,,	4½	,,

The Engine is applied to Organ by feeders designed by Mr. Lewis, connecting Engine with reservoirs. The Engine works well, and is amply sufficient. The Organ is on a very large scale throughout, and requires an immense amount of wind.

WALTER SERGISON,
Organist, St. Peter's, Eaton Square.

2-HP.

THE ORATORY, BROMPTON ROAD, LONDON, S.W.

Particulars of ORGAN driven by 2-HP. "OTTO" Gas Engine.—Four key boards, 73 stops, 13 composition pedals, 32 feet wood opens on pedals; 40 feet wide, 20 feet deep. *Makers:* Bishop & Son.

The Engine is applied to Organ by reservoirs in basement of building. The Engine does its work *perfectly*. Make any use you like of this.

WILLIAM PITTS,
Organist at the Oratory, London.

2-HP.

ST. BARTHOLOMEW'S CHURCH, ARMLEY, LEEDS.

Particulars of ORGAN driven by 2-HP. "OTTO" Gas Engine.—Four manuals and pedal, 63 stops, and 9 composition pedals. *Makers:* Edmund Schulze, of Germany.

The Organ is blown by water forced by Gas Engine. The Gas Engine works quite satisfactory. The Organ has 11 feeders and bellows.

THOMAS CAWTHRA, Organist.

2-HP.

Lichfield, November 8th, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I shall be pleased to give you the required information respecting the "OTTO" Engine now in use at the Lichfield Cathedral, but, if you are in no hurry, I would rather wait till your representative is in Lichfield. In the meanwhile, I may say that your Engine works perfectly well in every way. I am, gentlemen, yours faithfully,

JOHN B. LOTT, Organist.

1-HP.

ST. MICHAEL'S CHURCH, MACCLESFIELD.

Particulars of ORGAN driven by 1-HP. "OTTO" Gas Engine.—Three manuals and pedal board, full compass 30 notes, 30 sounding stops, 5 couplers, 6 combination pedals. *Makers:* Hill & Son, London.

The Engine is applied to Organ by lever at the keyboard, under the control of the organist. The speed of the Engine can be reduced to half by a second lever, which lifts the governors. At this speed sufficient wind is supplied by the bellows for a moderate Organ tone.

This Engine answers remarkably well and gives thorough satisfaction.

1-HP.

Berwick, 29th October, 1886.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—Replying to yours of 28th inst., I give you the following information regarding Organ Blowing gear here; and if you desire anything further, and will specify it, I shall be glad to give you the same.

Yours truly,
J. W. LOGAN.

Engine and Blower 80 yards from Organ, which is a divided one. *Builder:* Harrison, Durham.

Great Organ,	11 stops,	wind pressure	3 inches.
Swell	12 "	"	3 "
Choir	10 "	"	2½ "
Pedal	3 "	"	4¾ "
Couplers	6 "		

Total......42 stops.

Engine drives a pair of cylinders, 16 in. diameter by 18 in. stroke, at 60 revolutions per minute. Each cylinder is really a double-acting pump; they deliver air to a bellows placed over them, and weighted to 4¾ in. When these bellows rise they, by a series of levers, gag the *suction* valves in each cylinder, preventing any more air going into the bellows than is really wanted. It is entirely automatic, and has been allowed to run for fourteen hours at a stretch. Erected in June, 1882. Costs for gas, 1½d. per hour, with gas at 5/- per 1,000 feet.

1-HP.

A. G. S. MEAGER, Esq., MELLINCOURT, THICKET RD., PENGE.

Particulars of PRIVATE CHAMBER ORGAN driven by 1-HP. "OTTO" Gas Engine.—Height, 25 ft. 6 in.; width, 18 ft.; depth, 16 ft. Design: two 8 ft. decorated fronts one above the other, with 16 ft. decorated side towers; 49 stops, inclusive of couplers; 4 manuals.

The Engine is applied by fast and loose pulley working feeders placed in engine house, which supply the main and 5 smaller wind reservoirs in various parts of Organ—the wind pressure varying from 3¼ in. to 6 in.—this latter as applied to Solo Organ and Pedal Trombone. The above forms a very efficient, yet simple, mode of blowing—being self-regulating as to demand and supply of wind. The "OTTO" I have now had in use 5 years, and it has so far gone in a very satisfactory manner.

ALFRED G. S. MEAGER.

1-HP.

Sir W. H. SALT, MAPLEWELL HALL, LOUGHBOROUGH.

Particulars of ORGAN driven by 1-HP. "OTTO" Gas Engine.—In chamber 15 ft. 9 in. by 10 ft. 6 in.; 3 manuals, 23 speaking stops and couplers. Independent pedal Organ of 2 stops. *Makers:* Brindley & Foster, Suffolk Road, Sheffield.

The Engine is attached to separate bellows, fixed in a basement under the Organ, the wind being conveyed by a trunk. The working of the Engine is very satisfactory.

1-HP.

ROYAL NORMAL COLLEGE AND ACADEMY OF MUSIC FOR THE BLIND, UPPER NORWOOD, S.E.

Particulars of ORGAN driven by 1-HP. "OTTO" Gas Engine.—Two of 2-manuals and two of 1-manual, each used about 12 hours per day. Vary from 6 to 30 stops. *Makers:* Foster & Andrews.

The Engine is situated out of the building. Power conveyed by a belt. The wind supplied to a common reservoir and carried by conductors or pipes to the various Organs.

Upper Norwood, S.E., 4th Nov., 1886.

Gentlemen,—I am glad to tell you how much we are pleased with the Gas Engine which you put in for us.

In the first instance we planned to have it supply wind to one or two Organs, a third was afterwards added and finally a fourth.

The four Organs are now used 12 hours per day. Our students are able to go to the Organs the same as others go to pianos, they are always ready and no time is lost owing to the want of wind.

For such purposes I consider your Engine invaluable.

I am, gentlemen, yours faithfully, F. J. CAMPBELL.

1-HP.

W. H. FOSTER, Esq., SPRINGHEAD, NORTHOWRAM, HALIFAX.

Particulars of ORGAN driven by 1-HP. "OTTO" Gas Engine.—Two-manual and pedal, 17 sounding stops (including 8 ft. open diapason great), 16 ft. open pedal. *Maker:* Hill, London.

The Engine acts through gearing direct on French Feeders which always run at a uniform speed. Special extra blow-off reservoir on top of feeders is fixed so that when other reservoirs are full they are not acted upon by wind and remain almost perfectly steady.

1-HP.

C. E. GREEN, Esq., THEYDON GROVE, EPPING.

Particulars of ORGAN driven by 1-HP. "OTTO" Gas Engine.—Ten feet deep, 14 feet 6 inches high; 3 manuals, 14 stops, 4 couplers. *Makers:* Messrs. Kirkland, Lichfield.

The Engine—an "OTTO"—and blower are situated in a building about 290 feet from Organ Chamber. The Organ is blown by one of Blakey's Patent Pressure Blowers, the wind being conducted in iron pipes underground to bellows under Organ. An exhaust valve in Engine-room allows spare wind to escape, and regulates the supply for bellows.

The great distance the wind has to be driven makes the work rather hard upon the Engine, otherwise it does its work very satisfactorily.

C. E. GREEN.

½-HP.

BAPTIST CHAPEL, HARROGATE.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Three manuals, 40 stops. *Makers:* W. Hill & Son, London.

The Engine is in a chamber underneath, and does its work well.

½-HP.

Mr. DENHAM, CAIN LANE, SOUTHOWRAM, HALIFAX.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Applied to Organ from feeders adjoining the Engine-room, then through a line of earthenware pipes about 12 in. diameter, extending from the north-west corner to the chancel, the Organ being in the chancel. Two manuals, 27 stops. *Maker:* Abbott, Leeds.

The Engine answers its purpose remarkably well. I never have any trouble with it.

½-HP.

JOHN ROBERTS, Esq., M.P., BRYNGWENALLT, ABERGELE.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Two manuals, 16 stops. *Makers:* Gray & Davison, London.

The Engine works well.

(Signed) JOHN ROBERTS.

½-HP.

J. SENDELL, Esq., THORPE.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Fifty speaking stops, 8 couplers, 53 pneumatic movements. *Makers:* Norman Brothers, Norwich. Automatic system is applied to both wind chests.

High pressure wind chest of 30 ft. super. area, 9 in. wind, and low pressure wind chest of 45 ft. super. area, 4½ in. wind, supplying pneumatic action and 50 speaking stops, are easily worked by the ½-HP. Gas Engine.

Any organist, &c., who would like to see my arrangement can do so by writing direct to me for an appointment.

J. SENDELL.

½-HP.

MANCHESTER ROAD WESLEYAN CHAPEL, HASLINGDEN.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Three manuals, 43 draw stops (inclusive of couplers). *Makers:* Brindley and Foster, Sheffield.

The Engine is applied to Organ with Crossley's Blowing Gear. I have had this Engine in (almost daily) use for nearly 12 months with perfectly satisfactory results. It has given me no trouble in its working, and the cost of gas consumed has been very trifling. During the time it has been at work no single derangement or hitch has occurred in any part of it. The cost of running, with gas at 3/9 per thousand, is about 1½d. per hour. I am pleased to send you this note, and am, gentlemen,

Yours faithfully,

JOHN STOTT.

½-HP.

ST. THOMAS'S CHURCH, OLDHAM.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Four manuals, 64 stops. *Makers:* W. Hill & Son, London.

The Engine drives a shaft which is connected with the feeders through the medium of a strap. Satisfactory.

GEORGE MARSDEN,

Mus. D., Cantab.

½-HP.

W. PENTLAND, Esq., 34, NEWGATE STREET, MORPETH.

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—*Makers:* Harrison & Co., Durham.

Organ is blown by special feeders driven by the Engine. The wind is forced into a reservoir. It gives every satisfaction and makes the playing much steadier.

½-HP.

J. STAGG BYERS, Esq., PARADISE ROW, STOCKTON-ON-TEES

Particulars of ORGAN driven by ½-HP. "OTTO" Gas Engine.—Twenty feet wide, 18 ft. high, 14 ft. deep; 3 manuals and pedal, 40 sounding stops—thus: 11 on great, 15 on swell, 8 on choir, 6 on pedals. *Makers:* T. C. Lewis & Co.

The Engine is applied to Organ by a pair of horizontal feeders worked by levers off disc driven from counter shaft, making about 30 strokes per minute—Engine always running full speed—driving belt thrown automatically in and out of gear. There is ample power, and the Engine works the apparatus admirably.

5-MP.

HOLY TRINITY CHURCH, COOMBE DOWN.

Particulars of ORGAN driven by 5-MP. "OTTO" Gas Engine.—Two complete manuals of 56 each, and pedal Organ, 30 notes, 27 stops, 1,244 pipes. *Makers:* Clark & Sons, Bath.

The drum of Engine drives a large 4-feet wheel with a belt. The shaft, by means of an eccentric, drives a double feeder. The strap works in a fork, and is moved from the loose to the tight pulley by a horizontal rod, which is worked from the bellows above. Upon the top of the bellows is fastened a piece of projecting wood. This strikes a rod up and down as it fills and empties, playing in a notch. The rod can be drawn back, and then the bellows empties itself. It is so arranged that a draw stop brings the wind on by depressing the rod, and when it is pushed in the rod is pushed back and the wind goes off. The arrangement is very simple and works very well. We find the Gas Engine the greatest comfort and convenience.

C. G. AINSWORTH, M.A.,

Vicar of Coombe Down, Bath.

It is found impossible to exhaust the wind with the full work on, and the Engine would work a larger feeder, for I have tried in vain to stop the Engine.

5-MP.

J. LOWE, Esq., BROOKLANDS.

Particulars of ORGAN driven by 5-MP. "OTTO" Gas Engine.—Three manuals and pedal, 30 stops, 4 reservoirs of separate pressures of wind. *Makers:* Thorold & Smith, late Jardine & Co.

The Engine is applied to Organ by crank to cuckoo feeders. I am perfectly satisfied with the Engine. It blows the Organ admirably, and I can make any demand upon it. It has never yet failed me, and the cost of working is so little that it is hardly worth mentioning. My quarter's gas bill for the separate meter to Engine has never exceeded 3/-, which includes for all my practising, recitals, and Organ-tuning. I have no other means of blowing the Organ, and I can highly recommend your Engines for blowing purposes.

(Signed) JAMES LOWE.

5-MP.

NORTH WYLAM CHURCH, NORTH WYLAM, NEWCASTLE.

Particulars of ORGAN driven by 5-MP. "OTTO" Gas Engine.—Two manuals, 14 stops. *Maker:* F. C. Nicholson, 46, Dunn Street, Newcastle-on-Tyne.

5-MP.

KIRKCUDBRIGHT PARISH CHURCH.

Particulars of ORGAN driven by 5-MP. "OTTO" Gas Engine.—Thirty draw stops (27 speaking), 2 manuals, and pedal organ; divided case. *Makers:* Harrison & Harrison, of Durham. Cost about £1,000, with engine and feeders.

Horizontal double-action feeders, with reservoir above, which again supplies two reservoirs in the Organ itself. The Engine is in cellar under the minister's vestry; and the feeders are worked in the vestry by means of a belt passing through the floor from the Engine.

(Signed) J. F. KALTOFEN, *Organist.*

5-MP.

E. GRANGE, Esq., ASHTON-ON-MERSEY.

Particulars of ORGAN driven by 5-MP. "OTTO" Gas Engine.—Three manuals and 28 stops, including 5 couplers. *Maker:* E. Wadsworth, Oxford Street, Manchester.

The Engine is attached to feeders under the Organ, and is so arranged by a valve that any spare wind is carried outside. I may say that the cost of the gas consumed is comparatively nothing. The Engine also works the wringing machine in laundry.

LIST OF USERS.

	HP.	
ABERGELE	—	J. Roberts, Esq., M.P., Bryngwenallt.—(*See Test.*)
ALMOUTH	½	Parish Church.
ARMLEY (*Leeds*)	2	St. Bartholomew's Church.—(*See Testimonial.*)
ASHTON-ON-MERSEY	5-MP.	G. Grange, Esq.
BACUP	½	Mount Pleasant Chapel.
BERWICK-ON-TWEED	1	Parish Church.
BIRKENHEAD	1	St. John's Church, Borough Road.
BLAIR DRUMMOND	½	C. S. H. Drummond Murray, Esq.
BLACKBURN	1	Congregational Church.
BOWDON	1	J. Sidebottom, Esq., Erlesdene.
,,	5-MP.	G. M. Little, Esq.
BRIGHTON	½	H. Tanner, Esq., Ship Street.
BRISTOL	2	Clifton Victoria Rooms.
BROOKLANDS	5-MP.	James Lowe, Esq., 2, West Grove.—(*See Test.*)
BURNLEY	5-MP.	Bethel Chapel, Hammerton Street.
CAMBRIDGE	½	Jesus College.
COOMBE DOWN	5-MP.	Parish Church.—(*See Testimonial.*)
DOVER	5-MP.	R. Chignell, Esq., Castlemount.
EDINBURGH	3½	St. Giles's Cathedral.
,,	3½	St. Mary's Cathedral.
,,	½	United Presbyterian Church, Morningside.
ETON	2	(Vert.) Eton College.
FAVERSHAM	3½	Henry Woolwright, Esq., Berkeley Lodge.
FOLKESTONE	1	St. Mary's Church.
HALIFAX	1	W. H. Foster, Esq., Springhead, Northouran.
,,	½	St. Ann's-in-the-Grove Church.
HARROGATE	½	Baptist Chapel.—(*See Testimonial.*)
HASLINGDEN	½	Manchester Road Wesleyan Chapel.
HULL	2	Holy Trinity Church.
KIRKCUDBRIGHT	5-MP.	Parish Church.
LONDON	9	W. Hill & Son, 372, York Road, Camden Town, N.W.
,,	3½	St. Paul's Cathedral.
,,	2	St. Peter's Church, Eaton Square.
LONDON	2	The Oratory, Brompton Road, S.W.
,,	2	Westminster Abbey, The Cloisters.
,,	1	Church of St. John the Divine, Vassal Road, Brixton, S.W.
,,	1	Royal National College for the Blind, Upper Norwood.
,,	1	M. R. Lockner, Esq., 133, Lancaster Road, Notting Hill.
,,	1	S. E. A. Meager, Esq., Mellincourt, Thicket Road, Penge.
,,	1	C. Green, Esq., Theydon Grove, Epping.
,,	½	The Great Assembly Hall, Mile End, E.
,,	½	Spa Fields Chapel, Pentonville, W.
LONDONDERRY	½	(Vert.) Cathedral.
LOUGHBOROUGH	1	Sir W. H. Salt, Maplewell Hall.
LICHFIELD	2	Lichfield Cathedral.
MACCLESFIELD	1	St. Michael's Church.
MORPETH	½	W. Pentland, Esq., 34, Newgate Street.
NEWCASTLE-ON-TYNE	2	St. Nicholas's Cathedral.
OLDHAM	2	St. Thomas's Church.
PORTSMOUTH	½	Gladstone Buildings.
SALISBURY	3½	Salisbury Cathedral.—(*See Testimonial.*)
SHEFFIELD	2	The Albert Hall Company.
SOUTHPORT	2	St. Andrew's Church.
,,	2	Holy Trinity Church.—(*See Testimonial.*)
STOCKTON-ON-TEES	½	J. S. Byers, Esq., Paradise Row.
THIRSK	5-MP.	Parish Church.
TODMORDEN	½	Zion Chapel.
WEST BROMWICH	1	Improvement Commissioners Town Hall.
WINCHESTER	2	Cathedral.
WORKINGTON, *via Penrith*	½	P. Kirk, Esq., Bankfield.
WYLAM (*Newcastle*)	5-MP.	North Wylam Church.—(*See Testimonial.*)

CROSSLEY BROTHERS LIMITED,

OPENSHAW, MANCHESTER.

Selection of Testimonials

FROM USERS OF

CROSSLEY'S "OTTO" GAS ENGINE

IN THE

TEXTILE TRADES.

JANUARY, 1888.

MANUFACTURING.

COTTON.

12-HP. *Oldham, December 28th*, 1885.

Messrs. Crossley Brothers Limited, Openshaw.

Gentlemen,—Replying to your memo., I am glad to say the 12-HP. "OTTO" Gas Engine is working very satisfactorily. It is turning twenty large Braiding Machines for manufacturing Engine Packings, with necessary Winding, &c., Frames, and four Belting Looms, requiring, in the total, about 8-horse power, and the weekly consumption of gas is from 3,500 to 4,000 feet. The great difficulty in our case was the fact that our machines are constantly on and off; but your governor is so sensitive, we have no hesitation in saying that, after a full trial, we are now perfectly satisfied.

I am, yours respectfully,
RITCHIE LEETHAM.

2-HP. *South Hanover Street, Glasgow, 16th February*, 1881.

Messrs. Crossley Brothers Limited.

Dear Sirs,—I have much pleasure in expressing my entire satisfaction with the 2-HP. Engine had from you in December, 1879. I use it to work a Hoist, a 16-spindle Pirning Machine, and an 8-spindle Balling Machine, and have still a considerable reserve of power.

I am, yours faithfully,
J. P. HARRINGTON.

1-HP. 12, *St. Peter Street, Blackburn, February 16th*, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—My Engines (1-HP.) I received from you are still working satisfactorily, driving Coloured Winding Machines, all kinds of Coloured Cottons and Wool Yarns upon Tubes, Spools, and Warpers' Bobbins, for the manufacturers here and surrounding district; also two Patent Drop-box Experiment Looms; and I frequently see people to whom I have sold your Engines, and all give satisfaction.

I have also one Engine (1-HP.) working at my Dyeworks, driving Coloured Winding Machines and a heavy Indigo Mill satisfactorily.

Yours respectfully,
J. MERCER.

LINEN.

3½-HP. 22 *and* 24, *Leighton Lane, Park Lane, Leeds, May 23rd*, 1883.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have great pleasure in recommending your Silent "OTTO" Gas Engine as being suitable in every respect for my trade and requirements; it has answered my purpose *remarkably well*, not having had the slightest trouble since it was set down. It is most undoubtedly the best Engine in the market at the present time.

I remain, yours truly,
Pro JOHN EVERS,
H. WORSNOP.

WOOLLEN.

12-HP. *Brick Buildings, Thornton Road, Bradford, May 29th*, 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—I have worked the 12-HP. "OTTO" Gas Engine eighteen months. It turns three sets of Machines and 1,300 Mule Spindles. Up to the present it has given general satisfaction.

Yours truly,
EDWARD STEVENSON.

This gentleman has now three Engines.

8-HP. *Greenfield, near Manchester, 9th January*, 1883.

Sir,—We have received your favour of the 6th inst. We work an 8-HP. Gas Engine, made by Messrs. Crossley Brothers Limited, Manchester. It gives us thorough satisfaction.

It drives thirty-one Woollen three-box Power Looms made by Hutchinson, Hollingworth & Co., Dobcross, some two tons each in weight, and which are generally known in Yorkshire.

We are of opinion that it would drive sixty such looms. The speed is remarkably steady and uniform.

Yours truly,
JAMES BOTTOMLEY.

To Mr. Crabtree, Bradford.

6-HP. *Lindley, Huddersfield, May 23rd*, 1883.

Messrs. Crossley Brothers Limited.

Gentlemen,—The 6-HP. Gas Engine you supplied us a year ago, we are happy to say, is working admirably. Previously, we have been tenants at three different mills under steam; but for steadiness and uniformity of running, the "OTTO" far surpasses our former experience. We have ten Dobcross Looms, with two beams each, weaving heavy backed worsted coating, Beaming Machine, Winding Machine, and Warp Drying Balloon, and the exhaust pipe is utilised for drying the warps on the Balloon. We run the Engine from 6 a.m. to 8.30 p.m., and the cost in gas is about 13s. per week; and for the same machinery we should have to pay, as tenants, 30s. per week.

We are, gentlemen, yours truly,
AINLEY, HAIGH & CO.

3½-HP. *Town Hall, Yeadon, September 2nd,* 1881.

The Trustees of the Yeadon Town Hall and Mechanics' Institute have pleasure in bearing testimony to the efficiency of the "OTTO" Silent Gas Engine.

Messrs. Crossley Brothers, of Manchester, kindly lent, on the occasion of a Bazaar and Exhibition at Yeadon, one of their 3½-HP. Silent Gas Engines, which for four days found power for five Box Looms, weaving six and seven quarter fancy woollen goods; two Carding Machines; and a Shoe-Blacking Machine.

The Engine was fixed on the schoolroom floor, and was attended by Mr. J. Crabtree, of Horton Lane, Bradford, and run the Looms and Machines with the greatest steadiness and regularity during the whole time, and gave every satisfaction to the trustees and to the exhibitors of the Looms and Carding Machines. For the Trustees,

LEVI HAIGH, *Hon. Sec.*

3½-HP. *The Yorkshire College, Leeds, June 11th,* 1883.

Messrs. Crossley Brothers.

Gentlemen,—I have pleasure in stating that the 3½-HP. Gas Engine you placed here in September, 1878, has been running ever since, and the cost of repairs from that time to the present is under 5*d.*

It turns seven Looms, including Jacquard, Dobby, and Tappit.

I find it easy to manage, reliable in speed, clean in appearance, and cost in gas under twopence per hour. Yours truly,

JOHN BEAUMONT.

BLANKET.

3½-HP. *Dewsbury Moor, January 11th,* 1886.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have had one of your 3½-HP. Gas Engines turning a Blanket Raising Gig for three years. The last six months we have run it eleven hours a day, and gives every satisfaction.

Yours truly,

GEO. CROWTHER.

YARNS.

1-HP. *Bradford, Yorkshire, May 22nd,* 1883.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We have great pleasure in stating to you, that the little Engine (1-HP.) we have had from you three years ago, has given us every satisfaction. It has been in work up to its full capacity ever since, and we have not had to spend a penny yet on it for repairs.

Yours faithfully,

LINDNER & HOLZHAUSSEN.

FLAX AND JUTE MACHINERY.

6-HP. *Calcutta Buildings, Commercial Street, Dundee, August 4th,* 1881.

Messrs. Crossley Brothers, Manchester.

In reply to your favour of 2nd inst., the purpose for which we use the 6-HP. "OTTO" Gas Engine supplied to us is working two Hoists, Pumps for Hydraulic Packing Press, working to two tons per square inch; and driving a Machine for cleaning flax and jute wastes. So far we find that it works very satisfactory. Yours truly,

J. & W. SMITH.

REED AND HEALD MAKING.

1-HP. *College Road, Bradford, May 5th,* 1880.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—In reply to yours of April 30th, 1880, I beg to say that my Engine (1-HP.) continues to work satisfactorily. I have never had any trouble with it since I made myself acquainted with the working of it.

Yours respectfully,

JOHN ASPINALL.

RAG SHAKING.

3½-HP. *Prospect Road, Ossett, October 28th,* 1878.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to your letter of the 23rd inst., asking how I like your 3½-HP. Gas Engine, I may say that I am perfectly satisfied with it; indeed, it has exceeded my most sanguine anticipations. Since it started, last February, we have not had the least trouble or expense with it, and it continues to do its work splendidly. Its cost also is, if anything, under your estimate. Its work is to drive a 3-feet Rag Shaker and Hoist. The Shaker is very irregular in the power that it requires, but still it regulates itself wonderfully, not varying its speed anything so much as a steam engine. Competent men consider it requires from 3 to 4-HP. (steam) to drive a Shaker, yet we can, at the same time the Shaker is working, lift a 3 or 4-cwt. bale with the Hoist without pulling her up. I may also say that we have run her for twelve or fourteen hours a day occasionally, without any loss of power. You are perfectly at liberty to use this if you think it will be of any service to you.

I remain, yours truly,

EDWARD CLAY.

2-HP. *Wellington Road, Dewsbury, May 23rd,* 1883.

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—We have much pleasure in informing you that the "OTTO" Gas Engine, supplied to us nearly three years ago, has proved perfectly satisfactory, and we can confidently recommend it for its utility, safety, and simplicity of construction.

Yours respectfully,

GEO. SYKES & SONS.

ROPES, TWINE, &c.

3½-HP. *Collyhurst Road, Manchester, November 17th,* 1880.

Messrs. Crossley Brothers.

Dear Sirs,—In reply to your favour of yesterday respecting our 3½-HP. "OTTO" Gas Engine, we beg to inform you it performs its work to our complete satisfaction in every respect, and regret we had not it sooner.

Yours truly,

CAMPBELL & REDMAYNE.
T. CAMPBELL.

½-HP. *Carnyard Hill, Glasgow, October 24th,* 1882.

Messrs. Crossley Brothers Limited.

Gentlemen,—Our ½-HP. Engine is now working very satisfactorily; cost of running being only 3/3 for 57 hours.

Yours, &c.,

J. C. THOMPSON & CO.

HOSIERY.

8-HP. *Leicester, May 23rd,* 1883.

Messrs. Crossley Brothers.

Gentlemen,—We are pleased to say that your 8-HP. Gas Engine has given us entire satisfaction in every way. It has been running for more than two years and has required no repairs worth naming.

We are, gentlemen, yours respectfully,

ANGRAVE BROTHERS.

3½-HP. *Crafton Street, Leicester, April 3rd,* 1878.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 3½-HP. Silent Gas Engine gives great satisfaction. We do not wish to relate what has already been said. It does its work steady, and works smoothly, which is of great importance to us in the manufacture of looped fabrics for men's and women's jackets, &c., &c. The bulk of the machinery is very delicate, and the textures fine, so that any jerking would be fatal to the goods. The Engine turns twenty Machines, and the manual labour for turning one of these would cost more than the gas consumed. But the chief advantage to us is the *fact* that no steam is required to be got up. The man under whose care it is turns off the gas, and in just one minute all the gas is pumped out, and he is able to leave the works with the other people; and in starting not more than two minutes are required to put all the machinery in motion.

Yours respectfully,
GUNN & CO.

N.B.—This firm have since put in a 12-HP.

3½-HP. 37, *Crafton Street, Leicester, February 19th*, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—Having used one of your 3½-HP. Gas Engines for the last three years, allow me to say that it has answered our expectations in every way. We are now driving twenty-four Machines with it.

Believe me, gentlemen, yours truly,
R. ORSON.

2-HP. 23, *Willersley Street Nottingham, January 6th*, 1886.

Messrs. Crossley Brothers Limited.

Gentlemen,—Replying to yours, I have pleasure in giving you the information below.

The 2-HP. "OTTO" Gas Engine I purchased from you drove three "twelve-at-once Rotary Rib Frames," built by Messrs. Moses Mellor and Sons, Nottingham; and I have no doubt would be sufficiently powerful to drive at least one more. The Engine worked at least sixty hours per week at a uniform speed—a desirable feature in motive power for the hosiery trade.

Yours respectfully,
A. WOODWARD.

2-HP. 30 *and* 32, *Brandon Street, Belgrave Road, Leicester, January 7th*, 1886.

Messrs. Crossley Brothers.

Gentlemen,—Class of work done by our Engine is Hosiery Manufacturing. We drive seven Machines, and the consumption of gas is about 5/- per week. In my opinion the Engines are good.

Yours truly,
W. GILBERT.

ELASTIC WEB.

3½-HP. *Selhurst Street and Craven Street, Hyson Green, Nottingham, December 24th*, 1885.

Messrs. Crossley Brothers Limited.

Gentlemen,—Having lately bought the business of my former employer, Mr. R. Tolley, who bought a 3½-HP. "OTTO" Gas Engine in September, 1883, it gives me great pleasure to testify to the general efficiency, and also great saving in expense there is in using your "OTTO" Gas Engine. In my Elastic Web Factory it now drives eight Looms (and soon another will be added), Winding Engine of forty spindles, Filling Machine of twenty spindles, and Doubling Mill of ten spindles, besides a Gassing, Calendering, and Stretching Machine, the latter requires very strong power to drive it. To me its great beauty is in the saving of time, fuel, and a man's wages, as it only takes one minute to start and a few seconds to stop it at any time during the two years and more it has been in my factory. I have not had to loose one hour all the time, from stoppages, &c., &c. The cost per week of running it is a trifle, as a few shillings pays for running it all the week, ten hours a day. Hoping this may be of service,

I am, gentlemen, yours truly,
J. PURDUE.

SILKS.

2-HP. *Manchester, May 31st*, 1883.

Messrs. Crossley Brothers Limited.

Gentlemen,—The 2-HP. "OTTO" Gas Engine has been in constant use since June, 1882. I have much pleasure in testifying that it has given every satisfaction. For working 54 hours weekly, cost of gas 3s. Remarkably easy to work. I feel bound to recommend it, as it is doing its work admirably.

Yours respectfully,
E. N. DAVIES.

2-HP. *Coleman Street, London, 16th February*, 1881.

Messrs. Crossley Brothers Limited.

Gentlemen,—We have pleasure in stating that the 2-HP. "OTTO" Engine which you supplied to us about eighteen months since answers our purpose well, for driving our Silk Winding Machinery and our Hoist. Anyone who is introduced by you is welcome to see it working.

Yours truly,
J. VANNER & SONS.

1-HP. 24 *and* 26, *Wilson Street, Finsbury, London, August 4th*, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The Gas Engine supplied by you last November is employed in driving Silk Winding Machinery. It has been working for us since, regularly, and gives us no difficulty.

Yours respectfully,
STEP. WALTERS & SON.

1-HP. 24 *and* 26, *Wilson Street, Finsbury, London, January 11th*, 1886.

Messrs. Crossley Brothers Limited.

Gentlemen,—In reply to your letter addressed to our Taunton factory, respecting the Gas Engine, we use it for driving Silk Winding Machinery, consisting of somewhere about 500 spindles, and since we have had it it has worked very satisfactorily. The consumption of gas, as near as we can tell, is about 7,000 feet per quarter.

Yours respectfully,
STEP. WALTERS & SON.

½-HP. *Stour Valley Iron Works, Sudbury, Suffolk, October 18th*, 1882.

Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

Gentlemen,—In reply to yours of this morning, the ½-HP. Gas Engine we supplied to Messrs. Kippling, Pain & Co., for driving Silk Winding Machinery, we believe is giving very great satisfaction. They formerly drove the machines by two men, for which they paid 24s. per week, and the Engine is now doing it at less than 3s. per week, with gas at 4s. 10s. per 1,000.

Yours truly,
BARTON & STEARN.

½-HP. 15, *Sepulchre Street, Sudbury, Suffolk, Jan. 12th*, 1886.

Gentlemen,—In reply to yours, the number of Machines driven by the Gas Engine, used for Winding and Re-winding Umbrella Silks, is twelve. Average size, 17 ft. by 3 ft. 8 in.; 66 spindles to each Machine. Cost for gas (at 4/10) 3/6 per week; hours of work from 9 till 5, and half holiday on Saturdays. It could do double the work, but of course would consume more gas. It is far superior to hand turning. We are perfectly satisfied with it.

Yours truly, B. BROWN.
To Messrs. Crossley Brothers. For KIPLING, PAIN & CO.

HAT & BONNET MANUFACTURERS.

3½-HP. *St. Ann Street, Newcastle-on-Tyne, 28th December*, 1885.

Messrs. Crossley Brothers Limited, Openshaw.

Gentlemen,—In reply to your inquiry as to the working of our Gas Engine—a 3½-HP.—we can but state, as we have on several occasions to your agents, that it is quite satisfactory, and answers well for our business, that of hatters' furrier.

We proved, after careful testing, that it was much more economical than steam power—the gas costing much less than coals, firing, and attention.

Yours respectfully,
W. & R. WILSON.

½-HP. 133 & 135, *Kingsland Road, London, February 16th*, 1881.

Messrs. Crossley Brothers Limited.

Gentlemen,—I have great pleasure in stating that the ½-HP. supplied to me about 18 months since, is working very satisfactorily, and to much greater power than indicated. It is doing easily all that was expected of it, and would apparently do much more if required.

Yours respectfully,
H. F. FREUTEL.

½-HP. *Stockport, July 3rd*, 1883.

Messrs. Crossley Brothers Limited, Manchester.

Dear Sirs,—"OTTO" Engine (½-HP.) is used for driving fifteen Sewing Machines and Leather-stitching Machines. Only a third of its power is used. The Engine exceeds our expectations.

Yours, &c.,
T. W. BRACHER & CO.

Have since put down a 4-HP.

STAY MAKING.

3½-HP. *Glasgow, May 23rd*, 1883.

Messrs. Crossley Brothers.

Gentlemen,—We have had one of your 3½-HP. "OTTO" Gas Engines at work for nearly two years, during which time it has given us the utmost satisfaction. The class of work for which we require it is for the driving of Sewing Machines, in the manufacture of light and *heavy seam Stays*, Serge, Tweed and Duck Jackets, Trousers, &c., &c. Owing to the regularity of speed, we are able to produce better workmanship than when the Machines were driven by foot, and at much less cost.

We are, gentlemen, yours, &c.,
McEACHRAN, LOUDON & CO.

GLOVE MAKING.

1-HP. *Yeovil, October 28th*, 1878.

Messrs. Crossley Brothers Limited.

Gentlemen,—In answer to your inquiry, we are perfectly satisfied with the 1-HP. Silent Gas Engine supplied us April 22nd; it runs very smoothly, and is in every respect what you represented it to be.

We are, gentlemen, yours,
THRING, LUFFMAN & CO.

THREAD MAKING.

6-HP. *Thread Street, Paisley, May 29th*, 1883.

Messrs. Crossley Brothers, Manchester.

Dear Sirs,—Replying to yours of yesterday, the "OTTO" Gas Engine referred to is used in driving Twisting Frames, and gives entire satisfaction.

ROBERT KERR & SON.
J. W.

LACE & TRIMMING MANUFACTURERS.

8-HP. *Nottingham.*

Messrs. Crossley Brothers Limited, Manchester.

Gentlemen,—I have pleasure in saying that my 8-HP. Engine continues to give me every satisfaction. At present it drives the following:—Two 24-quarter Lace Curtain Machines, two 30-spindle Spool Winding Engines, one 140-Brass Bobbin Engine, one Jacquard Card Punching Engine. The above is just half our work. I hope soon to get on the rest of my Machines, and do not expect to experience the slightest difficulty in driving them.

Yours respectfully,
HERBERT REDGATE.

6-HP. *Nottingham, January 5th*, 1886.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to your memo. of December 23rd, we beg to say we have been perfectly satisfied with the working of your "OTTO" Gas Engine.

When we are in full swing it drives about forty Gophering and twenty Sewing Machines, and also Ventilators in roof. The power is transmitted from cellar to sixth storey.

M. JACOBY & CO.

3½-HP. 24, *Ingram Street, Glasgow, December 10th*, 1885.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have much pleasure in stating that we have worked your 3½-HP. "OTTO" Gas Engine for the last four years, during the whole of which time it has given us great satisfaction, and no trouble whatever, and can with confidence recommend it to anyone who may have light work to do. We are driving 160 spindles, that is four Winding Machines of forty spindles each, and on an average we have only used about 6d. worth of gas each day, of 8½ hours per day.

Yours truly,
MUIR, TOWARD & CO.

2-HP. *Lurgan, Ireland, December 10th*, 1885.

Messrs. Crossley Brothers Limited.

Gentlemen,—Our 2-HP. "OTTO" Gas Engine has now been working seven years, and giving as much satisfaction now as during first year. Our only expense during this time has been refacing of slides, and no part of Engine shows any sign of requiring to be replaced. The Engine is driving Winding Machines ten hours a day, and would do much more work than we require.

Your truly,
JOHN DOUGLAS & SONS.

1-HP. *Beeston, near Nottingham, May 12th*, 1883.

Messrs. Crossley Brothers Limited.

Dear Sirs,—I am happy t say the 1-HP. Gas Engine you sent me, is working very satisfactorily. I is driving two small Lace Machines, as well as a large Warping Mill, and a Slip Winding Engine. We have not had a single hitch since it started last December, and I feel satisfied it would do twice the work allotted to it without inconvenience.

I may further add, that, up to the present, it has proved more economical than you led me to expect when I ordered it.

Yours faithfully,
WM. KIRKLAND.

The Grange, Beeston, Notts., May 12th, 1883.

1-HP. 47, *Stoney Street, Nottingham, December 28th*, 1885.

Messrs. Crossley Brothers Limited, Openshaw, nr. Manchester.

Gentlemen,—We have the pleasure of informing you that the Engine No. 5278, supplied October, 1882, has given us entire satisfaction. The cost of gas is very trifling, and the only other expense has been for oil, refacing the slides a few times, and cleaning out the exhaust once. We are driving a Ventilating Fan at high speed, and a number of Sewing and other light Machines. No other motive power that we know of would answer our purpose as well, and we can highly recommend your Engines for similar work.

Yours respectfully,
THOS. EAST & CO.

½-HP. 20, *Stoney Street, Nottingham, December 24th*. 1885.

Messrs. Crossley Brothers Limited, Openshaw.

Dear Sirs,—In reply to your circular of the 23rd inst., we are pleased to say that the Gas Engine we had from you has given us satisfaction, and were we purchasing again, we see no reason for placing our order elsewhere.

We are, dear sirs, yours truly,
BROOKSBANK & SANBY.

LIST OF USERS.

MANUFACTURING.

COTTON & LINEN.

	HP.	
Accrington	3½	Joseph Baron, Yarn Manufacturer, School Road (Looms.)
Barnsley	2	John Carr & Sons. (Bobbin Winding and Cloth Cutting.)
Belfast	8	Belfast Technical School. (Looms).
Blackburn	1	J. Mercer. (Winding.)
Brechin	2	J. Dakers, 92, High Street. (Winding.)
Bridport	½	H. E. Honcell & Co., Pelican Works. (8-spindle Spooler for Cotton Winding.)
"	½	H. E. Honcell & Co., Pelican Works. (Spooling Machines for Cotton.)
Glasgow	3½	Muir, Foward & Co., 3, North Court, Royal Exchange. (Winding.)
"	2	J. P. Harrington, South Hanover Street.
"	1	J. Houston, 62, Hutcheson Street. (Winding.)
"	½	W. Cross & Sons, 45, Montrose Street.
Gt. Harwood	1	Jonathan Mercer, Indigo Mills. (Three Colour Winding Machines.)
"	2	Thomas Bell & Son, Bell Vue. (Winding).
Huddersfield	2	G. D. Sykes, Upper Head Row. (Looms for Weaving Sacks.)
Kilmarnock	5-MP.	A. Westwarter & Co., Links, East End. (Winding.)
Leeds	3½	John Evers, Park Lane. (Linen.)
London	½	J. Tommas, 105, Herbert Street, New North Rd. (Lampwicks, Engine Packings, &c.)
Lurgan	2	John Douglas & Son, William Street. (Winding).
"	6	Murphy & Stephenson.
Oldham	12	Ritchie Leetham. (Looms and Braiding Machines for Engine Packings, Lampwicks, &c.)
Tyldesley	2	Clark, Taylor & Co., Hope Mills. (Warping.)

WOOLLENS, WORSTEDS, &c.

Bradford	12	Bradford Technical School. (Looms.)
"	3½	J. Moorhouse, Westholme Street. (Willowing.)
"	3½	Richard Higgins, Union Street. (Weaving.)
Huddersfield	8	J. & H. Blanires, Phœnix Mills, Leeds Road.
Halifax	3½	Edmund Priestly, Hope Mill.
Haworth	½	W. Smith, Belle Isle. (Warp Dressing Frame.)
Leeds	3½	Yorkshire College, College Road, Woodhouse Lane. (Weaving).
Lindley	6	Ainley, Haigh & Co., Lindley. (Cloth Looms.)
Rastrick	1	J. T. Clay & Son, High Street. (Power Looms for Patterns.)
Uppermill	8	S. Schofield, Heathfield. (Woollen Manufactory for Carding and Spinning.)

CLOTH CUTTING.

London	4	Stapley & Smith, London Wall, E.C. (Also Hoisting).
"	1	Hibbert & Co., 16, James Street, Haymarket, W.
"	½	Grocott Brothers, Tynedale Works, Canonbury Lane, N.
"	½ (Vert.)	W. N. P. Keeble, 19, Bread St. Hill, E.C.
"	5-MP.	(Per Aublett, Horry & Co.)

WOOL SORTING.

Bradford	12	Fox & Whiteley, Houldsworth Street. (Fan for Sorting Wool.)

FULLERS' MACHINERY.

Rochdale	14	S. Heap & Son, Caldershaw.

YARNS.

	HP.	
Bradford	12	E. Horsfall. (Twisting).
Glasgow	3½	Muir, Toward & Co. (Winding.)
Keighley	3½	E. Banks, Cavendish Street. (Finishing.)
Leeds	½	Robinson & Mathewman, Victoria Mills, Hunslet (Winding and Balling.)
Leicester	½	F. Volie, Wellington Street. (Winding.)
Manchester	3½	J. A. Turner & Co., 53, Peter Street. (Five Winding Frames.)
"	2	E. V. Davies, Peel Street, Cannon Street. (Winding.)
	1	Thomas Roberts, 34, Melton Street. (Winding.)

FLAX AND JUTE MACHINERY.

Dundee	6	J. & W. Smith, Commercial Street.

FLOCKS, BEDDING, &c.

Heckmondwike	3½	G. Crowther, Blanket Manufacturer, Dewsbury Moor. (Blanket Making.)
Leeds	6	Joseph Longley, 47, Lands Lane. (Flock Machine.)
Southport	½	J. E. White. (Flock Cleaning Machines.)

REEDS, HEALDS, &c.

Accrington	3½	Joseph Baron, Taylor Street.
Blackburn	½	John Carruthers, Byrom Street.
"	½	A. Driver, St. Peter's Street.
Bradford	1	John Aspinall, College Street. (Reeds and Healds.)
Chorley	½	James Kellett, Fellery Street. (Reeds.)
Darwen	3½	J. M. Daltry. (Healds.)
"	3½	James Daltry, Blackburn Road.
"	½	Thomas Leech, Ashton Street.
Halifax	3½	Chas. Swindells, Leafland St. (Hackle and Gill.)
Huddersfield	8	Walter Ellis, Commercial Street. (Healds.)
Keighley	3½	Burwin & Co., Wire Mills. (Shuttles, &c.)
Leeds	3½	John Hardaker, 1, Grace Street. (Temples.)
Liversedge	2	William Scholes, Scots House. (Card Setting.)
Preston	1	Hulme & Co., 39, Alfred Street. (Healds.)
"	½	Joseph Clayton, Porter Street.
Rochdale	6	J. T. Collinge, Whitworth. (Spindle and Fly.)
Yeadon	½	J. Clayton & Sons. (Reeds and Healds.)

SAILS, FLAGS, TARPAULINS, &c.

Cellardyke	½	J. Martin & Co.
Chatham	6	H. M. Dockyard. (Sail Making.
"	3½	H. M. Dockyard.
Glasgow	3½	J. McAllister & Sons.
Gosport	½	Lapthorn & Ratsey.
London	1	Gellatly, Hankey, Sewell & Co.
Manchester	3½	Campbell & Redmayne, Collyhurst Road.
Rushden	5-MP.	J. Barwick.
Sunderland	½	W. Dawson, Villiers Street South.

ROPES AND TWINE.

Bolton	4	J. Taylor, Lever Street.
Dukinfield	6	Kenyon & Son.
Glasgow	½	S. H. McDonald McFarlane, 338, Garngad Hill.
Hepburn-on-Tyne	16	T. W. Spencer & Co. Limited.
Manchester	3½	Campbell & Redmayne.
Poole	6	G. R. Penny & Co
Walton-le-Dale, *Preston*	6	Woodhouse Brothers.

RAG MANUFACTURERS.

	HP.	
Ashton	8	J. Bottomley. (Waste Willeys.)
Bradford	3½	Joseph Moorhouse, Thornton Road. (2 Waste Willeys.)
Canterbury	6	W. Howard. (Ragduster and Waste.)
Dewsbury	2	George Sykes & Son.
London	12	W. Culff, Railway Arches, Bow Common.
„	8	R. O. Hearson, 8, King's Leadenhall Street.
„	6	Barron & Hirst, 54, Carnaby Street, Garden Square.
Ossett	6	R. E. Phillips, Mungo Merchant. (Rag Shaking.)
„	3½	Edward Clay, Prospect Road. (Rag Shaking.)

SACK MAKING.

London	6	E. Carr & Son, The Grange, Bermondsey, S.E.

HOSIERY.

Aston	½	G. J. Storey. (Winding Machine.)
Balbriggan	3½	Deeds, Templar & Co.
Hinckley	6	Blackwell & Co.
„	2	Smith, Hannibel & Co., Stockwell Head.
„	2	Job Illiff, 22, New Street. (Stocking Looms.)
Leadgate	½	R. W. Shaw.
Leicester	12	Gunn & Co., Grafton Street.
„	8	Angrave Brothers, Jarrom Street. (Stocking.)
„	3½	Robert Orson, 34, Grafton Street. (Fancy.)
„	3½	W. & H. Howe, St. George Street. (Fancy.)
„	3½	G. Hall & Co., Millstone Lane. (Fancy.)
„	3½	Faire Brothers, Willow Street. (Smallware.)
„	3½	Thomas Coleman & Co., Belgrave Gate.
„	3½	London and Leicester Hosiery Co., Wineford Street.
„	3½	Alfred Spence, near Dewick Place, Mansfield Street.
„	3½	C. Smith & Brother, 31, Halford Street.
„	2	Isaac Anderson, 1, Gold Street. (Fancy.)
„	2	Thomas Morley, 176, High Cross Street.
„	2	W. Gibbert, Brandon Street.
„	2	B. Russell & Son, Belvoir Square.
„	2	John Pick, 5, Paddock Street.
„	2	Raven & Wormleighton, Grafton.
„	2	Henry Wall & Sons.
„	1	C. Smith & Brother, 31, Halford Street.
London	3½	E. Stilwell & Son, 25, Barbican. (Braid Looms.)
„	½	W. Morgan Brown, 38, Southampton Buildings, Chancery Lane. (Stocking Looms.)
Manchester	2	John Briscoe, 23, Milton Street.
Norwich	3½	F. W. Hamer & Co.
Nottingham	3½	Ashworth & Co.
„	2	A. Woodward.
„	1	Cooper & Elliott.
Paisley	1	John Murray, Causey Side.

STAYS.

Glasgow	3½	McEachran, Loudon & Co.
Ipswich	6	C. A. Sewell & Co., Foundry Road.
„	3½	C. A. Sewell & Co., Foundry Road.
Market Harboro'	3½	R. & W. H. Symington.
Rothwell	8	R. & W. H. Symington & Co.
Rugby	8	Rugby Corset Company.
Sudbury & Ipswich	4	Footman, Pretty & Co.
„	3½	Footman, Pretty & Co.
„	3½	Footman, Pretty & Co.

ELASTIC WEB MANUFACTURING.

	HP.	
Nottingham	3½	Joseph Vurdue, Hyson Green.
Oldham	12	Ritchie Leetham, 153, York Street.

SILKS, VELVETS, &c.

Failsworth	4	Cliff & Tonge.
London	3½	Slater, Son & Slater, Plaistow, E.
„	2	J. Vanner & Co., 1, Coleman Street.
„	1	Stephen Walter & Son, Wilson Street, Finsbury.
„	1	Vavasour, Carter & Collier, New Nicholas St., Shoreditch.
„	½	James Brown, 14, Newcastle St., Farringdon St.
Middleton	½	Harry Jones, High Street.
Norwich	3½	Edward Willett, Nephew & Co. (Winding.)
Sudbury	½	Kipling, Pain & Co. (Silk Winding.)
Taunton	½	S. Walton & Co., Silk Spinners.
„	½	Walters & Co.
„	5-MP.	A. Melson, 10, Orange St., Bethnal Green, E. (Spinning Silk.)

CAP AND BONNET MANUFACTURERS.

Kilmarnock	2	W. Thomson.
Leeds	2	Joseph Brook, Grace Street.
Luton	2	E. Stratford, 21, Park Square.
„	½	E. Stratford, 21, Park Square.
„	½	E. Stratford, 21, Park Square.
Manchester	3½	M. Doniger, Miller Street.
Stockport	4	— Bracher, Hat Manufacturer.

GLOVES.

Leicester	2	F. & J. Ellis, Rutland Street.

CRAPE.

Norwich	8	Norwich Crape Company.

SHAWLS.

Paisley	6	R. Kerr & Co., Thread Street.
„	3½	B. Smith & Co., 1, Forbes Place.

THREAD MANUFACTURERS.

Paisley	6	Robert Kerr & Son.

LACE & TRIMMING MANUFACTURERS.

Beeston	1	W. Kirkland.
Coventry	½	T. W. Robinson, 77, Jordan Well.
London	8	Tufnell Park Mills Company, Holloway.
„	3½	Perry & Dawson, 50, Redcross Street, E.C. (Artificial Flower Manufacturing.)
„	2	Hartley & Bolton, 252, Old St., E.C. (Frilling.)
„	2	Adams & Co., St. Mary Axe. (Gold Lace.)
„	2	Surrey Band and Fancy Cord Company, Rye Lane, Peckham.
„	1	Dalton Barton & Co., King Edward Street. (Trimming.)
„	1	Swainson & Son, Olive Yard, City Road, N.
Newcastle-on-Tyne	3½	Robert Wilson, St. Anne's Road.
Nottingham	8	H. Redgate. (Lace Curtains, &c.)
„	6	M. Jacoby & Co.
„	1	East & Co.
„	½	Brooksbank & Sanby, 20, Stoney Street.
Stockport	2	George Barnsley, Canal Street.

CROSSLEY BROTHERS LIMITED, Engineers, OPENSHAW, MANCHESTER.

1,000. 12/87. CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

Selection of Testimonials

FROM USERS OF

THE "OTTO" GAS ENGINE

FOR DRIVING

SEWING MACHINES,

And Machines-used in the Clothing Trade generally.

SEWING MACHINES.

Leeds, July 30th, 1885.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In answer to your enquiry as to our experience of the "Otto" Gas Engine. We have two at work here, one a 16 H.P. driving 850 feet of shafting with Sewing Machines and eight Haworth's Radial Arm Ventilators, and the other at 8 H.P. driving a Hoist and a number of Cutting Machines. Consumption of Gas for the two Engines, 600 feet per hour. At another place we have a 12 H.P. Engine driving 700 feet of shafting with Sewing Machines, and a Ventilator, at a consumption of 240 feet of Gas per hour.

With careful attention to cleaning and oiling we find them work *very* satisfactory.

Yours truly,
JNO. BARRAN & SONS.

Leeds, July 30th, 1885.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have pleasure in stating that the 12 H.P. "Otto" Gas Engine is working very satisfactory in every respect. It drives 200 Sewing Machines, two Heavy Cutting Machines, the Hoist, Ventilating Fan, and the ordinary appliances of the mechanics' workshop, without shewing signs of being at all over-taxed. The consumption of Gas is about 12,500 feet per week of 52½ hours.

The 8 H.P. Engine is also giving satisfaction, but we only run it when we require a smaller driving power than usual.

Yours faithfully,
JOSEPH HEPWORTH & SON.

Leeds, 16th Feb., 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 8 H.P. "Otto" Gas Engine which we had from you last year, is working to our entire satisfaction, and requires very little attention. It works the Hoist, two Cloth Cutting Machines, and 120 Sewing Machines.

Yours faithfully,
JOSEPH HEPWORTH & SON.

Dantzic Street, Manchester, May 28th, 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 6 H.P. "Otto" you put down for us last autumn has met all our expectations. Independent of the saving of dust and dirt, the cost of gas is less than the wages of a stoker would be, leaving out of question the cost of coal and carting of cinders, and not having accommodation for keeping either, the Gas Engine became a desideratum for us.

Yours respectfully,
HENRY MARSDEN & CO.

Hebden Bridge, via Manchester, May 28th, 1883.

Messrs. Crossley Brothers.

Gentlemen,—The Engine 6 H.P., you supplied me with nearly two years since has answered all my expectations, and fully justified the recommendation your Mr. Crossley gave me when I ordered it. We pay for gas after the rate of 4s. per 1,000, and I may say that, on the above scale, it has cost us only 6/9 per week from the time of putting down, a result with which I am perfectly satisfied, while the cost in other respects is only nominal.

Yours truly,
JOHN HORSFALL.

Wimbledon Works, Leicester, July 22nd, 1885.

Messrs. Crossley Brothers, Limited. Manchester.

Gentlemen,—It gives us great pleasure to state that the 6 H.P. Gas Engine you supplied us with in 1883 is all that we could desire. At the present time it is driving only about 50 Sewing Machines for the Tailoring Trade at a cost of about 2/- per day of 10 hours. Its working is very good, and has caused us but very little trouble.

We may further state that, in our opinion, the system of driving Sewing Machines by power is an advantage alike to employers and employed.

(Signed) HART & LEVY.

Grace Street, Leeds, July 23rd, 1885.

Messrs. Crossley Brothers.

Gentlemen,—I have pleasure in stating that the 6 H.P. "Otto" Gas Engine you supplied me with works very satisfactory, and the 3½ H.P., one of the same make, worked three years without repairs.

Yours respectfully,

JOSHUA BROOK.

16, *Newton Street, Manchester, 5th June*, 1883.

Messrs. Crossley Brothers, Limited.

Dear Sirs,—We have pleasure in stating that the Gas Engine supplied by you to our City Factory, Londonderry, has given us great satisfaction, and we have formed a very favourable opinion as to its merits.

Yours faithfully,

Mc.INTYRE, HOGG & CO.

(This firm has since ordered two other Engines.—C.B., Ld.)

41, *York Street, and* 3 *and* 5, *Faulkner Street, Manchester, November 4th*, 1878.

Messrs. Crossley Brothers.

Gentlemen,—The 3½ H.P. "Otto" Gas Engine you supplied to Messrs. Sparrow, Hardwick & Co. is working very satisfactorily, driving 150 feet of shafting and over 60 Sewing and Embroidery Machines with the greatest ease and steadiness, at a cost of 2½d. per hour. It can be started and stopped at a minute's notice, with its full power, and is working in the same room as about 60 machinists, without any inconvenience to them from noise, dirt, &c. I consider it a splendid Engine where small power only is required.

Yours truly,

J. REYNOLDS, Manager.

257, *Argyle Street, Glasgow, July 24th*, 1885.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have pleasure in saying we have used one of your "Otto" Gas Engines for the past three years, and still have it in use. It has given us every satisfaction. We do not require the full power it is capable of giving, but at present we run with it 50 or 60 Machines, and in addition it supplies power for other Machines, such as Plating and Die Cutting Machines, Fanners, and Cutting Knives. The cost of Gas is about 7/6 per week.

Yours truly,

J. & P. PRITCHARD & CO.

12, *Richmond St., Minshull St., Manchester, October 13th*, 1880.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In answer to your enquiry, we are running over 100 Sewing and Braiding Machines with the 3½ H.P. Gas Engine which you supplied to us.

We must express our entire satisfaction with the working of the Engine.

Yours truly,

REYNOLDS BROS.

12 & 13, *Bride Street, Dublin, July 30th*, 1885.

Messrs. Crossley Brothers, Limited, Dublin.

Gentlemen,—In answer to your enquiry, as to the capability of your Gas Engines for driving Sewing Machines, we have very much pleasure in stating that the 3½ H.P. Engine we have had from you two years ago works beautifully. We get a very uniform speed on our Sewing Machines, and when we use our Cutting Machine it in noway slackens the even speed of the Engine.

We find that at the price of Gas in Dublin (3/9 per 1,000) it costs about 9/- per week.

Yours truly,

CONNELL BROS. & CO.

Scouringburn Works, Dundee, 14th Feb., 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 3½ H.P. "Otto" Gas Engine which we got from you in January, 1879, had to drive 17 Sack Sewing Machines, two Cope Machines for ditto, and one large Sack Cutting Machine, and when kept clean and with a little attention, it did its work with ease and regularity.

We clean it thoroughly once a month.

The figure which we had taken from it showed a load of fully 4 H.P.

Cost of keeping it per week of 56 hours, 12/-.

Yours truly,

HUTCHINSON & GRAY.

40, *Westgate, Bradford, July 24th*, 1885.

Messrs. Crossley Brothers.

Dear Sirs,—The ½ H.P. Gas Engine you supplied me with in October, 1882, has answered my purpose very well, for a number of Sewing Machines and a Circular Knife. It will average about 2/6 per week for Gas, and does my work easy.

I remain, yours, &c.,

S. R. SCHOFIELD.

Leeds, July 23rd, 1885.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have pleasure in testifying to the excellence of the "Otto" Gas Engine you supplied us with about a year ago, for Band Knife and Sewing Machines

It has proved "thoroughly satisfactory," being almost noiseless and requiring very little attention.

Yours truly,

J. W. BENNETT & CO.

Buck Street, Leeds Road, Bradford, August 20th, 1885.

To Messrs. Crossley Brothers, Manchester.

Gentlemen,—I have much pleasure in saying that I have had the 2 H.P. "Otto" Gas Engine over five years, and have found it so far to work very well, and with little trouble. It now drives four Sack Sewing Machines, two Cutting Machines and Hoist, and its cost is about 5/- per week in gas. I can with confidence recommend the "Otto" for this class of work.

Yours truly,

WILLIAM STOTT.

——:o:——

CLOTH CUTTING.

3 *and* 4, *Aldermanbury, London, E.C., February 17th*, 1881.

Messrs. Crossley Brothers.

Dear Sirs,—I have much pleasure in informing you that the 2 H.P. Gas Engine had from your works suits us admirably. We drive a Band Knife Cutting Machine with it, and there is some power to spare.

I am, dear Sirs, yours truly,

THOMAS KNIGHT.

St. Paul's Street, Leeds, 17th February, 1881.

Messrs. Crossley Brothers, Limited.

Gentlemen,—We have given your 3½ H.P. "Otto" Gas Engine a fair trial, and are well satisfied with the manner in which it has proved itself, and can safely recommend it to all Cutting Machines in the Clothing Trade.

Yours respectfully,

JAMES RHODES & CO.

2 and 3, Aldgate, London, 18th February, 1881.

Messrs. Crossley Brothers, Limited.

Dear Sirs,—The 2 H.P. "Otto" Engine you put down at our Swindon Factory about two years ago performs its work admirably. It drives one of Greenwood and Batley's Cloth Cutting Machines, and has not necessitated the stoppage of a day's work during the whole of this period.

The 6 H.P. Engine which you have recently erected at our Crewe Factory does its work equally well. This Engine drives 102 Sewing Machines and one Cloth Cutting Machine, and there is sufficient power to increase the number of our machines 50 per cent.

We are, dear Sirs, yours truly,

J. COMPTON & SONS.

(This firm has since changed its 2-h.p. to a 6-h.p. Engine.—C.B.Ld.)

Bradford, 16th February, 1881.

Messrs. Crossley Brothers, Limited.

Gentlemen,—In reply to your enquiry about the 3½ H.P. Gas Engine furnished to us, we have to say that it works Rolling Machines, Cutting Machines, Measuring Machines, and Hoist, and we have no doubt would work a good deal more than we require from it. We calculate that it costs us about 1/- per day in gas and oil. It requires no attendance, and we keep it always locked up. We may inform you that the hoist works far better in every way than the one we left that was run by a 16-horse engine. We can stop it with the slightest touch, it is so beautifully balanced.

JNO. H. BANKART & CO.

138, *Queen Victoria Street, London, October 28th,* 1878.

Messrs. Crossley Brothers, Limited.

Gentlemen,—We are well pleased with the 3½ H.P. "Otto" Silent Gas Engine supplied in May last. It is now driving two Cloth Cutting Machines at a speed of 900 revolutions per minute; it also drives one Hoist, carrying 8 cwt. up 65 feet.

Yours respectfully,

T. J. THOMAS & ELLIS JONES.

Belgrove Street, Glasgow, February 15th, 1878.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have much pleasure in testifying to the qualities of your "Otto" Gas Engine (3½ H.P.) The one we got from you in March, 1879, has given us every satisfaction. We drive about 60 (or thereabouts) Sewing Machines, Cutting Knife, and 130 feet of Shafting.

We are, yours respectfully,

J. & L. BAIRD.

Hyde, near Manchester,
May 30th, 1885.

Messrs. Crossley Brothers, Limited.

Gentlemen,—In reply to your enquiry respecting the 2 H.P. "Otto" Gas Engine, I am glad to report that it does its work well, and I am quite satisfied with it. The weekly consumption of gas is about 1,200 feet for 56½ hours. I use it for Sewing Machines and Cloth Cutting.

Yours respectfully,

GEORGE BROWNSON.

(This firm has since changed its 2-h.p. for a 7-h.p.)

—:O:—

LAPPING, ROLLING MACHINES, &c.

11, *George Street, Manchester, 15th February,* 1881.

Messrs. Crossley Brothers.

Gentlemen,—The 2 H.P. Gas Engine which you erected for us last year works extremely well, and answers every purpose for which it was intended.

We are, gentlemen, yours obediently,

J. W. & F. BAXTER.

28, *High Street, Manchester, February 15th,* 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 1 H.P. "Otto" Engine has been at work in our warehouse driving Lapping Machines two years. It has given us great satisfaction, has not required repairing or caused trouble. If we wanted more power, and had no steam boilers at hand for other purposes, we should use these Engines in preference to any motive power we are acquainted with.

Yours faithfully,

RICHARD HAWORTH & CO.

ABRIDGED LIST OF USERS OF THE OTTO ENGINE FOR DRIVING SEWING MACHINES, CLOTH CUTTING, &c.

SEWING MACHINES.

BACUP	½	J. Greenwood & Co., Church Street.
BELFAST	6	R. Crawford, Alfred Street.
,,	3½	Hy. Davies, Linenhall Street.
,,	3½	Thos. McCann, 6, Dougall Street Square, East.
Bp. AUCKLAND	12	Co-operative Society (Sewing Machines and other machinery).
BLACKBURN	1½	v Moore.
,,	½	S. Pickering & Sons, Mill Lane.
BRADFORD	2	W. Stott, Buck Street, Leeds Road.
,,	½	G. R. Schofield, 40, Westgate.
BRISTOL	6	Clarke & Co., Colston Street.
CARDIFF	½	J. Reddaway.
CELLARDIKE	2	John Martin & Co. (Waterproofs).
CHATHAM	6	H.M. Dockyard (Sails and Flags).
,,	3½	,, ,,
COLCHESTER	3½	H. E. M. Moses, Priory Street.
COWES (I. of W).	½	Ratseys & Lapthorn (Sails, &c.).
CREWE	6	Compton & Sons, 3, Aldgate.
DEPTFORD	2	J. Smith & Co.
,,	1	John Clemson, Esq., Spa Lane Walks.
DERBY	2	Jno. Smith & Co.
,,	½	W. H. Holmes, Woollen Merchants.
DUBLIN	3½	J. Ireland & Co., Ellis Quay (Army Clothiers).
DUNDEE	8	Forbes & Christie, Victoria Road
,,	2	J. P. Smith & Co., Draper, High Street.
GLASGOW	9	Stewart & McDonald, Dunlop Street.
,,	8	Tillie & Henderson, 83, Dunlop Street.
,,	7	Harris & Dietrichsen, 28, Ingram Street.
,,	6	Alexander & Co., Buchanan Street.
,,	6	Hunter, Barr & Co., 37, Jamaica Street.
,,	6	Jas. Millar & Sons, 56, Brunswick Street.
,,	6	D. McArthur & Co., Cadogan Street.
,,	4	Alexander Bros., Cumberland Street (Bridgeton).
,,	3½	J. & L. Baird, Graham Square.
,,	3½	McAllister & Sons, Mavisbank Quay.
,,	3½	J. Horn & Co.
,,	3½	Brooks & Hamilton, 27, Ann Street.
,,	3½	J. & R. Pritchard & Co., 249, Argyle Street.

ABRIDGED LIST OF USERS—Continued.

Glasgow .... 2 Murdock & Ramsey, Miller Street.
" .... 2 Johnson & McLeod, 128, Ingram Street.
" .... 1 Begg & Co., 34, Argyle Street.
" .... 1 Torrance & Co., Cumberland Street (Bridgeton).
" .... ½ Glasgow & South Western Railway Co., Cook Street.
" .... 5M Singer Manufacturing Co.
" .... Muir, Clark, Don & McLeon, 65, Virginia Street.
Gloucester ... ½ Gloucester Shirt Co., Gloucester.
Gosport .... ½ Lapthorn & Ratseys (Sails, &c).
Hebden Bridge 8 J. Hilton & Co., Bridge Street.
" .... 6 J. Horsfall.
" .... ½ William Gill, Wholesale Clothier.
Hyde .... 2 George Brownson.
Leeds... ... .16 John Barran & Sons, St. Paul's Street.
" ....16 James Rhodes & Co., Oxford Road, Park Lane.
" ....12 Buckley & Sons, Greek Street.
" ....12 F. Beecroft & Co.
" ....12 Wilkinson & Chorlton, St. Paul's Street.
" ....12 John Barran & Sons, St. Paul's Street.
" .... 8 " " "
" ....12 J. Hepworth & Son, Wellington Street.
" .... 8 " " "
" .... 6 Stewart & McDonald, Wellington Street.
" .... 6 Joshua Brook, Grace Street.
" .... 3½ W. Blackburn & Co., Aire Street.
" .... 3½ J. W. Bennett & Co., Aire Street.
Leicester ...... 6 Hart & Levy (Wholesale Clothiers).
" .... 3½ W. H. Symington & Co. (Stay Manufacturers).
" .... 2 F. & J. Ellis, Rutland Street.
" .... ½ Gamble & Co., Pocklington's Walk.
" .... ½ J. O. Rice & Co., Newark Street.
" .... ½ Singer Machine Co., Granby Street.
" .... 5M J. L. Berridge, Fox Lane.
" .... 5M T. Brown & Co., Brown Street.
Liverpool ...... ½ G. W. Toll, 102, Park Roads.
" .... ½ Linton & Co., Brownlow Hill.
London............ 8 Hyam & Sons, Redcross Street, E.C.
" .... 8 J. J. Thomas, Son & Co., 138, Queen Victoria Street (Cloth Cutting, &c).
" .... 6 Carr & Sons, Bermondsey.
" .... 2 W. D. Chamberlain & Co., 6, Wells Court, Queen St.
" .... 1 Gellatley, Hankey, Sewell & Co., Narrow Street, Limehouse.
" .... 1 Proudfoot & Willis, 10, Johnson Street, Commercial Road, E.
" .... ½ Wilcox & Gibbs.
" .... ½ Dr. Jargers Clothing Establishment, 95, Milton Street, E.C.
" .... ½v Kohler Sewing Machine Co., 64, Fore Street, E.C.
" .... 5M " " " "
" .... Grocott Bros., Tyndale Works, Canonbury Lane, N.
Lurgan............ 6 Robertson, Sons & Co.
" .... 3½ " "
" .... 2 Jno. Maxwell, High Street.
Manchester ...16 Turner & Goodard, 47, Temple Street.
" .... 6 Knowles & Lindley, Grosvenor Street.
" .... 6 Hy. Marsden & Co., 51, Dantzic Street.
" .... 6 Hammond, Thomas Street.
" .... 6 McIntyre, Hogg & Co., 16, Newton Street.
" .... 6 McLeod Bros., China Lane, Piccadilly.
" .... 3½ Lomas & Co., 110, Great Ancoats Street.
" .... 3½ Reynolds Brothers, 12, Richmond Street, Minshull Street.
" .... 3½ J. C. Smedley & Co., 1, Auburn Street, London Road
" .... 3½ Tootal, Broadhurst & Co., Ogden Street, Cornbrook.
" .... 3½ Mark Doniger, 20, Miller Street (Cap Manufacturer)
" .... 3½ Portland Street Shirt Manufacturing Co.
" .... 3½ Brown & Murray.
" .... 3½ McIntyre, Hogg & Co., 16, Newton Street (Handkerchiefs).
" .... 3½ Bullock, Hamilton & Co.
" .... 2 Mr. Brown, 7, Blackfriars Street.
" .... 2 J. R. Fell, 28, Molyneux Street, Stockport Road (Handkerchiefs).
Market Harboro' .... 3½ W. H. Symington & Co.
Newcastle-on-Tyne .... 6 George Bainbridge & Co.
" .... 3½ " "
Northampton. 6 Bird Bros., Maple Street.
" .... 3½ G. M. Tebbutt, Robert Street.
" .... 2 H. Timson, Duke Street.
Norwich .... 3½ F. H. Hamer & Co., Bethel Street.
Nottingham ... 6 M. Jacoby & Co.
" .... 3½ Rogers & Black, Stoney Street.
" .... ½ Cooper & Elliott, Hounds Gate.
Sudbury .... 3½ Footman, Pretty & Nicholson (Stay Makers).
Portsmouth ... C. Groom, 42, Broad Street (Sails).
" .... 8 H. & W. Davies.
Rishton .... ½v Turner, Draper, Rishton.
Rotherham .. 6 J. Smith & Co., Sewing Machines, Park Gate, Nr.
Rothwell ...... 8 R. W. H. Lymington & Co. (Stay Manufacturers).
Rugby .... 8 The Rugby Corset Co.
Stockport...... 4 F. W. Bratcher & Co., 51, Higher Hillgate (Leather bands for hats).
Stowmarket.. 3½ Footman & Co.
" .... 2 " "
St. Helens ... 8 *Per* F. W. Webb, of L. & N. W. Ry. Co., Crewe.
" .... 3½ J. P. Coope (Wholesale Clothier).
Sunderland... ½ W. Davieson, Villiers Street South (Sail Making).
Walsall ......12 J. Shannon & Son.
" .... 8 Fairbanks, Lavender & Co., Elder Street
Whitby ...... 3½ Geo. Remmer, Shirt Manufacturers.
Whitchurch... 1 Geo. Remmer (Shirts).

CLOTH CUTTING.

Basingstoke .. ½ Hy. Smith, Station Hill.
Bradford ...... 8 J. Lumby & Co., Swain Gate.
Bristol .... 2 Brodericks, St. James.
Crewe .... 6 J. Compton & Sons.
Derby .... 2 J. Smith & Co.
Derry .... 8 McIntyre, Hogg & Co.
Glasgow ...... 8 Tillie & Henderson, 83, Dunlop Street.
" .... 3½ J. & R. Pritchard & Co., 249, Argyle Street.
" .... 3½ Arthur & Co., Queen Street.
" .... 1 Mann, Byers & Co., 21, Glassford Street.
Hyde .... 2 Geo Brownson.
Leeds ... .16 J. Barran & Sons.
" ....16 Jas. Rhodes & Co., Oxford Road, Park Lane.
" ....12 Buckley & Sons, Greek Street.
" .... 8 J. Barran & Sons.
" .... 8 " "
" .... 8 Jos. Hepworth, Wellington Street.
" .... 7 Jno. Barran & Sons, St. Paul's Street.
" .... 7 Mason & Nicholson, St. Paul's Street.
" .... 7 Talbot & Sullivan, Grace Street.
" .... 7 D. Little & Co., Aire Street.
" .... 6 Willie & Cliffe, Wellington Street.
" .... 4 Hunter & Barr, Park Cross Street.
" .... 4 Hepton Bros., Bishopgate Street.
" .... 4 Horner & Nicholson, York Place.
" .... 3½ W. Blackburn & Co., Anne Street.
" .... 2 Wm. Blackburn, The Calls.
" .... ½ J. W. Sunderland & Co., Mill Garth Street.
Liverpool ...... 6 P. Williams & Co., Paradise Street.
London ....12 M. Hyam & Co., 69 to 75, Cannon Street.
" .... 8 T. & E. Jones, 138, Queen Victoria Street.
" .... 6 Hollington Bros., 37, Commercial Street.
" .... 4 Stapley & Smith, London Wall, E.C. (also Hoisting).
" .... 3½ Copper Box & Co., 105, Queen Victoria Street.
" .... 3½ Schneider & Sons, 27, Commercial Street.
" .... 3½ Rylands & Sons, Limited, Wormall Street, E.C.
" .... 2 " " " "
" .... 2 R. Goodson, 20, Cross Street, Upper Street.
" .... 2 Thos. Knight & Son, Aldermanbury.
" .... 2 Devas, Routledge & Co., 20, Canon Street.
" .... 2 T. J. Barrett & Co., 14, Knightrider Street.
" .... 1 Hibbert & Co., 16, James Street, Haymarket.
" .... ½ H. F. Fentel, 133, Kingsland Road.
" .... ½ W. & P. Keeble, 19, Bread Street Hill, E.C.
" .... ½ Aublet, Harry & Co., 71, Scrutton Street.
" .... 5M " " "
Manchester... ½ J. Pilkington, 17, Marsden Square (Tailor).
Perth .... 2 J. Jamieson & Co., Athole Street.
St. Helens ... 3½ J. P. Coope (Wholesale Clothiers).
Swindon......... 6 J. Compton & Sons.
Stroud .... 3½ Holloway Bros.
" .... 3½ " "

FOLDING, MEASURING, ROLLING, &c.

Ballymena ... 2 J. & R. Young.
Bradford ...... 8 J. Lumby & Co., Swaine Street.
" .... 6 Horner & Craven, Midland Buildings.
" .... 3½ R. Higgins, Union Street.
" .... 3½ H. J. Blair & Co. (Stuff Merchants).
" .... 3½ Leigh Mills & Co., 39, Leeds Road.
" .... 3½ J. W. Greeves, Hall Ings.
" .... 3½ R. Taylor, Leeds Road.
" .... 3½ W. Critchley & Co., 37, Booth Street.
" .... 3½ Cook & Co., Peel Place.
" .... 2 Jno. Ambler & Son, 40, Hall Ings.
" .... 2 Fraser, Fleming & Co., Hall Ings.
" .... 2 F. O. Fraser, Sons & Co , 37, Leeds Road.
" .... 2 A. O. Shalders & Co., Piccadilly.
" .... ½ T. Sutcliffe & Co., Drake Street.
Dublin .... 2 R. & J. Turbett.
London .... 3½ J. Swaagman.
Manchester..12 Novelli & Co.
" .... 3½ Ellinger & Co., 8, Minshull Street.
" .... 3½ Hamilton Bro. & Co., Minshull Street.
" .... 1 R. Haworth & Co., High Street.
" .... ½ Marshall & Aston, 15, Tib Street.

BUCKLEY & BLAND, PRINTERS, 21, CANNON STREET, MANCHESTER.

3½-HP. *19 and 20, King Square, 12 and 13, Lower Gay Street, Bristol, April 16, 1883.*

Messrs. Crossley Brothers Limited.

Gentlemen,—Your card drew my attention to the Engine, otherwise we so very seldom hear of it that it escapes our attention.

Its history since I bought it in April, 1878, five years ago, has been—working every day, ten hours average; exceptions—Sundays, holidays, and overtime, when we work it thirteen hours.

We have had an Engineer only once, to put in the reserve new slide valve you supply. I thought he had better do it. Otherwise no repair.

It appears to-day to be working all you can wish, an even smooth motion, without jerk or vibration; the bevel wheels now make less noise than when new.

If there is any part you think should be specially looked to, please advise us.

You can use these statements without hesitation in which way you please.

I am, yours truly,
THOMAS J. COE.

P.S.—The 3½-HP. "OTTO" is used for turning—

One Pair of Rollers.
Five Eccentric Sole Cutting Presses.
One Split-lift Machine.
One Pairing Machine (high speed).
One Heeling Machine for attaching them.
One Blake Sole Sewing Machine.
One Wax Thread Upper Sewing Machine.

Engine works well; no trouble.

T. J. C.

3½-HP. *Church Gate, Leicester, May 21, 1883.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 3½-HP. Gas Engine you supplied us in 1878 continues to work well; it is at present driving the undermentioned Machinery, viz.:—

An "Eccentric Press."
Three Chopping Machines.
One Heel Pressing and one Heel Fixing Machines.
Pairing, Split-lift, Skiving, and Picking.
One Set Rollers.
Two *Sole* Sewing and six ordinary Sewing Machines.

As well as other small Machinery necessary in a modern Shoe Factory. The Engine is both economical and cleanly, and gives us every satisfaction.

Yours truly,
E. JENNINGS & CO.

3½-HP. *Bristol.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—The 3½-HP. "OTTO," No. 1639, is used for driving—

Boot Machinery.
Blake Sewing Machines.
Screwing Machine, which requires 1½-HP. Rollers.
Pairing Machine.
Two Cutting Presses.
Emery Wheel, &c.

It is giving every satisfaction.

Yours, &c.,
J. W. MAGGS.

3½-HP. *39, Albion Street, Leeds, February 18, 1881.*

Messrs. Crossley Brothers Limited.

Gentlemen,—I have had one of your 3½-HP. Gas Engines working for about two and a-half years. During that time it has worked to my entire satisfaction. I use it to drive the following Machinery, viz.:—Rough Cutting, Pairing, Heeling, and Heel-building Machines. I should not like to be obliged to use a steam engine after my experience.

Yours truly,
PAUL STEAD.

3½-HP. *22, Boar Lane, Leeds, July 12, 1885.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We have been using your "OTTO" Silent Gas Engine since November last. We have had no trouble with it whatever. It does its work sweetly and pleasantly; but the greatest satisfaction is in the immense saving as compared with the steam engine with which we previously worked our machinery. Calculating cost of fuel, cleaning flues, and removing ashes, we calculate our saving at 75 per cent., besides being so much cleaner. We have pleasure in bearing this testimony.

Yours truly,
S. T. MIDGLEY & SON,
pro EDWIN OLDROYD.

3½-HP. *Ross, March 19, 1878.*

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to your inquiry respecting the 3½-HP. Engine, we have very great pleasure in saying that, for cheapness and efficiency, it has exceeded our most sanguine expectations, having only consumed twenty-four thousand feet of gas for the last twelve weeks—average working, about fifty-five hours per week—and driving the whole of the Machinery, Presses, &c., with a steadiness equal to the largest steam engine. We shall be pleased to answer inquiries, or show it to anyone who may favour us with a call.

Yours respectfully,
EDMUND TURNER & CO. LIMITED.
pro E. T.

Ross Shoe Factory, Ross, May 16, 1883.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In reply to yours "*re* Gas Engine," we can now, by the test of experience, confirm what we wrote five years ago, and add that, although doing considerably more, it continues to work very satisfactorily.

Yours respectfully,
pro EDMUND TURNER & CO. LIMITED.
EDMUND TURNER.

2-HP.

New Street, Hinckley,
August 29, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—In answer to yours of 26th, the 2-HP. Gas Engine I had of you is used in the manufacture of Boots and Shoes, and is driving two Sole Presses, two Lift-cutting Machines, pair of Rollers, Heel Pairing Machine, and a Blake Sewing Machine; and I am pleased to say gives great satisfaction.

Yours respectfully,
H. PERKINS.

2-HP.

Maple Street, and 4, Woburn Street,
Northampton, June 17, 1881.

Messrs. Crossley Brothers, Manchester.

Gentlemen,—We are perfectly satisfied with the 2-HP. "OTTO" Silent Gas Engine you supplied to us in 1879. It is now driving two Blake Sole Sewing, three Goodyear Stitching, one Champion Pegging, one Standard Screwing, and one Waxed Thread Winding Machines. It works on an average 61 hours, and consumes about 2,000 feet of gas. We confidently recommend the Engine to anyone requiring power without heat.

We are, yours truly,
BIRD BROTHERS.

Abridged List of Users of the "OTTO" Gas Engine for Driving Boot and Shoe Machinery.

TOWN.	HP.	NAME OF USER.
ABERDEEN	2	William Peters, Crimson Place.
ARBROATH	3½	Patrick Brown, Leather Merchant.
AYR	3½	Murdock, Stanton & Co., Maybole.
BISHOP AUCKLAND	12	The Co-operative Society. (With various other Machines, Hoists, &c.)
BRADFORD	3½	J. Riley & Co., 32, Sunbridge Road. (And Hoisting.)
BRISTOL	8	Smith & Sons, Boot Manufacturers.
"	3½	J. Maggs, Broad Weir.
"	3½	R. W. Ashley, 34, Portland Square.
"	3½	J. Coles, 15, Portland Square.
"	3½	T. J. Coe, King's Square. (Drives one Pair Rollers, five Eccentric Sole-cutting Presses, one Split Lift Machine, one Pairing Machine, one Heeling Machine, one Blake Sewing Machine, one Wax Thread Upper Sewing Machine. Says—"Engine works well; no trouble.")
"	3½	J. Porter, Old Market Street. (Eight Machines.)
"	3½	Bird Brothers, Kingswood Hill.
"	2	J. Gleddon, 24, Upper York Street, St. Paul's.
"	½	Bird Brothers, Kingswood Hill.
BURSLEM	3½	S. Tipper, Market Place.
CORK	2	Cork Boot Manufacturing Company.
DEPTFORD	1	J. Clemson, Esq., Spa Lane Works.
DUBLIN	8	T. Drury & Co., Merchants' Quay.
"	8	J. Winstanley, Back Lane.
"	1	Thomas Ovans, 14, Merchants' Quay.
EALING	6	Peal & Co., Northfield Lane.
"	3½	Peal & Co., Northfield Lane.
GLASGOW	6	James Markland, 24, St. James Street, Paisley Road. (Drives one Sole Cutter, one Peg Cleaning Machine, one McOrr Heeler, one Roller, one Split Lift, one Heel Burnisher, one Blake Sewing Machine [Sole], one Pairing Machine, one Blake Standard Screw, and eighteen Sewing Machines—twenty-seven in all.)
"	3½	Hornlidell & Co., 24, Ingram Street. (Drives two Blake Sole Screwing Machines, one Edge Pairer, fifteen Sewing Machines, one Leveller, one Ranging Machine, one Roller, two Presses, and one Pump Wash—twenty-four in all.)
"	3½	P. & G. Purdie, 22, Pitt Street.
"	2	S. F. Scott, 45, Bridge Street.
"	1	Jackson & Lamb, 106, Dunlop Street.
HALIFAX	1	J. Brearley, 12, Swine Market.
HECKMONDWIKE	3½	Co-operative Society.
HIGHAM FERRERS	2	W. Claridge, Rushden.
HINCKLEY	2	Henry Perkins.
HITCHIN	½	T. Watts, Myrtle Street.
IPSWICH	3½	W. Garrard, Old Foundry Road.
KETTERING	2	W. F. Farey & Son.
"	½	W. Cattell, 8, Treestone Row.
LEEDS	6	Raywood & Carnley, Semers Street.
"	6	Henry Walker & Son, Kirkstall Road.
"	3½	Paul Stead, Albion Street.
"	3½	S. T. Midgley & Son, Swinegate.

TOWN.	HP.	NAME OF USER.
LEEDS	3½	Leeds Co-operative Society (Boot and Shoe Department), Marshall Street.
"	3½	E. Blakey & Son, Lady Lane.
"	3½	W. Green & Co., 13, Cookridge Street.
"	3½	Ross Brothers, Bramley.
"	3½	W. & J. Gray, Camp Road Mills.
"	2	James Dennell, 3, Swinegate.
"	2	W. Slater, York Street.
LEICESTER	8	Co-operative Society (Shoe Warehouse), Duns Lane.
"	6	Bradshaw & Payne, 181, Humberstone Road.
"	6	T. Roberts & Son, Clinton Street.
"	3½	B. Ellis & Co., Marble Street.
"	3½	E. Jennings & Co., Church Gate.
"	3½	F. Taylor, Free School Lane.
"	3½	C. G. Allan, 70, Oxford Road.
"	3½	Leavesley & North, Erskine Street.
"	3½	W. D. Judd & Co., South Bond Street.
"	3½	G. Hassell & Co., 145, Willow Street.
"	2	Joseph Thornton, 91, Humberstone Gate.
"	2	T. Roberts, Clinton Street.
"	2	Jones & Tailby, Friars Causeway.
"	1	G. P. Simon, 11, Wellington Street.
"	1	Smalley Briggs, 26, Morlidge Street.
"	1	W. Richards, 65, Denman Street.
"	1	H. O. Bridgewater, Southgate Street.
LONG BUCKLY	3½	William Sanders.
LONDON	8	Jonas Turner & Son, Church Street, Edgware Road.
"	6	Rabbitts & Son, Newington Butts, Borough.
LONDON	3½	J. Magnus, Skinner Street, Finsbury.
"	2	E. & A. B. & S. Machinery Company.
"	1	F. James, 33, Scawfell, Hackney Road.
"	½	— Samethoss, 25, Market Place, Oxford Market, W.
"	½	A. Stacy, Victoria Park Square, Bethnal Green.
NORTHAMPTON	8	J. Laycock & Sons, Bird's Piece.
"	6	— Derby.
"	6	— Collier.
"	6	Bird Brothers, Maple Street.
"	6	Mansfield & Sons.
"	3½	Hornby & West, Overstone Road.
"	3½	R. Taylor, Kettering Road.
"	3½	Church & Co., Duke Street.
"	3½	F. Bostock, Victoria Street.
"	3½	F. Bostock, Victoria Street.
"	3½	G. M. Tebbutt, Robert Street.
"	3½	W. R. Cooper, 81, Newland.
"	2	Thomas Laycock, 56, North Street.
"	2	H. Timpson, Duke Street.
"	1	F. Bostock, Victoria Street.
"	1	T. B. Roe, 16, Newland.
"	½	Simonds & Fowkes.
"	½	Bird Brothers.
NORWICH	3½	Willis & Southall, Upper Market.
"	2	John Henry Smith, Charing Cross.
NOTTINGHAM	3½	Samuel Smith, Derby Road.
PAISLEY	½	Gavin Crawford, 97, High Street.
PLYMOUTH	2	F. R. Blight, Frankfort Lane.
ROSS	3½	E. Turner & Co.

CROSSLEY BROTHERS LIMITED

Engineers,

"OTTO" Gas Engine Works, OPENSHAW,

MANCHESTER.

1,000. 11/88. CUTHBERTSON & BLACK, *Printers*, 1, Minshull Street, Manchester.

List of a Few of

CROSSLEY'S "OTTO" Gas Engines

Driving Tobacco Machinery.

	HP.	
AMLWCH (N. Wales)	3½	E. MORGAN HUGHES.
BRISTOL	12	HUDDEN & CO., Victoria Street.
"	8	E. RYMER & CO.
"	8	W. D. & H. O. WILLS.
"	8	FRANKLIN, DAVY & MORGAN.
CARNARVON	1	C. E. JONES & CO., Virginia Works.
CHESTER	3½	NICHOLLS & CO.
CORK	7	LAMBKIN & CO.
EDINBURGH	8	D. RITCHIE & CO., 51, Cockburn Street.
"	3½	C. D. RUTHERFORD, Johnstone Terrace.
GLASGOW	½	R. BARR & SON, 34, King Street.
GUERNSEY	1	BUCKTROW & CO.
HULL	1½	C. GIBSON.
KENDAL	½	J. T. ILLINGWORTH & CO.
LIVERPOOL	12	THOMAS OGDEN, 65, Cornwallis Street.
LONDON	8	W. & F. FAULKNER, 223, Blackfriars Road, S.E.
"	7	LAMBERT & BUTLER, 141, Drury Lane, W.C.
"	6	P. MORRIS & CO., Poland Street, W.
"	2	LEVANT CIGARETTE CO., 56, St. Mary Axe.
"	1	ISAAC ISAACS, 234, Pentonville Hill, N.
"	½	JONES & CO., Broadway, Hammersmith, W.
"	5-MP.	DALMON & GLUCKSTEIN, Whitechapel, E.

CROSSLEY BROS. LIMITED,

ENGINEERS,

Openshaw, Manchester.

1,000. 9/88.

Cuthbertson & Black, Printers, 1, Minshull Street, Manchester.

Motive Power Testimonials.

OTTO ENGINE, **About 45-48 indicated H.P.** MESSRS. IBOTSON & SONS, POYLE MILL, COLNBROOK. *3rd May*, 1888.	"We have been for some time using your patent gas generator in connection with Messrs. "Crossley Bros.' engines, as the motive power of our millboard mill. For the last eight months "we have been working an 'Otto' engine, indicating about 48 H.P., coupled to a turbine water wheel "to drive our beating engines—four in number—beating strong stuff together with rollers, pumps, &c. "We find the arrangement very simple and very economical. The consumption of fuel on a trial "extending over a week did not exceed 1·4 lbs. of coal per indicated H.P. per hour, including all the "coal used in lighting up on Monday morning. We drove three beaters on strong stuff, and one on "tender stuff, carrying two cwt. of stuff per engine day and night continuously for a week, with a "consumption of under three tons of coal. Any intelligent man can manage the whole apparatus "with ease."
OTTO ENGINES, *Aggregate Power.* **About 150 indicated H.P.** MESSRS. CROSSLEY BROS., LTD., OPENSHAW, MANCHESTER. *15th November*, 1886.	"Two years ago we wrote you that we made a careful estimate of the coal used during 35 weeks, for making gas in your plant to drive the engines at our works. The engines indicated an average of about 150 H.P., and the consumption of coal was only 1·3 lbs. per indicated H.P., per hour, including a waste of about 5 cwt. each Sunday. Since then the fuel consumption has continued at the same rate, and after more than three years' regular use, we are perfectly satisfied with the working of the apparatus. One man is well able to attend to it."
OTTO ENGINE, **About 35 indicated H.P.** MR. WILLIAM MOORE, FARNINGHAM. *3rd February*, 1885.	"Having had your Gas Apparatus at work for several months as a motive power for Messrs. CROSSLEY'S 16 H.P. OTTO engine, I have great pleasure in testifying to its thorough efficiency, having worked it day and night, driving three pairs of stones regularly, producing or grinding 5½ bushels each per hour—occasionally four pairs—the consumption of coal not exceeding half-ton in 24 hours. I consider it far more economical than steam, and a fairly intelligent labourer can work it successfully."
OTTO ENGINE, **About 35 indicated H.P.** MESSRS. J. HALL & SONS, BROADMEAD, BRISTOL. *August*, 1884.	"Dowson's Gas— "Consumption—44 hours work of 20 H.P. with CROSSLEY'S 16 H.P. Gas engine— s. d. "Coal 9 cwt. 8 1½ "Coke 2½ " 1 10½ } =2¾d. per hour for materials. Water nominal. "One man's time to apparatus." [*i.e.* Gas Plant and Engine.]
OTTO ENGINE, **About 20 indicated H.P.** MESSRS. HALL & DAVIDSON, EWELL, SURREY. *31st December*, 1885.	"In answer to your enquiry as regards the efficiency and economy of your Gas, we have pleasure in stating that, after 12 months' experience, we have every reason to be satisfied in both respects. With a 12 H.P. OTTO engine we drive two pairs of stones continuously both day and night, using anthracite coal, of which we find we use *barely* 1½ lbs. per H.P. per hour. This we take to be a very considerable saving as compared with steam power. The apparatus is easily worked, and our repairs up to this time have been next to nothing."
OTTO ENGINE, **About 35 indicated H.P.** MR. W. HITCHCOCK, BRINKWORTH, CHIPPENHAM. *6th January*, 1886.	"Having worked your Gas Apparatus for 10 months with a 16 H.P. OTTO engine, I have much pleasure in saying it has given very good satisfaction. I usually work 2 pairs of four feet stones and flour machine, and occasionally three pairs of stones, with a consumption of 5 cwt. of coal and 2 bushels of coke in 12 hours. The repairs to it have been trifling, and, with a little instruction, a fairly intelligent labourer can soon take the management of it. I consider it far more economical than steam."
OTTO ENGINE, **About 36 indicated H.P.** MESSRS. HURST BROS., ST. JOHN'S MILLS, EASTBOURNE. *19th January*, 1887.	'We have now worked your Gas Apparatus for some months in conjunction with a 16 H.P. (nom.) gas engine. We can only say we are perfectly satisfied with it; it is simple, easily managed, and the cost far less than the ordinary town gas. We get as much power from it, and believe it to be in accordance with your representations."
OTTO ENGINE, **20 effective H.P.** MONS. CH. BARATAUD. MARSEILLES. *21st April*, 1888.	"Replying to your letter of 19th inst., I beg to state that I have always been satisfied during the time (over 2 years) in which I have used a 20 H.P. engine, driven by DOWSON GAS at my flour mill. The plant producing the gas occupies but little space, is easy to work and has never yet been out of order. The fuel consumption per hour is under 23 lbs. anthracite and 3 lbs. coke."
OTTO ENGINE, **About 35 indicated H.P.** MESSRS. ROBERT HARPER & CO. ADELAIDE. *6th January*, 1886.	"Our machine has now been at work for 14 months, and the result is satisfactory to us. In addition to the gas used for driving the engine, we have a supply which we use for roasting coffee and have one roaster going continually."

Motive Power Testimonials—*continued.*

OTTO ENGINE, 12 effective H.P. MESSRS. RUSS-SUCHARD & Co., NEUCHATEL.	*May 13th*, 1887.—*(Translation.)* "During the last period of trial, from the 7th February to the "19th April of this year, we have not had a single interruption. This period of 50 days "can, therefore, serve as a basis for an estimate of the consumption of coal and the cost of "working. We have arrived at the following figures from our observations: "6,542 kilogs. Anthracite @ francs 3 per 100 kilogs. "813 kilogs. Coke @ francs 3·30 per 100 kilogs. "produced a total of 7,243 H.P. hours, which shows a cost of say 3 centimes per H.P. hour produced "by Dowson Gas." [Or say, under ⅓rd of a penny per effective H.P. per hour, although fuel is "much dearer in Switzerland than in England.] *June 15th*, 1887.—*(Translation.)* "We have the pleasure to inform you that our installation of "Dowson apparatus is working to our entire satisfaction."
DELAMERE DEBOUTEVILLE ENGINE, 25 effective H.P. MR. THOMAS POWELL, ROUEN. *13th October*, 1887.	"Replying to yours of the 30th ult., I have much pleasure in stating that I worked a Delamere Debouteville gas engine in connection with your economic plant last year at the Marseilles Exhibition for 6 months, and was so satisfied with the result, that I afterwards obtained a set of your apparatus to work with a 25 H.P. at my works. Very exhaustive trials have been made with this by Professor Witz and ourselves, and the results are most satisfactory."
TWO OTTO ENGINES, Each about 35 indicated H.P. WALLSEND PONTOON Co., LIMITED, BUTE DOCKS, CARDIFF. *3rd October*, 1887.	"We have very great pleasure in stating that we have had your apparatus at work in our establishment here for over three years, and during that time it has given us every satisfaction, both as regards economy in fuel and ease of management. We sometimes use one generator for 3 weeks at a time, and find that we hardly need the spare one supplied by you."
OTTO ENGINE, About 35 indicated H.P. MESSRS. BONNETT & SHUM, 43 & 44, JEWIN STREET, E.C. *27th October*, 1887.	"Having had your gas apparatus in use for some months, we are able to speak of its merits from "actual experience. The engine we drive from it is a Crossley's 'Otto,' nominal 16 H.P., and "computing that we work it up to about 20 horse-power, at a consumption of about ¾ ton of "Gwaun Cae Gurwen anthracite per week, the cost with the wages of a capable stoker at about "30/- per week, amounts to from 45/- to 50/-, as against 100/-, which is the makers' estimate "of 1d. per hour per H.P. when the gas is drawn from the company's mains. Ours is certainly a "crucial test of the adaptability of your apparatus, because having not a single inch of open space, "we were compelled to erect it in a sub-basement, excavated especially for the purpose, beneath the "basement of our new premises in Jewin Crescent. We trust you may have the success which your "admirable invention so justly deserves."
OTTO ENGINE, 12 effective H.P. MESSRS. STADELMANN & Co., NUREMBERG, GERMANY. *4th May*, 1888.	"According to your wish to know about the result which we obtain in using your gas apparatus in "connection with a 12 H.P. 'Otto' Gas Engine, we beg to state that after about two-and-a-half "months' working, we have only reason to be satisfied with it. The management is very easy, and "the quantity of coals (anthracite) required is very small. The power of the engine is the very same "if not better than with ordinary coal gas. We shall be pleased to recommend such apparatus to "anybody who calls."
TWO OTTO ENGINES, Each 40 effective H.P. MESSRS. SELLA & Co., VALLE MOSSO, ITALY.	*May 12th*, 1888.—*(Translation)*. "In reply to your favour of the 2nd instant, we have no hesitation "in stating that we are satisfied with your apparatus for producing Dowson Gas, which has been "working here for six months, as it is easy to work, and realises for us a sensible economy in "comparison with steam power."
OTTO ENGINES, GASMOTOREN FABRIK, DEUTZ BEI COLOGNE. *6th June*, 1888.	"We have much pleasure in confirming that the K size Compact Gas Plant supplied by you has "been put up at our works, and has been working now for two years. We use the gas produced in "the apparatus for testing the Gas Engines which are to work with your gas before they leave our "works, and by frequent tests we have ascertained that the total amount of fuel consumed, when "working with your gas, does not exceed 1 kilogram per hour per brake horse-power (75 kilogram-"mètres). As we have informed you already, we intend shortly to work with your gas a number of "engines, driving the shafting in our workshops, and for this purpose we shall put up one of your C "size, and one of your K size Compact Gas Plants."
OTTO ENGINE, 45 to 48 indicated H.P. MESSRS. HOWARD & BULLOUGH, ACCRINGTON. *30th May*, 1888.	"In reply to your note of the 25th inst., we have been driving 40 H.P. by one of Crossley's Gas "engines, using your Gas Plant, since last January. We have pleasure in stating that the plant works "well, and so far we have had no trouble with it. We get 1 H.P. from an average consumption of "1·3 lbs. anthracite coal per hour."

Motive Power Testimonials—*continued.*

✢ PUMPING ✢ STATIONS. ✢

THE FOLLOWING PARTICULARS WILL BE ESPECIALLY USEFUL TO ENGINEERS, SURVEYORS AND MUNICIPAL AUTHORITIES, AS WELL AS TO ALL WHO APPRECIATE THE NECESSITY FOR REGULARITY, EFFICIENCY AND ECONOMY IN THIS CLASS OF WORK.

TWO OTTO ENGINES, **Each about 16 Indicated H.P.** MR. E. PRITCHARD, C.E., WELLINGTON WATERWORKS, SOMERSET. *14th October*, 1887.	"In reply to your favour, I have much pleasure in testifying to the success of the Dowson gas apparatus, which is giving every satisfaction in supplying and driving the gas engines upon works for which I am engineer, and my experience proves that it is, under certain conditions, more economical than steam, and is thoroughly efficient. The repairs to the present time are but slight."
TWO OTTO ENGINES, **Each about 20 Indicated H.P.** COUNTY ASYLUM, GLOUCESTER.	The gas power used for pumping water, &c., at this asylum has been repeatedly commended in the Annual Report of the Chairman of the Visiting Justices (*see page* 7).
TWO OTTO ENGINES, **Each about 10 indicated H.P.** J. C. BOTHAMS, ESQ., M.I.C.E., CITY ENGINEER, SALISBURY. *5th February*, 1886.	"I have much pleasure in stating that, during the past nine months, the Gas Generating apparatus supplied by you has been in daily use at the Salisbury City Sewage Disposal Works, and has given complete satisfaction." "The gas is used for driving sometimes one, and sometimes two Otto engines of 6 H.P. (nominal) each; also for heating a small stove. The cost of the engine power thus obtained is much less than with ordinary coal gas, or with steam. The fire can be lighted, gas generated, and the engines started in three-quarters of an hour. The apparatus is easy to manage."
OTTO ENGINE, **About 35 Indicated H.P.** MR. JOHN EDE, MANAGER, GODALMING WATER WORKS. *Nov. 12th*, 1887.	"In answer to your enquiry as to our 16 H.P. engine and Dowson Apparatus, it has been worked "since April last, running about 14 hours per day, driving two 8 inch pumps, which pump up 7,000 "gallons per hour 264 feet high, at a cost of 1¼d. per 1,000 gallons. I have great pleasure in stating "that it continues to give us the best satisfaction."
TWO OTTO ENGINES, **About 35 Indicated H.P.** MR. THOMAS WICKS, ENGINEER, BOROUGH OF WEDNESBURY SEWERAGE WORKS, BESCOT, NEAR WALSALL. *3rd May*, 1888.	"Your favour of the 2nd to hand, and in reply, I have much pleasure in stating that during the past "six or seven months the gas generating apparatus supplied by you has been in daily use at these "works, and has given the greatest satisfaction. The gas is used for one, and sometimes two of 'Otto' "16 H.P. nominal Gas Engines, indicating about 35 H.P. each. I find that one of your gas generators "(size H.) is capable of producing sufficient gas to work both engines at the same time. We use "anthracite coal, and it is taking about 1½ lbs. per H.P. per hour, which is much less than ordinary "gas or steam in cost. I have no hesitation in saying that the plant and power is quite in accordance "with your representations."
TWO OTTO ENGINES, **Each about 16 Indicated H.P.** MR. A. THUEY, C.E., STEVENAGE WATER WORKS. *12th June*, 1888.	"I am pleased to be able to state that the DOWSON Gas Generating Plant, supplied and erected "under my directions for the Stevenage Local Board Water Works, and in connection with Messrs. "Crossley's 9 H.P. 'Otto' Engine, has now been in constant use for about a year, and that it continues "to work admirably in every respect, and under the guaranteed rate of fuel consumption."

The DOWSON GAS has also been used or specified for driving Otto Engines at the following Pumping Stations:—

FINCHLEY SEWERAGE WORKS.	Two Engines, each to indicate about 20 H.P.
TEIGNMOUTH WATER WORKS.	Two ,, ,, ,, ,, 35 H.P.
NORWOOD SEWERAGE WORKS.	Two ,, ,, ,, ,, 7 H.P.
WIMBORNE WATER WORKS	One Engine, to indicate about 12 H.P.
MUNSTER WATER WORKS.	One ,, ,, ,, 40 H.P.

HEATING + BY + DOWSON + GAS.

THE smallest size Plant made by the Company has a production of 800 cubic feet per hour (equal to about 200 cubic feet of coal gas); and from Messrs. NESTLÉ's testimonial below it will be seen that a set of this small size is working efficiently and economically. On the other hand, the DOWSON apparatus has been erected for making as much as 100,000 cubic feet per hour. The Company are prepared to supply their Plant on any scale whatever.

Testimonials and Reports.

COOKING, HEATING WATER, &c., &c. *Extracts from Reports of Chairman of Visiting Committee, of Gloucester New County Asylum.*	*4th January*, 1884. "The presence of the patients has necessitated the use of the kitchen apparatus, the constant "employment of the gas engines to pump water into the water tower, the frequent heating of the "laundry boiler, and the constant manufacture of gas for the supply of the various apparatus. We "have therefore had full experience of the practical value of the new system of Dowson Gas, which "we have introduced into the second Asylum." *4th January*, 1887. "Another year's experience confirms the favourable reports that have been given of the efficient "and economic working of the Dowson Gas Apparatus."
HEATING BAKERS' OVENS. *From Ditto.*	"The baking had proved a complete success. They could bake with the Dowson Gas at an estimated "cost of one shilling per day, all the bread produced, which supplied sufficient bread (*about* 300 "*quartern loaves*) for the whole of the inmates in the old and new Asylums."
COCOA ROASTING. MESSRS. VAN HOUTEN & SON, HOLLAND. *May*, 1886.	Trials with the gas apparatus supplied, shewed that with English anthracite costing 16/- per ton, the cost of the Dowson equivalent of 1,000 cubic feet of ordinary lighting gas was 6½d. This result was certified by Messrs. Van Houten & Son.
GAS IRONS. MESSRS. CAREY, McCLELLAN & Co., ARDMORE, LONDONDERRY. *18th January*, 1884.	"Our experience of the Dowson Gas is altogether satisfactory. It was put in here about 3 years ago "to heat 40 smoothing irons used for finishing white shirts for the trade, in which a very small amount "of dirt or dust would be a fatal objection. Since the plant for making the Gas was put in, we have "added 12 more irons and 5 American ironing machines, all of which it is capable of supplying easily. "We have never yet reached the limit of capability. After having had a year's experience of it here "we put in a set of plant at our establishment in Londonderry, where similar work is carried on, and "although we had only a seven years' lease we considered it worth while to go to the expense of a set "of the Dowson Gas Plant."
VARNISH MAKING. MESSRS. GUITTET FRÈRES, HERBLAY. *19th August*, 1881.	After giving details of the cost of the Dowson Gas, they say:— "With this we produce 711 cubic mètres of gas, at an average pressure of 40 millimètres (*about* 1$\frac{6}{10}$ *inches*)." "The result is perfectly satisfactory to us." This is equal to 1·37 centimes per cubic mètre, or about 3½d. per 1,000 cubic feet, the anthracite being about 40 per cent. dearer than in England. In August, 1883, they decided to greatly extend the use of the Gas, and ordered additional plant.
CALENDERING & EMBOSSING FABRICS. MESSRS. GENTILLON, GARNIER, VIGNET & Co., LYON. *31st January*, 1884.	"The numerous tests we have made to ascertain the comparative calorific power of Dowson Gas and "ordinary coal gas, have shown that this varies from $\frac{1}{3.6}$ to ¼ according to circumstances. The "apparatus has worked to our entire satisfaction. It is easy to manage, and has wanted no repairs "during 6 months' working."
SINGEING FABRICS. MESSRS. PIERRON & DEHAITRE, PARIS. *23rd November*, 1883.	"Mr. HUBNER, of Moscow, at first erected two generators, and has now put up a third. He uses "the Dowson Gas for singeing cotton goods. The result must be satisfactory, as he has ordered a "third apparatus."
STENTERING. MESSRS. FENTON, CONNOR & Co., BELFAST. *10th January*, 1883.	"In reply to yours of 9th inst., we beg to say that we have been using your apparatus for some "months past, and that it has given great satisfaction." [They have since extended the use of gas, and have ordered more apparatus.]
STENTERING. MESSRS. RICHARDSON, SONS & OWDEN, LIMITED, GLENMORE, LISBURN. *9th June*, 1886.	"In reply to your letter of the 7th inst., we have to say that we have had your gas apparatus in "work for about 2½ years; and have pleasure in stating that it continues to give us entire satisfaction "as regards economy, and regular and successful working." [They extended the use of the gas in 1885, and doubled the gas making apparatus.]
GASSING YARNS. LA SOCIÉTÉ INDUSTRIELLE POUR LA SCHAPPE, BALE. *2nd February*, 1886.	After using the Dowson Gas about 15 months for gassing silk yarns, they sent very detailed returns of the cost of the Gas. They shew that with anthracite costing as much as 35 francs (about 28/-) per ton, and including wages, and 10 per cent. per annum on the total outlay, for interest and depreciation, the cost of the gas is only 1⅔ centimes per cubic mètre, or say 4½d. per 1,000 cubic feet.

Heating Testimonials—*continued.*

WOOL COMBS. MR. J. FULFORD VICARY, NORTH TAWTON. *13th October*, 1881.	"We have found your gas exceedingly useful to us during the summer, and a great saving. Before, "we had to keep a retort going with ordinary coal gas, solely for heating purposes during the summer "and of course this was expensive, which your gas has obviated."
TYPE FOUNDING, &c. MESSRS. HAZELL, WATSON & VINEY. AYLESBURY. *26th September*, 1884.	"Our gas works have been progressing very satisfactorily since you came, and we have used the gas "almost uninterruptedly; we shall be pleased to speak of its good qualities to anyone to whom you "may refer us."
GASSING YARNS. LA SOCIÉTE ANONYME DE FILATURES DE SCHAPPE, KRIENS, SWITZERLAND. *11th October*, 1887.	*(Translation.)*—"Replying to your favour of 30th ultimo, we beg to inform you that the gas made in your apparatus is at work here regularly, and completely satisfies us in every respect."
GASSING YARNS. MONS. G. HOPPENOT, TROYES, FRANCE. *3rd October*, 1887.	*(Translation.)*—"Replying to your letter of 30th September, we testify willingly to the practical and economical character of the apparatus erected here which continues to give us satisfaction."
SOLDERING. SOCIÉTÉ NESTLÉ, BERCHER, SWITZERLAND. *3rd October*, 1887.	"We hereby with pleasure certify that we are using your gas regularly for soldering our tin boxes, and that we find the apparatus economical and easy to work."
ENAMELLING STOVES, BRAZING, &C. MESSRS. HILLMAN, HERBERT AND COOPER, COVENTRY & NUREMBERG.	After careful trials the DOWSON GAS has been adopted at the Cycle Works of this firm, at Coventry and Nüremberg, Bavaria, for the heating of enamelling stoves—for brazing and soldering—as well as to drive some OTTO Gas engines.
ORE TREATMENT. PROFESSOR HUNTINGDON, METALLURGICAL LABORATORY, KING'S COLLEGE, W.C. *15th August*, 1884.	"The special means adopted for preventing the ore from clotting in a process for extracting gold and silver include the use of producer gas, which during the last eighteen months, I have made with a DOWSON GAS generator, sometimes using hard and sometimes using soft coal, I have found the gas easy and cheap to make and for the purpose I have required it, it has given uniformily satisfactory results."
WOOL COMBS. J. H. BLAMEY, LISKEARD, CORNWALL. *5th May*, 1888.	"I have used your gas apparatus for about eight months, and I find no difficulty in working it. The same man who fires the factory boiler looks after that, so the cost of labour is nothing extra, and with regard to fuel, it will do all your prospectus states."

The DOWSON GAS has been adopted by the following and many other firms:—

COCOA ROASTING, &c.	Messrs. CADBURY BROS., Bournville, Birmingham.
DITTO. DITTO.	Messrs. RUSS-SUCHARD & Co., Neuchatel.
COOKING, BAKING, &c.	Gregynog Hall, Montgomeryshire.
GLASS BLOWING.	Mr. ALBERT HOSTER, d'Aliermont, near Dieppe.
HEATING GAS IRONS.	Messrs. MCINTYRE, HOGG & Co., Londonderry.
HEATING STENTER FRAMES.	Messrs. RICHARDSON & Co., Lambeg, Ireland. Have since ordered additional Gas Plant.
DITTO. DITTO.	Messrs. THE YORK STREET FLAX SPINNING Co., Muckomore, Ireland.
JAPANNING, &c.	Messrs. HUNTLEY, BOORNE & STEVENS, Reading.
VARNISH MAKING.	LA SOCIÉTÉ DES PEINTURES-SOUS-MARINES, MARSEILLES.
SINGEING TEXTILE FABRICS.	M. MITTLESDED, Moscow.
TYPE FOUNDING.	M. TURLOT, Chateauroux.
STARCH DRYING.	Messrs. ONDERWATER & Co., Dordrecht.
UMBRELLA STICK BENDING.	Mr. C. HOOPER, Stroud.
HEATING HAT BLOCKS.	M. AMMANN LABHARDT, Bendlikon.
GASSING YARNS.	FLORET SPINNEREI, Gersau.
DITTO.	GLAMER ET FILS, Rehetobel.
DITTO.	LA SOCIÉTÉ FÉ DES FILATURES DE SCHAPPE, Moscow.

NOTE. When writing for Estimates, clients should state:—

(1) What fuel they are using for the work they propose to do with the Dowson Gas; (2) the quantity consumed per hour; (3) its cost, and (4) what ground space is available for the gas plant.

If the apparatus to be heated by the gas is not well known, rough sketches with dimensions should accompany the enquiry.

ATTENTION TO THESE POINTS WILL PREVENT MUCH LOSS OF TIME IN CORRESPONDENCE.

JULY, 1888.

[*All previous Circulars are withdrawn.*

APPENDIX FOUR

A reproduction of the English Patent No. 2081 of 1876, for the four stroke engine by N. A. Otto of Cologne.

A.D. 1876, 17th May. N° 2081.

Gas Motor Engines.

LETTERS PATENT to Charles Denton Abel, of No. 20, Southampton Buildings, Chancery Lane, in the County of Middlesex, for the Invention of "IMPROVEMENTS IN GAS MOTOR ENGINES." A communication from abroad by Nicolaus August Otto, of the Gas-Motoren Fabrik-Deutz, at Deutz, in the German Empire.

Sealed the 1st August 1876, and dated the 17th May 1876.

PROVISIONAL SPECIFICATION left by the said Charles Denton Abel at the Office of the Commissioners of Patents on the 17th May 1876.

CHARLES DENTON ABEL, of No. 20, Southampton Buildings, Chancery Lane, in the County of Middlesex. "IMPROVEMENTS IN GAS MOTOR ENGINES."

In gas motor engines as at present constructed, an explosive mixture of combustible gas and air is introduced into the engine cylinder, where it is ignited, resulting in a sudden expansion of the gases and development of heat, a great portion of which is lost by absorption unless special provisions are made for allowing the gases to expand very rapidly.

According to the present Invention combustible gas or vapour is introduced into the cylinder together with air or other gas that may or may not support combustion, in such a manner that the particles of the combustible gas are more or less dispersed in an isolated condition in the air or other gas, so that on ignition instead of an explosion ensuing, the flame will be communicated gradually from one combustible particle to another, thereby effecting a gradual development of heat, and a corresponding gradual expansion of the gases, which will enable the motive power so produced to be utilized in the most effective manner. The mode of using the gases and the arrangement of the engine may be variously modified in carrying out this Invention.

Thus according to one arrangement the gases are introduced into the engine cylinder at atmospheric pressure. The cylinder is for this purpose provided with a slide having suitable ports for the admission of air, and of an intimate mixture of combustible gas and air, and the movement of the slide is so regulated by means of a cam or eccentric on the engine shaft that during the first part of the stroke of the piston air alone enters the cylinder, while during a succeeding portion of the stroke the mixture of gas and air is introduced behind the air; this mixture in entering the cylinder will become more or less dispersed in the air previously introduced, the particles of the mixture being situated nearest together at the point where they enter the cylinder, and becoming gradually more dispersed as they mix with the air in front. A communication being now established by the slide between a small external gas flame and the contents of the cylinder at the point where the combustible mixture is most dense, this ignites, and the combustion of the whole charge takes place gradually, the mixture burning with gradually decreasing rapidity as the flame extends to those particles that are more diffused among the air. The gradual expansion of the gases thus produced causes the piston to complete its stroke, and on the return stroke, which may be effected either by the momentum of the fly wheel, or by the introduction of a similar charge at the other end of the cylinder, the products of combustion are expelled through a valve, after which the above described operation is repeated for the next stroke.

According to another arrangement the combustible gas and air or other gas are employed in a compressed state in the engine. For this purpose the engine may operate either as above described, the gas and air being simply compressed to the requisite degree before being introduced into the cylinder, or by preference the compression is effected in the cylinder itself in the following manner:—The cylinder is constructed of greater length than the stroke of the piston, so that there is a space beyond the latter when it is at end stroke. Assuming this space to be filled with a portion of the gaseous products of combustion resulting from the last stroke at atmospheric pressure, the piston in performing one part of its stroke draws in atmospheric air, after which it will draw in the combustible mixture during the remainder of its stroke. The cylinder will then be filled with three strata of different gases, more or less intermingled at their junction, namely, a stratum of products of combustion next the piston, then a stratum of air, and lastly the combustible mixture. The piston then performs its return stroke, whereby the gaseous charge is compressed into the before-mentioned space at the end of the cylinder. The gases will in this condition still retain their stratified position, the particles of combustible mixture being diffused to a certain extent through the other strata. The charge is now ignited and burns gradually, and with the same effect as described with reference to the first arrangement. On the return stroke the products of combustion are expelled with the exception of the quantity contained in the space at the end of the cylinder.

The regulation of the power of the engines operating according to the above-described Invention is effected simply by admitting more or less of the combustible gas for each charge, this being done by regulating the time of opening and closing of an admission valve on the gas supply pipe. The motion of the slide is regulated by a rotating cam, capable of being adjusted on its shaft relatively to a lever connected to the slide, which adjustment may be effected by any suitable known arrangement of governor.

SPECIFICATION in pursuance of the conditions of the Letters Patent filed by the said Charles Denton Abel in the Great Seal Patent Office on the 3rd November 1876.

CHARLES DENTON ABEL, of No. 20, Southampton Buildings, Chancery Lane, in the County of Middlesex. "IMPROVEMENTS IN GAS MOTOR ENGINES." A communication from abroad by Nicolaus August Otto, of the Gas-Motoren Fabrik-Deutz, at Deutz, in the German Empire.

In gas motor engines as at present constructed an explosive mixture of combustible gas and air is introduced into the engine cylinder where it is ignited, resulting in a sudden expansion of the gases and development of heat, a great portion of which is lost by absorption unless special provisions are made for allowing the gases to expand very rapidly.

According to the present Invention combustible mixture of gas or vapour and air is introduced into the cylinder together with air or other gas that may or may not support combustion in such a manner that the particles of the combustible mixture are more or less dispersed in an isolated condition in the air or other gas, so that on ignition, instead of an explosion ensuing, the flame will be communicated gradually from one combustible particle to another, thereby effecting a gradual development of heat and a corresponding gradual expansion of the gases, which will enable the motive power so produced to be utilised in the most effective manner. The mode of using the gases and the arrangement of the engine may be variously modified in carrying out this Invention.

Thus according to one arrangement the gases are introduced into the engine cylinder at atmospheric pressure. The cylinder is for this purpose provided with a slide having suitable ports for the admission of air and of an intimate mixture of combustible gas or vapour and air, and the movement of the slide is so regulated by means of a cam or eccentric on the engine shaft that during the first part of the stroke of the piston air alone enters the cylinder, while during a succeeding portion of the stroke the mixture of gas or petroleum vapour and air is introduced behind the air. This mixture in entering the cylinder will become more or less dispersed in the air previously introduced, the particles of the mixture being situated nearest together at the points where they enter the cylinder, and becoming gradually more dispersed as they mix with the air in front. A communication being now established by the slide between a small external gas flame and the contents of the cylinder at the point where the combustible mixture is most dense, this ignites and the combustion of the whole charge takes place gradually, the mixture burning with gradually decreasing rapidity as the flame extends to those particles that are more dispersed among the air. The gradual expansion of the gases thus produced causes the piston to complete its stroke, and on the return stroke, which may be effected either by the momentum of the fly wheel or by the introduction of a similar charge at the other end of the cylinder, the products of combustion are expelled through a valve, after which the above described operation is repeated for the next stroke.

According to another arrangement the combustible gas and air or other gas are employed in a compressed state in the engine. For this purpose the engine may operate either as above described, the gas and air being simply compressed to the requisite degree before being introduced into the cylinder, or by preference the compression is effected in the cylinder itself in the following manner:—The cylinder is constructed of greater length than the stroke of the piston, so that there is a space beyond the latter when it is at end stroke. Assuming this space to be filled with a portion of the gaseous products of combustion resulting from the last stroke at atmospheric pressure, the piston in performing one part of its stroke draws in atmospheric air, after which it will draw in the combustible mixture during the remainder of its stroke. The cylinder will then be filled with three strata of different gases, more or less intermingled at their junction, namely, a stratum of products of combustion next the piston, then a stratum of air, and lastly the combustible mixture. The piston then performs its return stroke, whereby the gaseous charge is compressed into the before-mentioned space at the end of the cylinder. The gases will in this condition still retain their stratified position, the particles of combustible mixture being diffused to a certain extent through the other strata. The charge is now ignited and burns gradually and with the same effect as described with reference to the first arrangement. On the return stroke the products of combustion are expelled with the exception of the quantity contained in the space at the end of the cylinder.

The regulation of the power of the engines operating according to the above described Invention is effected simply by admitting more or less of the combustible gas for each charge, this being done by regulating the time of opening and closing of an admission valve on the gas supply pipe. The motion of this valve is regulated by a rotating cam capable of being adjusted longitudinally on its shaft by any suitable known arrangement of governor.

Description of the Drawings.

In the accompanying Drawings Fig. 1 shews a longitudinal section of an engine cylinder A, having a piston B connected to a fly wheel shaft, an inlet passage C controlled by the slide D, and a passage E for the emission of the products of combustion closed by a valve F. When the piston is at the end of its in stroke its inner surface being at *a* the slide D is in such a position that as the piston begins its out stroke air entering by the aperture D^2 passes by D and C into the cylinder. When the piston has reached the point *b* the slide has moved so as to admit combustible gas or vapour from the passage G to mix with the entering air until the piston reaches the point *c*, when the slide has moved back to the position shewn, cutting off the gas and air supply and about to establish a communication between a small gas flame H and the charge in the cylinder. The combustible gaseous mixture entering the cylinder behind the air previously admitted, becomes partially mixed therewith, being thus dispersed more and more towards the piston, as indicated by the dots in the Drawing, which represent the combustible particles. On the ignition of the charge the combustion at and near the port C is comparatively rapid, but as the ignition extends towards the front of the charge it proceeds more and more slowly, owing to the greater dispersion of the combustible particles. The gradually increasing pressure thus produced by the gradual expansion of the products of combustion, and also of the surrounding fluid, due to the heat evolved, causes the piston to complete its outstroke, imparting motion to the fly wheel, the momentum of which causes the piston to perform its return stroke, expelling the products of combustion through the valve F, and also causing the piston to commence its next out stroke and draw in a fresh charge of air and gas. In order to vary the power of the engine the charge of gas or the proportion of the air and gas or vapour may be varied, and such variations may be controlled by means of a governor, as will be presently described. By this mode of operating shock resulting from sudden explosion is avoided, partly through the dispersion of the combustible charge, as described, and partly because the first admitted charge of air which does not become completely mixed with the combustible charge acts as a cushion between this and the piston; and owing to the gradual development of heat and expansion of the gases there is comparatively little loss of useful effect. Engines operating in this manner may either be single acting as shewn, the return stroke being effected by the momentum of the fly wheel, or they may be double acting, having a charge introduced at each end of the cylinder. They may also operate with the gases at atmospheric pressure or compressed to any desired degree. In the latter case, the engine may be like that above described supplied with compressed gases; I prefer, however, to dispense with compressing mechanism by arranging the engine to operate as I will now describe, referring to Figs. 2 to 13 of the Drawings. Fig. 2 shews a side elevation; Fig. 3 a sectional plan; Fig. 4 a back end view of an engine thus arranged; and Figs. 5 to 13 shew details of the valve gear. This engine being single acting, the cylinder A is open in front, at its closed back end it has, beyond the stroke of the piston B, a space A^1 preferably of conical form tapering to the inlet port C, and also communicating by a passage E with a valve F (Fig. 3) for discharging the products of combustion. The piston B is connected by the rod B^1 to the crank shaft I, on which is a bevil pinion I^1 in gear with a bevil wheel K^1, on a shaft K. On the other end of this shaft is a crank K^2, connected by a link D^2 to the slide D, which governs the admission of gas and air to the cylinder. The gearing I^1, K^1, is proportioned as 2 to 1, so that the crank K^2 makes one revolution, and consequently the slide makes one to and fro motion while the piston makes two double strokes. When the piston is at the point *a*, the end of its in stroke, and about to be moved outwards by the momentum of the fly wheel M, then the slide D (the construction of which will be hereafter explained) is in position to admit air through the passage D^1 and port C into the cylinder until the piston reaches the point *b*, when the slide attains such a position that combustible gas is drawn in together with air until the piston reaches the end of its out stroke, as shewn in Fig. 3. As before explained with reference to Fig. 1, the combustible mixture in partially mingling with the air previously introduced is more and more dispersed towards the front. The slide having now closed the inlet port C, the piston is caused by the momentum of the fly wheel to perform its in stroke, compressing the charge of gas and air into the space A^1 behind *a*, the combustible particles remaining in nearly the same unequally distributed condition as before compression. The slide now moves so as to admit the gas flame H, igniting the charge, and the combustion produces a gradual development of heat and expansion of the gases, whereby the piston is caused to perform its out stroke, imparting fresh momentum to the fly wheel. This momentum again causes the piston to perform its in stroke, expelling the products of combustion through the valve F, which is opened by a lever F^1, acted on by a cam F^3 on the shaft K. As the piston only moves back to *a*, a portion of the products of combustion remaining in the cylinder will partially mix with the air drawn in at the next out stroke, but as the combustible mixture afterwards introduced can burn independently of the gas surrounding its particles, the presence of these products of previous combustion will merely aid in preventing too rapid or explosive combustion and in acting as a cushion between the combustible charge and the piston. It will be evident that if the space A^1, or a separate chamber such as an air vessel communicating therewith, be made sufficiently large to contain the whole quantity of incombustible fluid requisite for each charge, no fresh charge of air need be drawn in at the commencement of the stroke. As before stated, the power of the engine may be regulated by regulating the quantity of combustible gas introduced at each charge. This is effected by the gas slide P, controlled by a governor Q, operating on a sliding cam R. Fig. 5, shews an enlarged front view of the gas slide, Figs. 6 and 7 vertical sections, and Fig. 8 a plan of the same. In the casing are two passages G^1 and G^2, the former communicating by a pipe G^3 with the gas passage G in the cover L of the main slide, and the latter with the gas supply pipe G^4. These passages have small side openings as shewn, which, when the slide P is as shewn in Fig. 7, both communicate with the cavity of the slide so that gas can pass from G^2 into G^1, and thence to the main slide D; when the slide is moved into the position shewn in Fig. 6 this communication and consequently the gas supply is cut off. On the slide P is mounted a roller P^1, bearing upon a cam R, which revolves with and can slide longitudinally along the shaft K. The slide is raised by the cam and is pressed down by a spring P^2. According as the cam is shifted relatively to the roller P^1 by the action of the governor Q and lever Q^1 (which has a fork taking into a collar on the cam), the slide is made to establish the communication between G^1 and G^2 for a longer or a shorter period, thus allowing a greater or less quantity of the combustible gas to pass into the cylinder A independently of the action of the slide D. The gas slide P is held against the face of the casing by a spring P^3 pressing against a cover P^4 on the back of the slide. The construction and mode of operating of the engine slide D will be understood on reference to Figs. 10 to 13, of which Figs. 10 and 11 represent longitudinal sections on the line Z, Z, of Fig. 12 of the slide D and its casing, shewing the slide in two different positions. Figs. 12 and 13 are transverse sections respectively on line X, X, and Y, Y, of Fig. 10. Fig. 9 represents diagrammatically the path of the crank K^2, in which the part 1 to 2 represents the motion of the slide during the time that the piston in its out stroke is drawing in the gaseous charge, the part from 2 to 3 the motion during the compression of the charge by the return stroke of the piston, 3 to 4 the motion during the working out stroke of the piston, and 4 to 1 the motion during the expulsion of the products of combustion by the last in stroke of the piston. Fig. 10 shews, first, the position of the slide at the point 1 of the crank path when the air passage D^1 is just about to communicate with the port C; and, secondly, its position at point 2, when the gas and air supply is just cut off. Although in the first position the gas passage G is about to open, the gas slide P prevents the admission of combustible gas until the requisite charge of air is first introduced. Fig. 11 shews, firstly, the position of the slide at the point 3 when the flame of the gas jet H is about to be communicated to the gaseous charge by a small quantity of ignited gas in the passage D^3; and, secondly, its position at the point 4 when the escape valve F is about to be opened. For effecting the ignition of the charge a small quantity of combustible gas is made to pass down a pipe S into a recess S^1 in the end of the cylinder, whence it issues through a small channel D^4 in the slide into the passage D^3. Here it is ignited by the jet H, and the flame is by the motion of the slide conveyed to the port C, the slide cover L being made to close the outer opening of D^3 before its inner opening communicates with C, as shewn at Fig 11. The gas passage G communicates with the air passage D^1 through a number of small openings, as shewn at Fig. 13, so that the gas in issuing in small divided jets into D^1 becomes mingled with the air, producing a combustible mixture. The opening of the escape valve F at the commencement of the second in stroke of the piston (when the slide crank is at the point 4 of Fig. 9) is effected by a bell crank lever F^1, connected at one end to the stem of the valve, and having at the other end a roller F^2, acted on by a cam F^3 on the shaft K. E^1 is the pipe for conducting away the products of combustion. The governor Q is driven by bevil gearing Q^2 from the shaft K, its arms move a sliding collar Q^3 up or down, and this collar by a bell crank lever Q^1 moves the cam R longitudinally. The cylinder A is by preference provided with a jacket through which cold water is made to circulate to take off any excess of heat. The engine may be made double acting, by providing the requisite valve gear for each end of the cylinder the front end of which would be closed; it may be arranged in a vertical or inclined position, and two or more engines may be connected to one crank shaft.

Having thus described the nature of the said Invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, it is claimed in respect of gas motor engines:—

First. Admitting to the cylinder a mixture of combustible gas or vapour with air separate from a charge of air or incombustible gas so that the development of heat and the expansion or increase of pressure produced by the combustion are rendered gradual, substantially as and for the purposes herein set forth.

Second. Compressing by one in stroke of the piston a charge of combustible and incombustible fluid drawn into the cylinder by its previous out stroke, so that the compressed charge when ignited propels the piston during the next out stroke, and the products of combustion are expelled by the next in stroke of the piston, substantially as herein described.

Third. Regulating the admission of the combustible gas or vapour to the cylinder by means of a separate slide controlled by a governor, so that when the speed of the engine increases the combustible charge is reduced, substantially as herein described.

Fourth. The construction substantially as herein described in reference to Figs. 2 to 13 of the drawings of a gas motor engine wherein by one out stroke of the piston separate charges of combustible fluid and air are drawn into the cylinder, which charges are compressed by the in stroke and then ignited so as to propel the piston, which by its return stroke expels the products of combustion.

In witness whereof, I, the said Charles Denton Abel, have hereunto set my hand and seal, this First day of November, in the year of our Lord One thousand eight hundred and seventy-six.

CHA^S. D. ABEL. (L.S.)

LONDON: Printed by George Edward Eyre and William Spottiswoode, Printers to the Queen's most Excellent Majesty. 1876.

A.D. 1876. May 17. N° 2081.
ABEL'S SPECIFICATION.

FIG. 2.

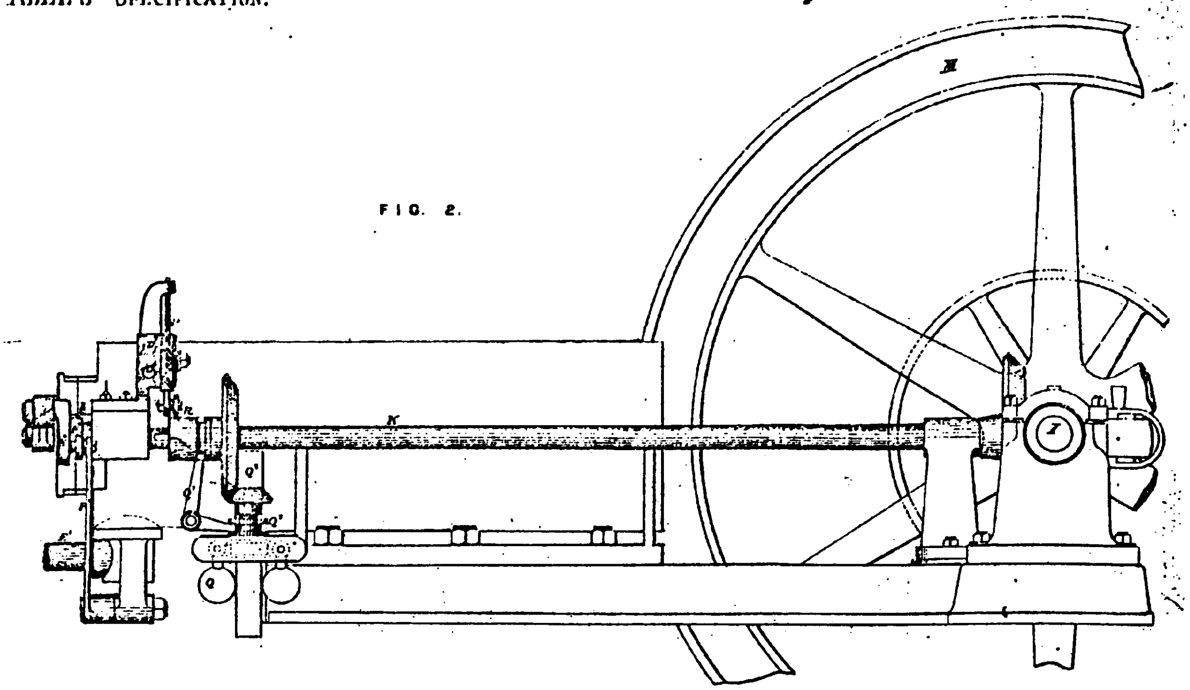


FIG. 4.

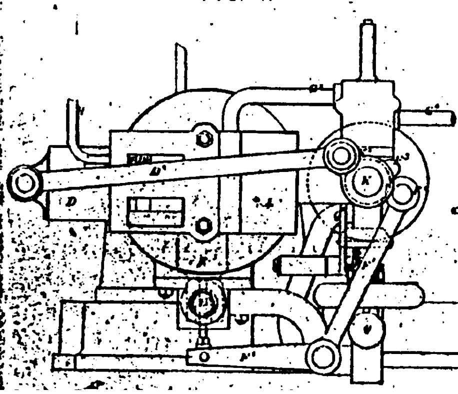


FIG. 1.

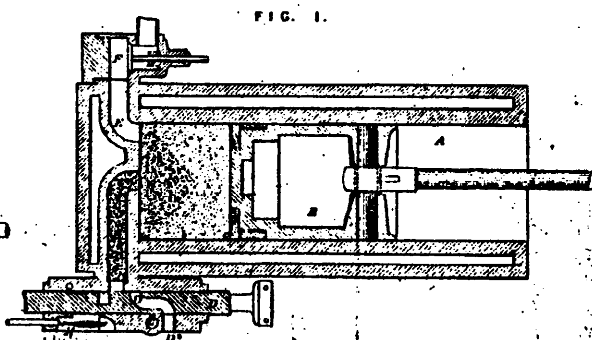


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FIG. 3.

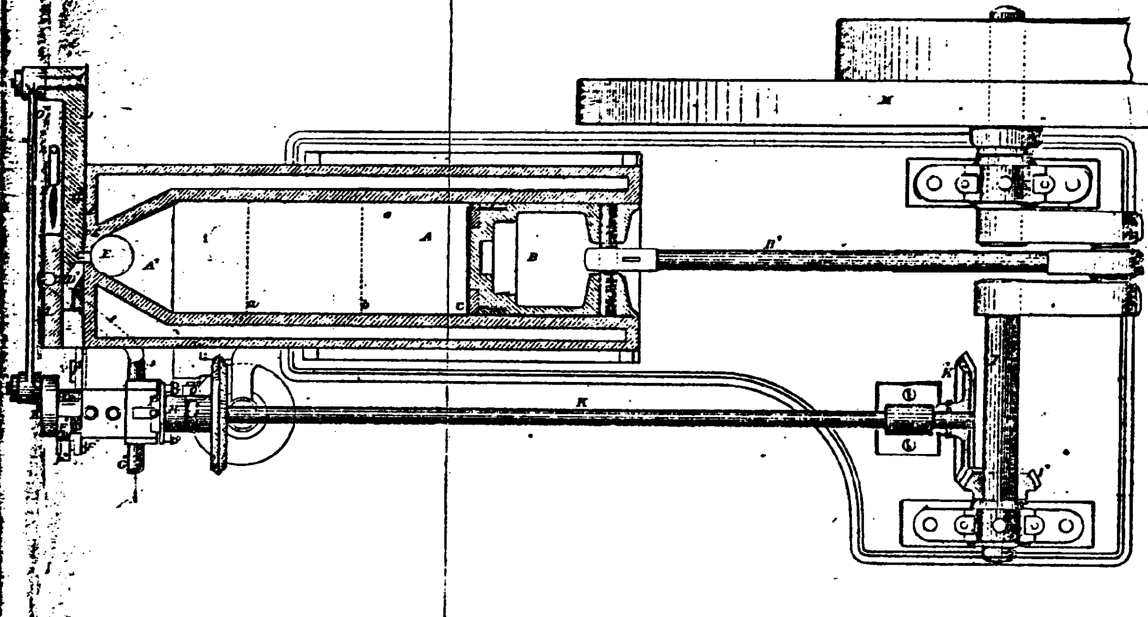


FIG. 5.

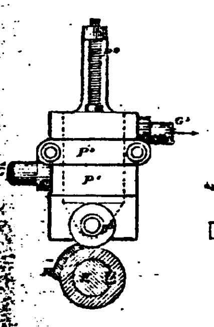


FIG. 6.

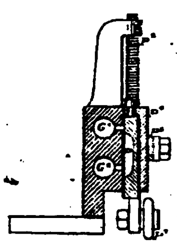


FIG. 7.

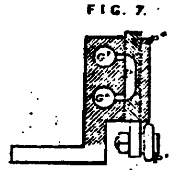


FIG. 9.

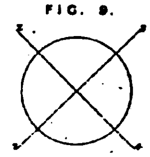


FIG. 12.

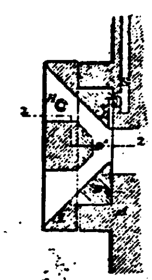


FIG. 13.

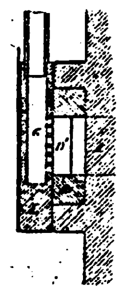


FIG. 10.

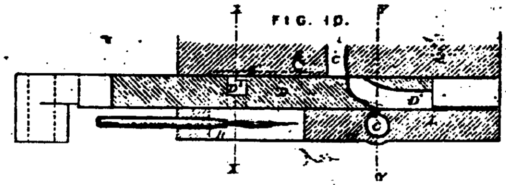


FIG. 8.

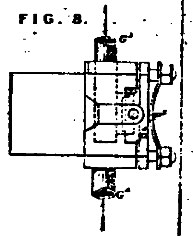
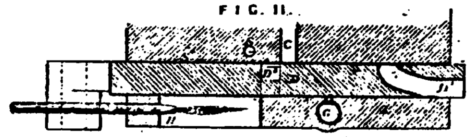


FIG. 11.



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