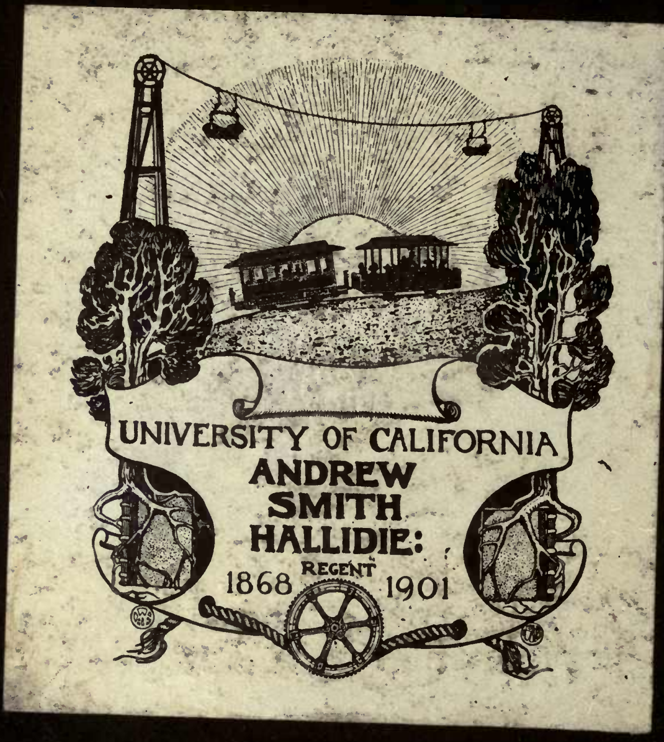
ON GAS ENGINES

T. M. GOODEVE, M.A.


UNIVERSITY OF CALIFORNIA
ANDREW
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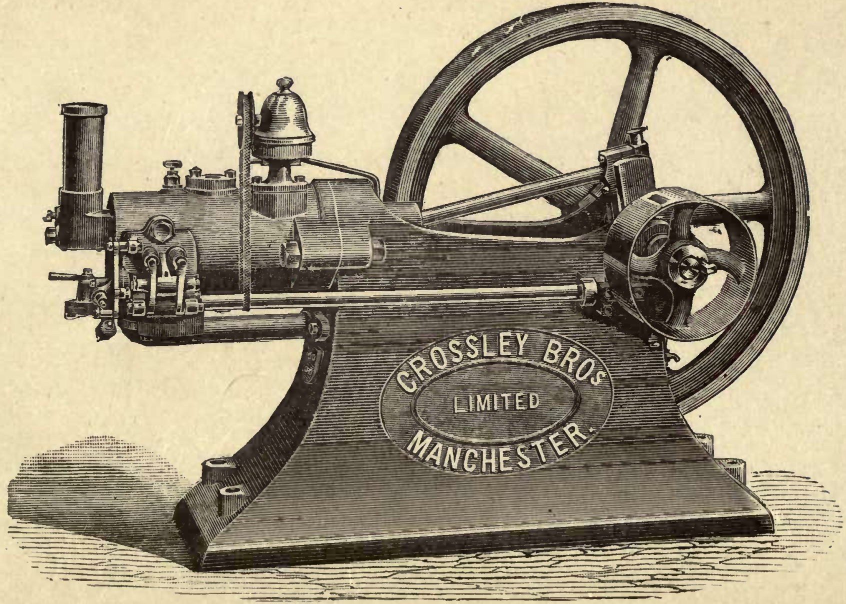
[*Frontispiece*



RECENT OTTO ENGINE, $\frac{1}{2}$-H.P., WITH TUBE IGNITER.

ON

GAS ENGINES

WITH APPENDIX
DESCRIBING
A RECENT ENGINE WITH TUBE IGNITER

BY

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AUTHOR OF 'TEXT-BOOK ON THE STEAM ENGINE' ETC.

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ON GAS ENGINES.

1. THERE are two numerical results connected with the theory of heat which are of the highest practical value. They are given in a Text Book on the Steam Engine written by the author, and are the following :—

(1) By an expenditure of 772 foot-pounds of mechanical work *one thermal unit* of heat is produced.

(2) In converting a quantity of heat into work the greatest amount of work which can by any possibility be obtained from a heat engine

$$= \frac{T - t}{T + 460} \times \text{total heat},$$

where T and t are the temperatures on Fahrenheit's scale between which the heat engine (supposed to be perfect) is working.

In applying these laws in the construction and management of heat engines, we begin by increasing the elasticity or pressure of a quantity of gas, such as air or steam, by heating it. Such heated gas is then passed into a cylinder and is expanded so as to do work. After a portion of its heat has been converted into work, the residue is expelled from the cylinder at a lower temperature.

The first operation, then, is to obtain a supply of heated gas, and here we encounter losses at every stage. Thus in burning coal for the generation of steam there is a continual

B

escape of heat by reason of the imperfections of the furnace, and by the discharge of heated products up the chimney.

Again, there are difficulties to be overcome in forcing heat through the shell of the boiler, and in conveying it into each individual particle of the water or steam.

It would appear, then, to be a manifest advantage if the heat could be applied directly to the elastic gas without the intervention of any furnace or boiler. An idea or suggestion so obvious as this can hardly have failed tc attract those who are in search of improvements, and, accordingly, numerous attempts have been made from time to time in order to obtain an elastic agent by setting fire to a mixture of coal gas and air within the very cylinder in which the piston of an engine is working. The heat developed in the gas during the act of burning would be thus compelled to supply a source of energy in the closest contact with the moving piece to which such energy is to be transferred.

No action can be more direct than this, and, in truth, it is the very thing which for centuries past has been done in a gun.

When gunpowder is fired in a closed chamber the temperature of the gases rises to a little above 2,000° C., and in the case of guncotton the temperature of the gases is about twice that of gunpowder (Noble).

The enclosed gases at these temperatures exert an enormous pressure, amounting in the case of guncotton of specific gravity ·55 to as much as 70 tons per square inch, whereas with gunpowder of specific gravity 1 and fired in a closed vessel the pressure would reach 43 tons per square inch (Noble).

Pressures such as these, generated suddenly in a closed vessel, cannot be dealt with in the present state of our knowledge, except for the discharge of projectiles. They are not suitable for driving the piston of an engine.

In order to adapt heated gas to the performance of useful work in an engine, we require (1) that its pressure shall not rise too suddenly, (2) that the intensity of the pressure shall be kept within reasonable limits.

These conditions can be fulfilled during the burning of coal gas or of some form of carburetted hydrogen when mixed with air.

2. Explosive Mixtures of Gas and Air.

Simple hydrogen explodes when mixed with oxygen in sufficient proportions. Thus

2 volumes hydrogen 1 volume oxygen	give a louder explosion than any other proportionate admixture.

It is a fundamental fact in chemistry that water is composed of hydrogen and oxygen in the above proportion.

For the purposes of an engine coal gas or some form of carburetted hydrogen is preferable to pure hydrogen, and we may point out that, speaking generally, 100 volumes of coal gas contain

Hydrogen	50 volume
Marsh gas	35 ,,
Carbonic oxide Carbonic acid Olefines Nitrogen	15 ,,
Total .	100

3. We now refer to experiments made in relation to the explosion of a mixture of marsh gas with air.

The substance *marsh gas* is carburetted hydrogen (CH_4), and it explodes when mixed with oxygen in sufficient quantity. The most violent detonation takes place when 1 volume of marsh gas is mixed with 2 volumes of oxygen. Thus—

$$CH_4 + 2O_2 = CO_2 + 2OH_2$$

The result of the combustion is carbonic acid and water in the form of steam, and it is calculated that the pressure of the heated gases would rise to about 37 atmospheres.

Since *air* contains $\frac{1}{5}$ of its volume as pure oxygen, the marsh gas would require 10 volumes of air for perfect combustion, and there would be present 8 volumes of inert nitrogen, which would reduce the force of the explosion.

Thus with 1 volume of marsh gas and 10 volumes of air the pressure of explosion is estimated at about 14 atmospheres.

With a larger amount of air the explosion becomes weaker, and with 18 volumes of air the mixture does not explode at all, but burns with a pale blue flame round a taper immersed in it.

It is matter of interest to find out (1) when there is just enough air for an explosion, and (2) when an explosion is arrested by the presence of too large a quantity of air.

Experiments for ascertaining these limits were made in 1877 by Coquillon ('Journal Chem. Soc.' 1877, vol. i. p. 166), who tested mixtures of marsh gas and air with the following results:—

Marsh Gas Volume	Air Volume	
1	5	No explosion.
1	6	First limit of possible explosion.
1	7	Sharp explosion.
—	—	. . . . .
1	12	Explosion weaker.
1	14	Same.
1	15	Same.
1	16	Slight commotion, this being the last limit of explosion. The air is in excess.

Similar results had been previously obtained when coal gas was mixed with air. There are limits of explosion in both directions; with too little air the mixture will not explode, and the same thing happens when the air is in excess.

Thus Wagner found (1876) that ignition of a mixture of gas and air by means of an electric spark began at a proportion of mixture of 1 of gas to 5 of air, and ceased when the mixture was diluted in the proportion of 1 of gas to 13 of air. Ordinary illuminating gas requires for its complete combustion 6·3 volumes of air to 1 of gas.

4. Pressures Produced by the Explosion of Gas and Air in a Closed Vessel.

Another point of inquiry is to ascertain by experiment the extent to which the elastic pressure of a mixture of gas and air is increased when the combustion or explosion takes place in a closed vessel

The first published experiments on this subject were made in 1861 by Hirn, who employed mixtures of hydrogen or coal gas with atmospheric air. The explosion vessels were cylindrical, one having a capacity of 3 litres and the other of 36 litres.[1] Taking a mixture of 1 volume of hydrogen with 9 volumes of air, the pressure on explosion rose to 3·25 atmospheres, whereas the pressure, as given by calculation, would have been 5·8 atmospheres. The student will understand that the method of calculation is the following:—

Conceive that we select a definite mixture of hydrogen and air. The burning of the hydrogen will give out a certain number of thermal units, and the product of combustion will be steam, having a known specific heat and a known latent heat. The rise in temperature of the contents of the vessel consequent on the explosion may, therefore, be estimated; and from the rise in temperature the increase in pressure of the gaseous products can be inferred. This rise in pressure would then be contrasted with that actually recorded by a pressure-gauge attached to the vessel.

Similar results were obtained with other mixtures of hydrogen and air, as well as with mixtures of coal gas and air. In all cases the observed pressures were much below those which theory would have led us to anticipate.

In 1866 Bunsen made experiments ('Phil. Mag.,' 1867, vol. xxxiv. p. 489), wherein he used a very small explosion vessel, having a capacity of only a few cubic centimètres.[2] Also he passed the igniting spark through the whole length of the vessel, in order to secure an instantaneous spread of the flame. His results supported those of Hirn, a similar

[1] 1 litre = 61·024 cubic inches.

[2] 1 cubic centimètre = ·061024 cubic inch.

difference between the calculated and observed pressures being established.

In 1880 there were again experiments by Mallard and Le Chatelier, giving a large difference between the calculated pressures and those actually obtained.

5. Dugald Clerk's Experiments.

We pass on to the experiments of Dugald Clerk, whose paper on the subject is inserted in vol. lxxxv. of the 'Proceedings of Inst. Civ. Eng.' Here the mixtures of gas and air were exploded in a strong cast-iron cylinder, the internal space being 7 inches in diameter and $8\frac{1}{4}$ inches long. The explosion was produced by an electric spark, and the pressures were marked on the drum of a Richard's indicator, which was caused to revolve uniformly by a clock train driven by a falling weight, and regulated by a fly or fan.

The revolving drum was enamelled, and a soft black-lead pencil attached in the usual way to the parallel motion marked on the drum a line which recorded the movement of the indicator piston. Also the drum itself rotated uniformly at the rate of 1 revolution in ·3 of a second, and it followed that the position of a mark made by the pencil recorded also the time elapsed since the instant of explosion.

Great care was taken in charging the vessel, the volumes and temperatures of the gas and air which were introduced being measured. The drum was then set in rotation, and, the spark being passed, a line was traced upon the drum which we propose now to examine.

It has been found that in different towns the quality of coal gas varies, and Mr. Clerk has been careful to distinguish the gas accordingly.

In this notice it will suffice to select a few prominent results as indicating the character of the curves.

Thus : Taking Glasgow coal gas and air.

Temperature before ignition = 18° C. Atmospheric pressure = 14·7 lbs.

Vol. Gas	Vol. Air	Greatest Pressure in pounds per sq. inch above Atmosphere	Time elapsed after Passage of Spark
(*a*) 1	7	89 lbs.	·07 second
(*b*) 1	11	63 lbs.	·18 second
(*c*) 1	13	52 lbs.	·28 second

The curves corresponding to (*a*) (*b*) (*c*) are given below, and marked on the diagram, the vertical lines corresponding to intervals of ·06 of a second.

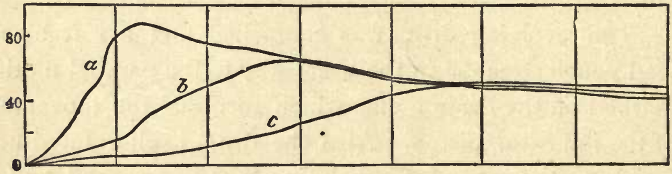


FIG. 1.

The gradual falling off in pressure, as shown by the curves, indicates the loss of elasticity due to the passage of heat through the walls of the cylinder.

It is important to observe that in curve (*a*) the pressure rises rapidly to the full intensity, and then falls gradually by reason of the cooling action of the surface of the cylinder.

Whereas in (*b*) the pressure reaches its greatest value more slowly and is sustained for some little time before it begins to diminish sensibly in intensity.

The same thing is shown in (*c*), and the explanation probably is that the complete combustion of the gas is retarded by the presence of an additional quantity of air.

As before stated, a pressure curve, such as that under discussion, shows different results with the gas supplied in different towns.

The practical point for consideration is, what proportion of air will give the best working pressure, and Mr. Clerk's deduction from these experiments is that with Glasgow coal gas the most economical mixtures would be 1 gas to 11 air, while with Oldham coal gas he would prefer to use 1 gas to 12 air.

6. When hydrogen takes the place of coal gas and the mixture is strong in gas, the explosion is so sudden and the rise of pressure so rapid that the effect produced is that of a blow.

Taking 2 volumes of hydrogen and 5 volumes of air where the air contains just enough oxygen to combine completely with the hydrogen, the pressure rose to its greatest amount in $\frac{1}{100}$th of a second. An action of this kind is unsuitable for the purposes of an engine.

It further appears from Mr. Clerk's experiments that when hydrogen is diluted with air in larger quantity the pressure rises less rapidly and becomes quite manageable, but it is less in amount than in the case of coal gas, and hydrogen is not at all a good gas to employ in an engine.

7. Comparison between Early and Modern Rifled Guns.

It is interesting to note that the same principle of sustained pressure and less rapid action which has obtained in gas engines has been applied in parallel lines to the modern rifled gun.

If gunpowder be exploded in a closed vessel and pressure-gauges be provided to indicate the tension of the gas, we find :

(1) The same reduction of pressure from the cooling effect of the vessel.

(2) The outline of the pressure curve varies considerably with different kinds of powder.

That is to say, there may be a rapid rise of pressure to a great height, the gas being formed suddenly and brought at once to the highest limit of pressure, or the pressure may, as it were, rise gradually, and be sustained for some little time at or near its greatest value, which is less in amount than when the rise in pressure occupied a shorter period.

The improvements made in modern artillery have been based upon these observations, and a comparison of the old and modern systems will be readily presented to the eye in the form of a diagram, where (A) represents the outline of a 25-ton gun as it would have been made some ten or fifteen years ago, and (B) is the outline of the same 25-ton gun as it is now made, the bore of (A) being 12 inches, and that of (B) being 10 inches

We are here quoting from a lecture given by Captain Noble at the Institution of Civil Engineers in 1884.

Upon each figure is drawn a pressure curve, the starting-point being the base of the projectile before firing, as shown in dotted lines, the vertical line indicating pressures, and the horizontal line giving the position of the projectile for each pressure. There is also a curve of velocities, show-

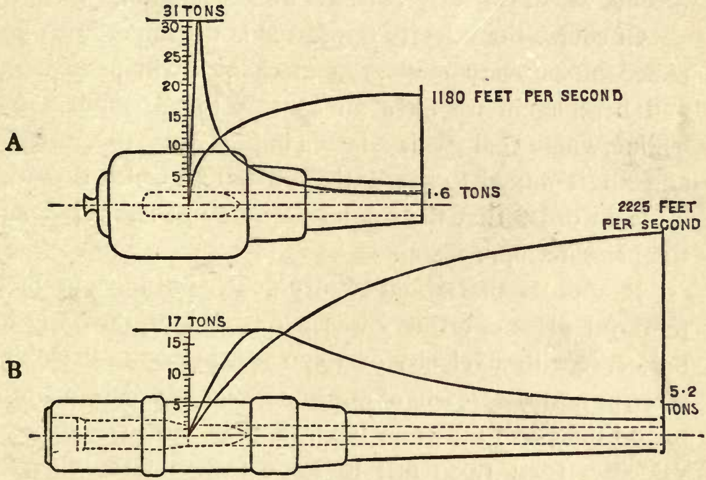


FIG. 2.

ing the velocity generated in the projectile during each instant of the motion.

Taking gun (A) it appears that the pressure rises rapidly to 31 tons per square inch, and falls along the expansion curve to 1·6 tons. This is analogous to the explosion of hydrogen in a gas engine.

The velocity generated is 1,180 feet per second. Gun (A) is not a breech loader, and on account of the sudden rise of pressure it becomes necessary to increase the thickness of the metal enormously around the powder chamber.

In gun (B) (which is a breech loader) the pressure rises only to 17 tons per square inch, and falls to 5·2 tons, but the rise is more gradual, and the intensity is sustained as shown by the curve. Also the gun is much longer, whereby the velocity generated rises to no less than 2,225 feet per second, which is nearly twice its former amount.

Of course the velocity impressed is the important thing aimed at, as every student of mechanics will understand, and here again we have an analogy to the modern gas engine, where coal gas is selected in preference to hydrogen, and air is mixed to nearly the full extent which is practicable in order that the combustion may be less rapid and the pressure more sustained.

It appears that about twenty-five years ago our most powerful piece of artillery was a 68-pounder, throwing its projectile with a velocity of 1,570 feet per second (Noble), whereas now the weight of our guns is increased from 5 tons to 100 tons, and the projectile from 68 lbs. to 2,000 lbs., the velocities from 1,600 feet to 2,000 feet, and the energies from 1,100 foot-tons to 52,000 foot-tons (Noble).

8. The Lenoir Engine.

A patent for the Lenoir gas engine was applied for on February 8, 1860, No. 335, by *J. H. Johnson*, being a communication from abroad by *J. J. E. Lenoir*, of Paris.

The specification stated :—‘This invention consists in the application and use of an inflammable gas mixed with a proper proportion of atmospheric air and ignited inside a cylinder by the aid of electricity; the expansion thereby produced acting upon the piston and imparting motion thereto, which motion may be transmitted in any convenient and well-known manner to a driving shaft.' Then it described the arrangement of insulated platinum wires in connection with a battery, and so disposed that an electric spark was produced at the right instant at either end of the cylinder, whereby the mixture of gas and air was fired.

Subsequently the lighting was effected by a jet of gas and a slide conveying a small flame of gas into the cylinder.

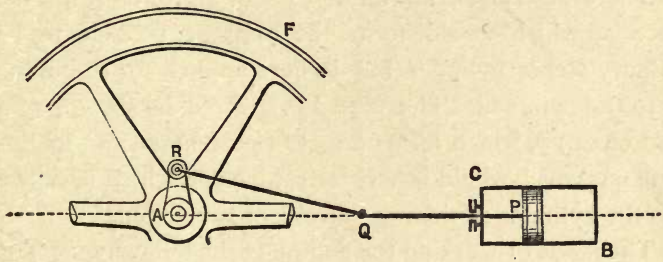


FIG. 3.

A general idea of the arrangement of the working parts will be obtained from the annexed diagram, where C B is the cylinder of the engine, P the piston, P Q the piston rod, A R the crank, R Q the connecting rod, and F the fly wheel.

The actual working of the engine may be understood by comparing together the remaining diagrams. Fig. 4 shows a horizontal longitudinal section through the axis of the cylinder, and also gives a vertical cross section through the cylinder.

As the cylinder when at work attains a considerable temperature, it is surrounded by a water jacket, shown in both sections, through which a supply of water is constantly circulating.

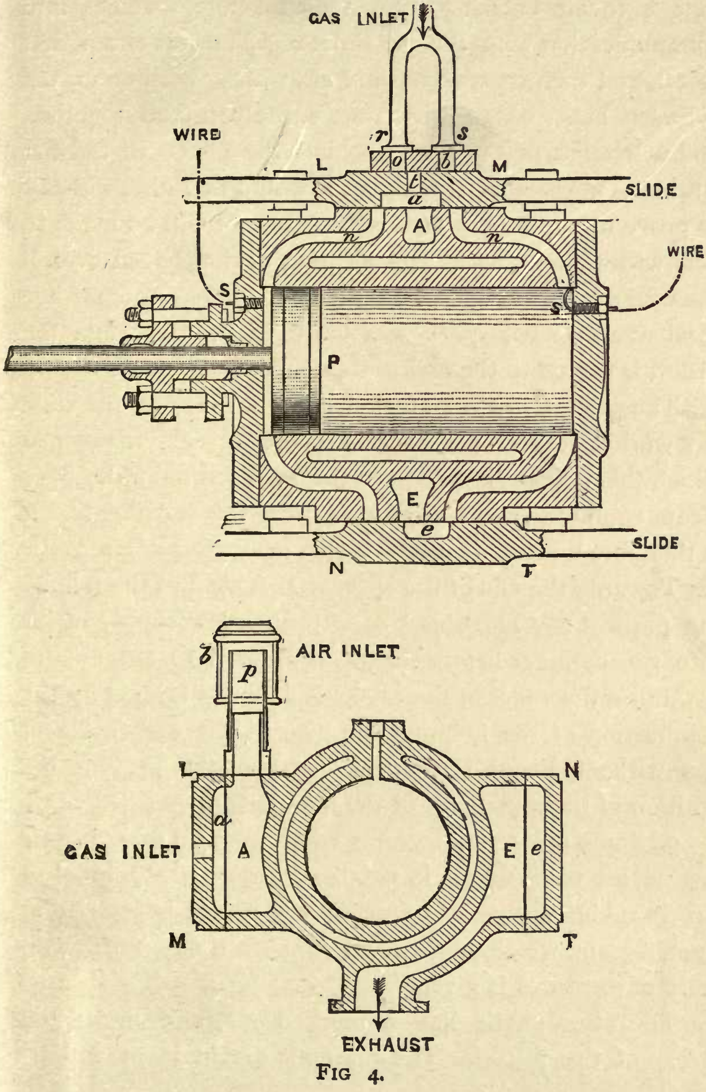
The slide L M regulates the admission of air and gas into the cylinder, while the slide N T is concerned only with the exhaust of the waste products of combustion. These sides are pressed against the faces of the cylinder by springs not shown in the drawing.

It will be observed that there is a gas inlet terminating in two forked branches *r* and *s*, which lead into gas orifices marked *o*, *b*.

There is also an air inlet *p*, communicating with the space A, which would form the exhaust passage in an ordinary steam cylinder, but is here applied for supplying air to the cylinder. The pipe *p* is covered, as shown, by a head or cap *b*, which forms a sort of gasometer, and retains some gas which would otherwise escape and which is drawn into the cylinder at the next stroke of the piston.

The mode of working the engine is the following :—The piston travels a certain distance along the cylinder by reason of its connection with the crank and fly wheel, and in doing so acts as a pump to draw in a charge of air and gas at a pressure equal to that of the atmosphere. When the piston has performed about half its stroke, the charge is fired by the electric spark, and the stroke is then completed under the pressure of the enclosed gases. On the return of the piston the waste products in the cylinder are expelled into the open air.

The patentee states that the slide L M opens the pas-


GAS INLET
WIRE
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AIR INLET
L
N
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GAS INLET
A
E
e
M
T
EXHAUST

FIG 4.

sage *n* to air entering from A, just before *t* comes into communication with the gas inlet *o*. Thus air enters first of all, and then comes gas and air, which 'both enter the cylinder but without becoming entirely mixed together, and will exist in the space behind the piston in distinct strata.' This is what is said, but it would be rather difficult to prove it, and in this treatise no attempt will be made to deal with the subject of stratification of the charge, even if there be such a thing. The slide now closes the passage *n*, when an electric spark sets fire to the mixture, and the piston is driven to the end of its stroke.

The products of combustion are got rid of by the slide N T working over the exhaust passage E. The manner in which this is done is precisely the same as in an ordinary steam engine, as will be apparent from the drawing, and it is therefore unnecessary to describe it.

Towards the end of the specification we find the following passage :—'The object of introducing a supply of air into the cylinder before the gas is allowed to enter is to neutralise the effect of the carbonic acid gas formed by the combustion of the inflammable gas, as the carbonic acid gas without being thus neutralised might prevent the ignition of the remainder of the inflammable gas.

9. Some indicator diagrams taken from an early Lenoir engine are to be found in vol. li. of 3rd series, 'Journal of the Franklin Institute.' One of the curves is set out in the diagram, which, however, is imperfect, inasmuch as no scale of pressures is given.

The atmospheric line is marked A B, and shows the stroke of the piston. The charge is drawn in at the atmospheric pressure, but the pressure of the mixture of gas and air falls to 11 lbs. above a vacuum or zero line just before explosion. It then rises in a steep, inclined line to 48 lbs., and the rest of the diagram tells its own tale.

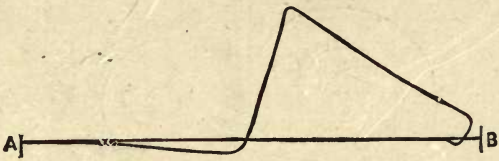


FIG. 5.

It is stated that the crank shaft makes 50 revolutions per minute, that the cylinder is $8\frac{2}{3}$ inches in diameter, the stroke of the piston being $16\frac{1}{4}$ inches, and that engines of this type are sold at from $\frac{1}{2}$ to 4 H.P.

10. THE OTTO AND LANGEN ATMOSPHERIC GAS ENGINE

is an engine of which large numbers were at one time made both in England and Germany, and which attracted a good deal of attention from the undoubted success with which it worked. It was the subject of a patent of 1866, No. 434, to *C. D. Abel.* In 1875 Mr. Crossley, of Manchester, read a paper before the Institution of Mechanical Engineers, wherein he described the construction of the engine and the manner in which it operated.

No doubt there were many valuable points about it, but being in truth, as its name implies, an atmospheric engine—that is, an engine with an *open* cylinder in which the piston is driven up by the pressure resulting from the explosion of a mixture of gas and air, and driven down by the pressure of the atmosphere—it is rather difficult, when the principles of the theory of heat have received full

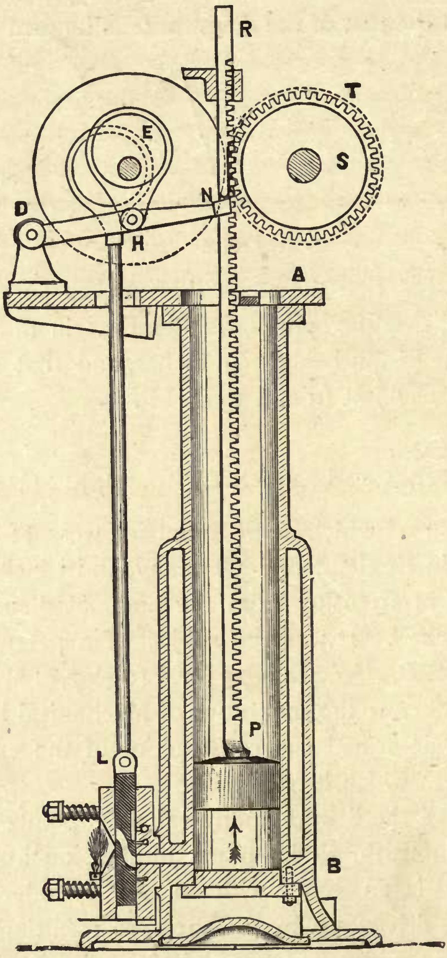


Fig. 6.

recognition, to understand how such an engine could continue for any length of time to occupy the first place.

It is rather unsafe to state positively the lines in which mechanical improvement will advance, and it happened that Mr. Crossley, in the paper referred to, adduced a variety of reasons to show that engines of the Lenoir type, in which a mixture of gas and air contained in a cylinder delivers its energy after combustion in driving a piston connected with a crank and fly wheel after the manner of an ordinary steam engine, were wrong in principle and could never succeed because the effect is that of a blow and is not a sustained pressure.

Then the argument advanced was that the Otto and Langen engine worked on the only true principle, viz. that of sustained pressure, and it did so in the following manner. The piston in an open cylinder is provided with a piston rod in the form of a rack. The piston is raised about $\frac{1}{11}$ of the stroke, and sucks in an explosive mixture. The charge is then fired, the engine being really a gun which stands vertically with open mouth pointing upwards, the explosive compound of gas and air taking the place of a charge of powder, while the piston represents the shot. The piston is free during its ascent, that is, it does not drive any of the mechanism of the engine, and the charge is not sufficient to force the piston out of the gun, but only to send it close up to the open end.

After explosion a partial vacuum is formed beneath the piston, which descends under the superior pressure of the atmosphere, the rack on the piston rod being now suddenly caused, by the operation of a friction clutch, to impart a sustained driving pressure to the fly-wheel shaft.

It is not the purpose of the writer to describe this engine with particularity, but only to give a general idea of its action.

The diagram shows the piston P, provided with a piston rod P R in the form of a rack, and working in the vertical open-mouthed cylinder A B, which has a water jacket as shown.

It should be understood that S is the main shaft of the engine, and that although P R is always in gear with a spur wheel T riding on the shaft S, yet there is inside that wheel, and not shown in the drawing, a friction clutch whereby T runs loose on the shaft S during the whole upstroke of the piston, but is locked thereto during the whole of the down-stroke. In other words, the piston is free during its ascent, but is a working piston during its descent. In the diagram the piston has been raised through about $\frac{1}{11}$ of the stroke, and has sucked in a charge of gas and air which is on the point of being fired by the slide L.

The piston is raised through this space by the lever D H N, operated by an eccentric E H on the shaft E, which is driven by spur wheels from the main shaft S. The end N of the lever D N, whose fulcrum is at D, actuates a tappet at N upon the rod P R, and leaves P R free to ascend after the explosion.

On the shaft E is a second eccentric, working the slide L by means of the rod shown in the diagram.

These eccentrics, which are made fast to each other, are carried loose upon the shaft E, and are started and stopped as required by an arrangement of a ratchet wheel and catch or paul not shown in the drawing. A movement of the eccentrics takes place when it is wanted, and not otherwise.

Outside the slide a small gas jet is kept burning, by means of which gas fed into a chamber in the valve is ignited, and at the right moment the opening of the chamber to the outside is cut off, and the flame therein is brought opposite the entrance to the cylinder and explodes the charge.

The piston being then driven to the top of its stroke, and the wheel T being, during this time, in effect an idle wheel, it will be found that the products formed within the cylinder by the burning of the gas rapidly fall in pressure.

11. The action within the cylinder will be made clear by an indicator diagram, which shows a sudden upward

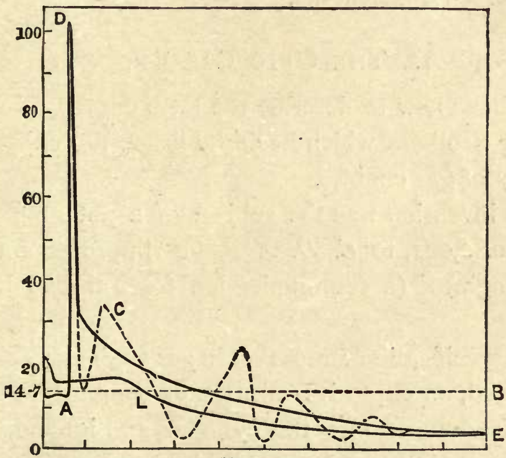


FIG. 7.

jump of the pencil at the instant of explosion, and then a series of oscillations, given in dotted lines, from which the mean curve of pressure, viz. D E, is deduced. It thus appears that the pressure within the cylinder falls to 11 lbs. per square inch below the atmosphere when the piston reaches the top of its stroke, and that the driving pressure in the return or working stroke, as recorded by E L, varies from 11 lbs. per square inch below the atmosphere to the atmospheric pressure itself, at about $\frac{4}{5}$ of the stroke, as shown by the position of L. It averages 9 lbs. during the time of action, and on the whole there is a mean of about 7 lbs. per square inch effective pressure during the period when the piston rack is driving the mechanism.

It is admitted that engines of this type are necessarily limited to a small power, and Mr. Crossley stated that no attempt had been made to increase their size beyond that of a 3-horse-power engine.

12. The Otto Gas Engine.

We have now to describe the Otto engine, as made by Crossley Brothers, which has established the efficiency and economy of gas engines.

This invention was the subject of a patent granted in 1876, No. 2,081, to *C. D. Abel*, for 'improvements in gas motor engines' (a communication from abroad by *N. A. Otto*).

The specification states that in gas engines, as previously constructed, an explosive mixture of combustible gas and air was introduced into the cylinder and ignited, whereby there resulted a sudden expansion of the gases, and a development of heat, a great portion of which was lost by absorption. According to the present invention, a combustible mixture of gas or petroleum vapour and air is introduced into the cylinder together with air in such a manner that the particles of the combustible mixture are more or less dispersed in an isolated condition in the air, 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.

A drawing showed the cylinder and piston in section, together with a slide for the admission of gas and air. The piston on moving outwards from the bottom of the cylinder drew in air for a certain space. It then moved an additional space and drew in combustible gas and air. The whole contents of the cylinder were at atmospheric pressure as in the Lenoir engine. The charge was then fired by the action of a small external gas flame, and the piston was driven to the end of its stroke. On the return of the piston the products of combustion were expelled into the atmosphere and the operation was repeated as before.

Then the patentee observes that by this mode of operating any shock which would result from sudden explosion is avoided, partly through the dispersion of the combustible charge, 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 might be single acting, the return stroke being effected by the momentum of the fly wheel, or they might be double acting, a charge being introduced at each end of the cylinder.

If the invention had remained at this stage it is probable that it would have attracted little attention, but the specification goes on to describe another and a different mode of working the engine which is of the highest possible value, and which forms, as the writer thinks, the real improvement disclosed in the specification. After a statement that the engine might operate with the gases at atmospheric pressure or compressed in any desired degree, there follows a description and drawing substantially the same as that annexed.

In this case the piston does not come close up to the cylinder cover on its return after ignition, as in the engine first referred to, but a considerable space is left at the end of the cylinder which becomes filled with the residue of the products of combustion at about atmospheric pressure. As soon as the piston begins its forward stroke, air is drawn in, and afterwards gas and air. On the return of the piston the whole contents of the cylinder are *compressed into the space at the end*, and the charge is then fired. The expansion drives the piston to the other end of the cylinder, then follows the exhaust, and the cycle of operations is repeated.

Referring to the drawing, the piston P is connected with a crank shaft, and the space between the dotted lines, *a*, *d*, is the length of stroke.

C is a passage for the entrance of the charge, while *e* is an exhaust passage, leading in another direction, for the escape of the waste products of combustion. C *a* is a considerable space or clearance which is filled with the pro-

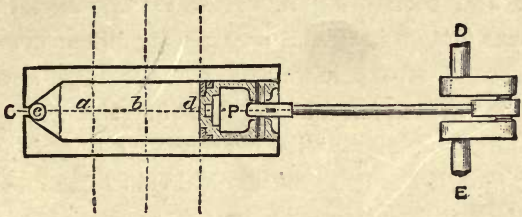


FIG. 8.

ducts of combustion at about atmospheric pressure when we commence to trace the working of the engine. The piston is driven by the fly wheel except during that particular stroke when there is explosion, and we propose to trace the operation of four strokes.

(1) As the piston travels from *a* to the position marked by the dotted line *b*, air is drawn in, then follows a mixed charge of gas and air till the piston arrives at *d*.

(2) As the piston returns from *d* to *a* the charge is compressed into the space C *a*, and may attain a pressure of (say) 40 lbs. on the square inch.

(3) The charge is fired by a gas flame and drives the piston from *a* to *d*.

(4) The piston returns from *d* to *a*, and expels part of the products of combustion through E, leaving the space C *a* filled with the residue at about atmospheric pressure.

The cycle of four strokes is then repeated, the piston being driven onwards always at the third stroke.

The question arises, what is the new principle, or new idea, here developed? No doubt it consists in the peculiar cycle of operations. Up to this time gas engines were worked by drawing in the charge during the first portion of a stroke and then firing it. Now, for the first time, the charge was drawn in at the first stroke, it was compressed at the second stroke, it was fired at the third stroke, and the residue was expelled at the fourth stroke.

This method of working was new and original, but it was also founded on true mechanical principles, and formed an excellent illustration of a useful application of the law of inertia of matter. Suppose we have a small heavy wheel mounted on bearings with its axis horizontal. It will be easy to keep it revolving by a series of pushes or impulses with the open hand. In doing so, as the wheel revolves faster and faster, each impulse may recur at longer intervals, and the speed of rotation may nevertheless continue to be nearly uniform.

So with the gas engine. The fly wheel of a small engine makes (perhaps) 180 revolutions per minute, at which speed the impulse of the burning gas may be given at intervals, but the rotation of the fly wheel may continue to be nearly uniform. We rely upon the inertia of matter to help us.

13. But not only is the mode of working practicable when looking at the question from a mechanical point of view, but there is also the direct and positive gain of dealing with a charge of compressed gas and air instead of a mixture at or about the atmospheric pressure. The engine acts as its own compressing pump. To start at the instant of explosion with the compressed contents of a whole cylinder full of gas and air instead of the uncompressed

contents of half a cylinder, is an advantage pretty evident to ordinary apprehension, and which may be made more clear by calculation.

Then also it is claimed that the residue of unburnt products remaining in the cylinder will act as a cushion to moderate the effect of the explosion upon the working piston.

14. Having described in general terms the Otto engine as specified, we pass on to give a particular account, with diagrams, of an Otto engine of half horse-power, recently furnished by Messrs. Crossley to the Normal School of Science as an example of the type of engine which they recommend at the present time.

It will be convenient to commence with an explanation of the method of charging the cylinder with gas and air, then to discuss the arrangement for firing the charge, as well as the method of getting rid of the waste products. Finally, the comparative position of the slide and piston will be shown, the action of the governor will be explained, and a general view of the engine will conclude this notice.

15. Charging with Gas and Air.

As in the gas engine last described, a slide is employed for charging the cylinder and also for conveying a flame to the charge. Such a slide is a flat plate of metal, having certain passages, straight or curved, which are so different from anything seen in a steam engine, that considerable attention is necessary before the action of the slide will be understood.

The annexed diagram shows a horizontal section through the cylinder with the piston P at the end of the stroke. The space C P is that portion of one end of the cylinder in which the charge is compressed and corresponds to C*a* in fig. 8. There is also a horizontal side passage terminating in a valve V, which leads to an exhaust pipe through which the waste products are discharged.

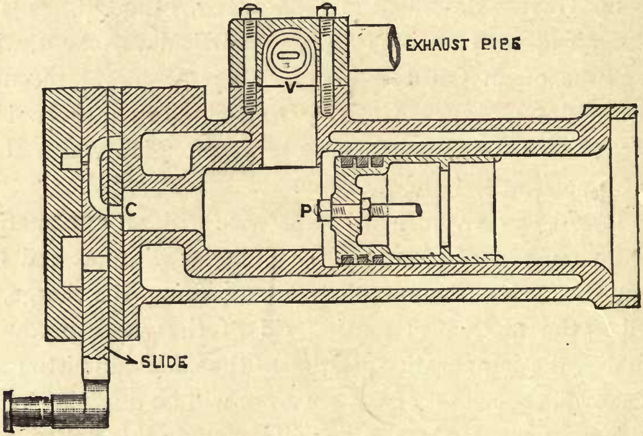


FIG. 9.

At the end, C, of the cylinder are three plates, the first marked *inner cover* as being nearest to the cylinder, the second being the slide itself, and the third being the *outer* cover. These plates are shown separately in a perspective view, in order that the student may form a better idea of their appearance.

The slide is faced on both sides and moves to and fro between the fixed covers, being operated by an eccentric as in a steam engine, but with this important difference, that the slide moves *once* to and fro while the crank shaft makes *two* complete revolutions. In other words, the slide makes two strokes while the piston makes four strokes.

The general arrangement of the working parts being thus made apparent, we have to point out that the slide has to fulfil two functions, viz. (1) the charging, (2) the lighting, and since it is arranged that one-half of the slide is concerned in the first operation, and the other half in the second, it becomes convenient to discuss each operation separately.

We refer now to fig. 10, which shows the slide and its

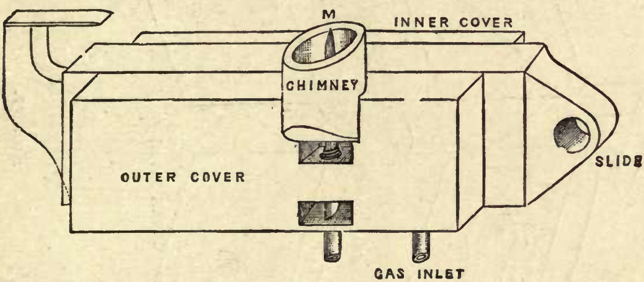


FIG. 10.

covers fitted together, and fig. 11 gives other views in which each cover is supposed to be placed at an angle to that face of the slide with which it is usually in contact, the object being to indicate the various openings and passages made in and through the slide and covers.

It appears that there are three principal openings in the inner cover, viz. (1) the gas inlet B, (2) the air inlet D, (3) the port opening to the cylinder, marked C, and inasmuch as it is necessary to charge the cylinder with both gas

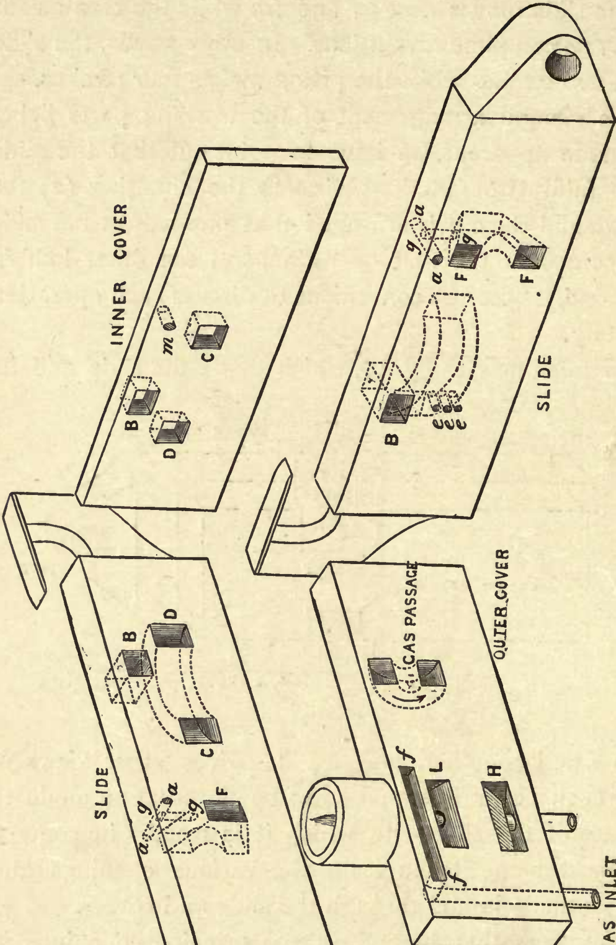

INNER COVER
B
D
m
C
SLIDE
a
g
F
e
SLIDE
B
D
C
a
g
F
GAS PASSAGE
OUTER COVER
f
L
H
GAS INLET

FIG. 11.

and air, it is obvious that passages must be contrived for conveying gas from B to C, and air from D to C.

We pass on to the sectional drawings, but the student should continually turn back to fig. 11 in order to trace the operation as completely as if he had the slide and covers before him.

In fig. 12, (1) shows a vertical transverse section of the slide and covers taken through the gas inlet B. Within

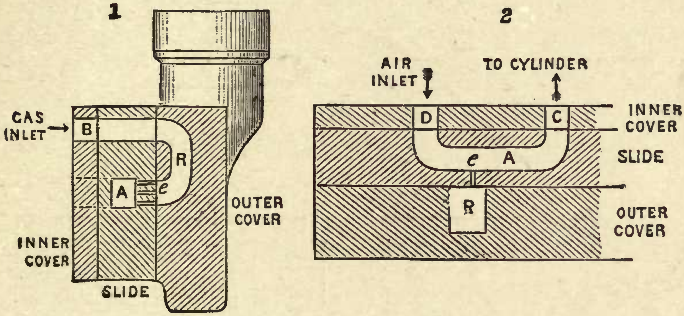


FIG. 12.

the material of the outer cover, which is a thick plate of metal, there is a curved passage R having two openings on the face of the cover. The bend R communicates by small ducts or perforations marked *e*, with another passage A, shown in section, which leads immediately to C. The object of these perforations is to check or throttle the flow of gas, and to prevent it from entering the cylinder too rapidly.

The gas having entered A, passes directly from thence to the cylinder, and at the same time becomes mixed with air. To make this clear we refer to fig. 12 (2), which is a horizontal section through the slide and covers taken on the level of C, the opening to the cylinder. Within the material of the slide is a curved passage D A C, having openings at D and C. The port D is the *air inlet,* and when the slide is in the position shown, there is a free passage of air into the cylinder. At the same time, gas entering A by the perforation *e* can pass directly to C.

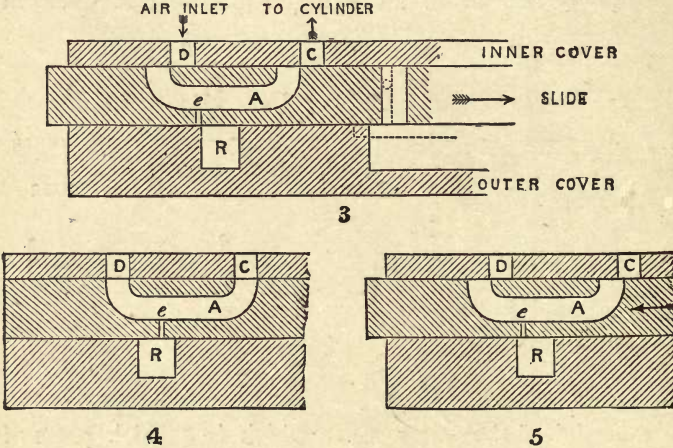


FIG. 13.

In the Otto engine supplied by Messrs. Crossley to the Normal School, which is of half horse-power, there is no provision for admitting *first* a supply of air to the cylinder, and *secondly* a supply of mixed gas and air. On the contrary, the gas and air are admitted together from the commencement, and it is during the last part of the admission that the charge becomes richer in gas, the object no doubt being to obtain a more combustible mixture at that end of the cylinder where the combustion flame enters.

In the annexed diagram three positions of the slide are given.

In (3) the slide is moving to the right and is about to open simultaneously both D and R to C.

In (4) the perforations *e* have come opposite the chamber R, also D is fully open to C, and the result is that gas and air are both drawn into the cylinder.

In (5) the slide now moves to the left, whereby the passage D becomes contracted, while *e* remains fully open. Hence the supply of air falls off, and the last mixture drawn into the cylinder becomes richer in gas, and therefore better adapted for accepting and carrying on the flame of ignition which lights the charge.

16. Firing the Charge.

We proceed to describe the method of firing the charge in the cylinder, and refer to fig. 14, which gives a vertical transverse section through the slide and covers, and should be compared with the complete drawing in fig. 11.

The chimney M is shown in section, and at the base thereof is a small jet of gas J, kept constantly burning, and called the *slide light.*

The slide is at one end of its stroke, and has the forked passage F in such a position that the lower branch of the fork is opposite to the air passage H, and the upper branch communicates with the base of the chimney.

It is to be noted that the single opening F, in which the forked passage terminates, is on a level with C, the opening into the cylinder.

On the side of the outer cover is a passage marked *f*, the general arrangement of which is better seen in fig. 11. This passage is freely open to a supply of gas passing along a pipe marked '*gas inlet*,' the object being to keep *f f* filled with gas, and ready to supply the chamber F, so as to support a flame of gas burning therein.

The passage marked *a a g g*, formed by the meeting of two cylindrical passages *a a*, *g g*, performs a double office,

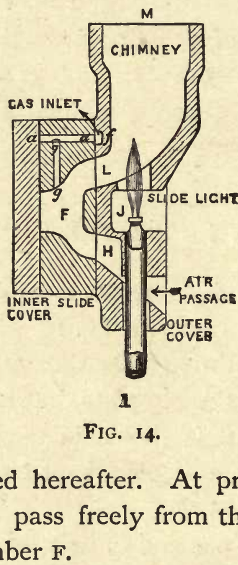


FIG. 14.

as will be explained hereafter. At present we regard it as allowing gas to pass freely from the gas inlet *f* to the interior of the chamber F.

The gas, on entering F, is carried by the draught of the chimney to the lighted flame, or slide light, J, and begins to burn, air being constantly supplied from below at H, whereby the chamber F is filled with the flame of lighted gas.

The gas, filling F, is readily lighted when the slide is in the position shown, and the object will be to keep the flame alight. In order to do so it will be necessary to supply F with both gas and air up to the last moment before the ignition of the charge.

The annexed diagrams, marked (2) (3) (4), are hori-

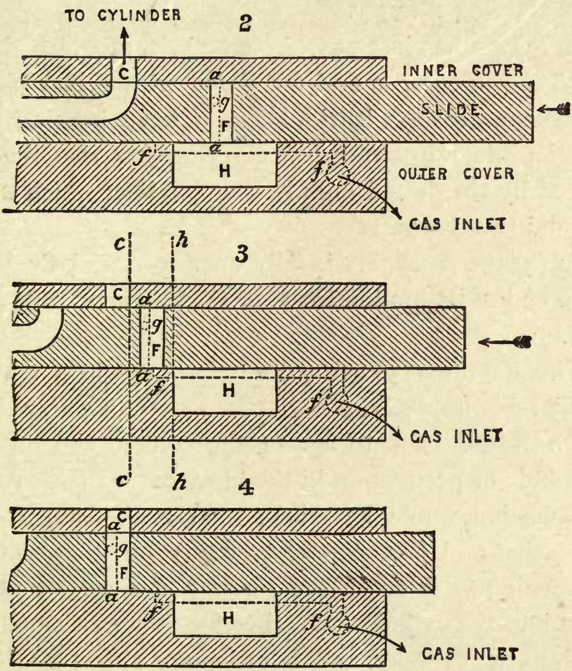


FIG. 15.

zontal sections through the slide and covers, taken on the level of the lower edge of the opening C.

In (2) the cylinder is receiving its charge, while F is becoming filled with the flame of burning gas.

It is particularly important to note the position of the passage *a a* with reference to the passage *f f*. Both these passages are shown by dotted lines, because they do not appear in the section, by reason of their lying on a different level, but they play their part notwithstanding.

Also (2) shows that *a a* is open to *f f*, which means that gas is entering F freely.

In (3) *a a* has just passed beyond *f f*, at which time no more gas can enter F, and the flame within that chamber would soon die out; it will, however, keep burning during the brief interval occupied in carrying F across the space marked by the dotted lines *c c* and *h h*, after which F opens to C and the charge takes fire.

In (4) the passage F is fully open to C, and the slide is at the end of its motion towards the left hand side of the diagram.

The diagrams (5) and (6) serve to explain a matter of considerable importance.

On turning back to fig. 11 the student will observe a small hole or perforation in the inner cover marked *m*, and the question would be asked, what is the object of this perforation? Upon careful examination it appears that the opening *m* is continued through the cover and leads direct into the cylinder. It, therefore, forms a small aperture into the cylinder, and is ordinarily closed by the face of the slide.

But *m* is on a level with *a a*, and in one position of the slide it will lead directly from the interior of the cylinder to *a a*.

(5) shows an elevation of the inner cover, and (6) is a sectional drawing corresponding to (3).

In the state of things shown in (5) and (6) the passage *m* is just on the point of opening into *a a*, and it will do so before the edge of F passes the edge of C.

At this time the burning mixture of gas and air in F is at the pressure of the atmosphere, while the charge in the cylinder is probably at about 40 lbs. pressure. It follows that if F were opened directly to C the sudden pressure of

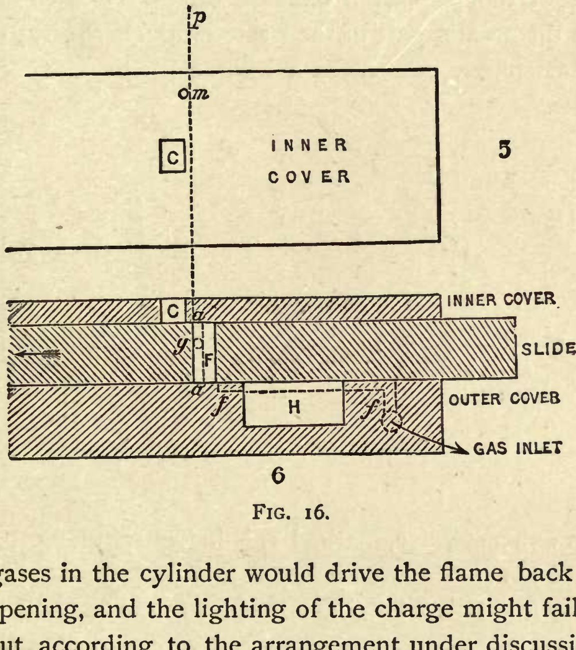


FIG. 16.

the gases in the cylinder would drive the flame back from the opening, and the lighting of the charge might fail.

But, according to the arrangement under discussion, *m* opens to *a a* before F opens to C, and as a consequence thereof the pressure of the contents of F is brought up to 40 lbs. by the entrance of gas and air from the cylinder, first through the passage *m* into *a a*, and then through *g g* into F. The result is that at the instant when the full opening is made from F into C there is an equilibrium of pressure in both F and C, and the lighting of the charge is safely carried out.

17. The Exhaust

It has been explained that upon each alternate return stroke of the piston, an exhaust valve is opened which allows the greater part of the waste products to escape into the atmosphere, but leaves a residue in the end of the cylinder.

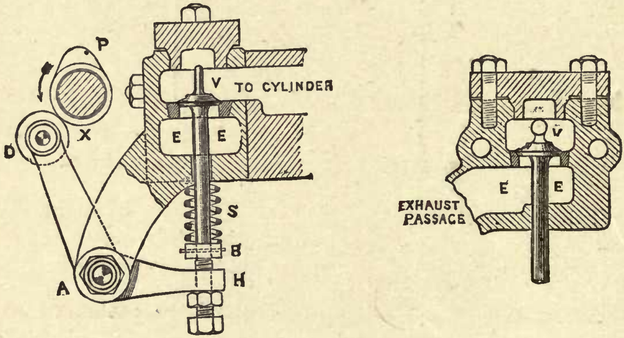


Fig. 17.

An exhaust valve, marked V, is indicated in fig. 9, and we have now to describe its operation and the method of working it. It will be remembered that the exhaust takes place through a branch passage leading out at right angles to the axis of the cylinder.

The annexed drawings show two vertical sections through the valve V, that on the right being parallel to the axis of the cylinder, and the other being transverse to it.

The valve V has a spindle V B provided with a collar at

B, which is attached to the spindle by means of a pin. A spring S abuts against B at one end, and against the valve casing at the other end, and retains the valve closed except when B is lifted by external pressure.

In order to lift the valve a cam P, keyed upon the shaft X, depresses the end D of a bell crank lever D A H, and thereby raises the end H of the arm A H. As soon as the cam P has passed under the roller D the elasticity of the spring comes into play, and the valve is closed, as shown in the sketch.

18. Regulator for Supply of Gas.

The pendulum governor of Watt is applied to the regulation of the engine, but its action is different from that in a steam engine, inasmuch as its function is not to control the rate of supply of gas by opening a valve in a greater or less degree, but simply to determine whether the cylinder shall receive a fresh charge, or whether for one or more complete double revolutions of the fly wheel the charge of gas shall be entirely cut off.

The drawing is taken from an end view of the engine, showing the slide in position as worked by a slide rod attached to a crank pin E at the end of a revolving shaft. The gas supply comes through a pipe on the right hand, provided with a stopcock, and having a valve V, closed by a spring, which controls the admission into the cylinder. The governor balls act upon a sleeve connected with the short arm of the lever A C D, whose fulcrum is at C, and which is provided with a vertical rod D T, hinged at D, and carrying a projecting piece marked T. On the slide is another projection, marked S, and when S and T are opposite each other it is apparent that a sufficient movement of the slide to the right hand will cause S to strike against T, and to push it to the right, thereby opening the valve V, and

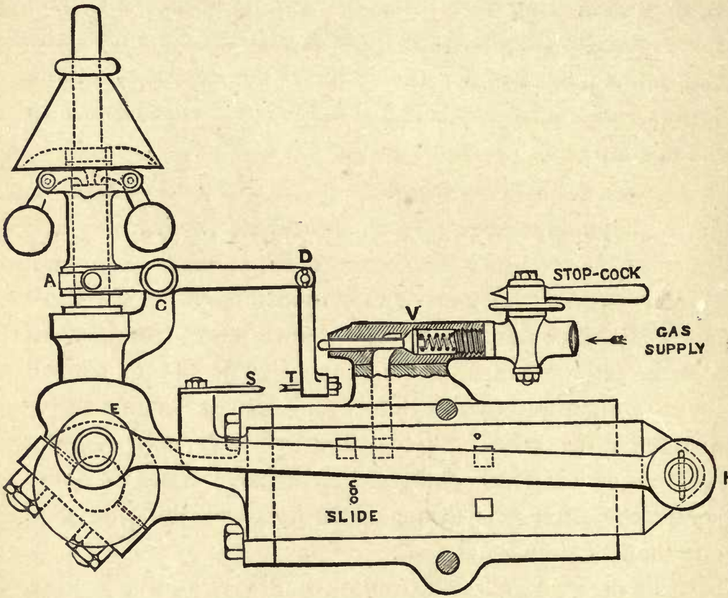


FIG. 18.

allowing the charge of gas to enter the slide, and so to pass on to the cylinder.

When the engine is at full work this would happen at every alternate forward stroke of the piston, and if the speed is accelerated, so that the balls rise higher, the end A of the lever A C D rises also, whereby T is depressed below S, and no gas is admitted into the cylinder.

When the rate of revolution of the balls returns to the normal state, it is apparent that T will come opposite to S, and that a mixed charge of gas and air will again be drawn into the cylinder.

If T were allowed to rise above S, there is nothing to bring it down again, and the engine would stop.

The cone on the top of the governor is a load which rests on a shoulder upon the spindle. The slowest working rate of the engine would just suffice to bring the sleeve in contact with the base of the cone, in which case the stop S would be exactly opposite to T.

If the balls tended to open still further, they could only do so by raising the heavy cone, and it follows that a considerable rate of increase in the speed of the engine will be necessary before T can be lowered sufficiently to fall below S, or before the supply of gas is cut off.

There are thus two rates of speed between which the engine can work in the usual manner. If the highest limit be exceeded, the cone is raised and the gas cut off, which soon brings down the rate, whereupon the supply of gas is automatically renewed. But there is no automatic recovery at any speed below the lower limit, or the engine will not work at less than a definite rate determined beforehand by the position of the governor balls.

19. Working of the Engine.

The annexed diagram taken from the gas engine under consideration is intended to show the positions of the piston and crank at certain periods of the working, and at the

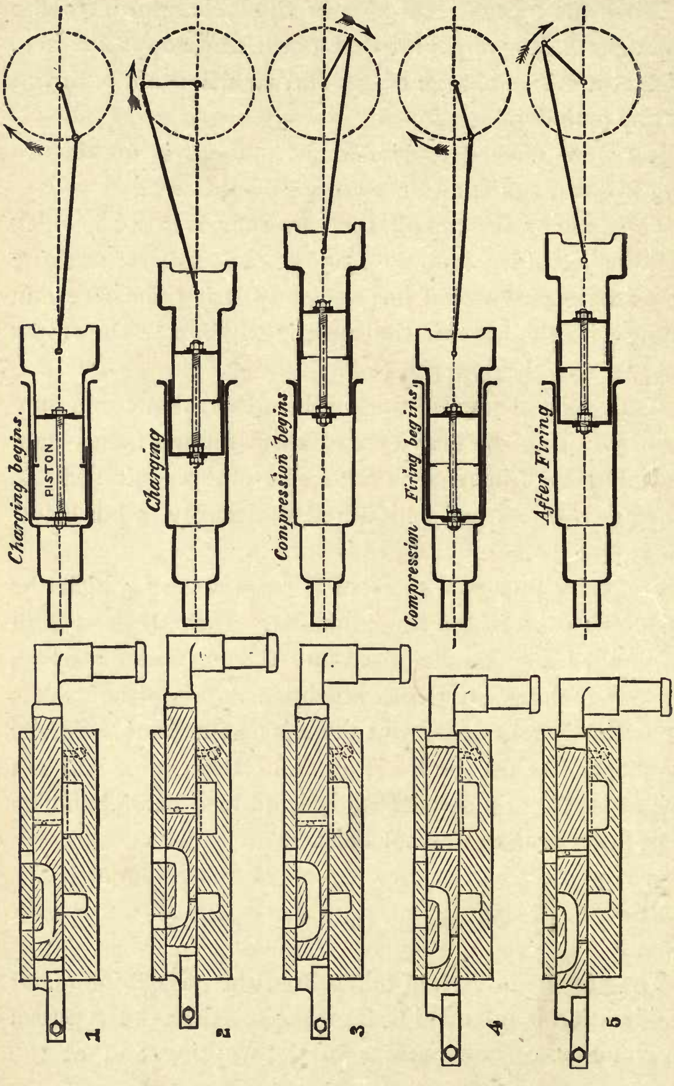

Charging begins.
PISTON
Charging
Compression begins
Compression
Firing begins.
After Firing
1
2
3
4
5

FIG. 19

same time to record the corresponding positions of the slide.

Taking the diagrams in regular order, we find in (1) that the slide is just about to admit the mixed charge of gas and air into the cylinder, the piston being near the end of its stroke, and the crank about to pass a dead point. This state of things is marked *charging begins.*

In (2), the crank is proceeding onwards, the charging is in full operation, and the slide is admitting the charge of gas and air freely into the cylinder.

In (3), the crank has passed the dead centre and the piston is beginning to return, whereupon the slide diagram shows that the end of the cylinder is closed and that compression has begun. At the same time the slide is beginning to assume the position necessary for firing the charges.

In (4), the slide has arrived at the point of its stroke where firing begins, and it will be seen that the piston is just approaching the final limit of its movement towards the left hand, the space into which the compressed charge of gas and air is forced just before the instant of firing being indicated by the hollow spaces under the word *compression.*

In (5), the mouth of the cylinder is again closed and the charge pent up becomes expanded and heated so as to urge the piston onwards and cause it to complete the working stroke. When the piston arrives at the position shown in the sketch, the exhaust valve commences to open, as may be clearly seen by inspecting the indicator diagram given in a subsequent article.

20. Plan View of the Otto Engine.

The annexed full-page diagram presents a general view of the complete engine now under examination, which is technically an engine of ½ H.P., and which may, as stated in a circular by the makers, be enlarged up to 12 H.P. Twin cylinder engines of the same type are also furnished which indicate 40 H.P.

We are now referring to a plan view of the engine, which shows a horizontal cylinder attached to a framing and having a crank and connecting rod together with a crank shaft and fly wheel arranged as indicated.

It appears from the previous drawings that the piston is a hollow trunk having guides of some length, and linked to the crank by a connecting rod as in an ordinary trunk engine.

The crank shaft carries a driving wheel marked (1) gearing with another bevel wheel marked (2) having double the number of teeth. This latter wheel is keyed to a shaft for working the slide, the object being to reduce the motion of the slide relatively to that of the piston and to cause the slide to make only two strokes while the piston makes four strokes. This reduction of motion is a fundamental characteristic of the Otto engine.

The slide is actuated by a slide rod shown in the diagram, one end of the rod being attached to a pin, placed eccentrically on the end of the driving shaft.

The position of the exhaust valve is also marked, as well as the position of the governor, and the mechanism

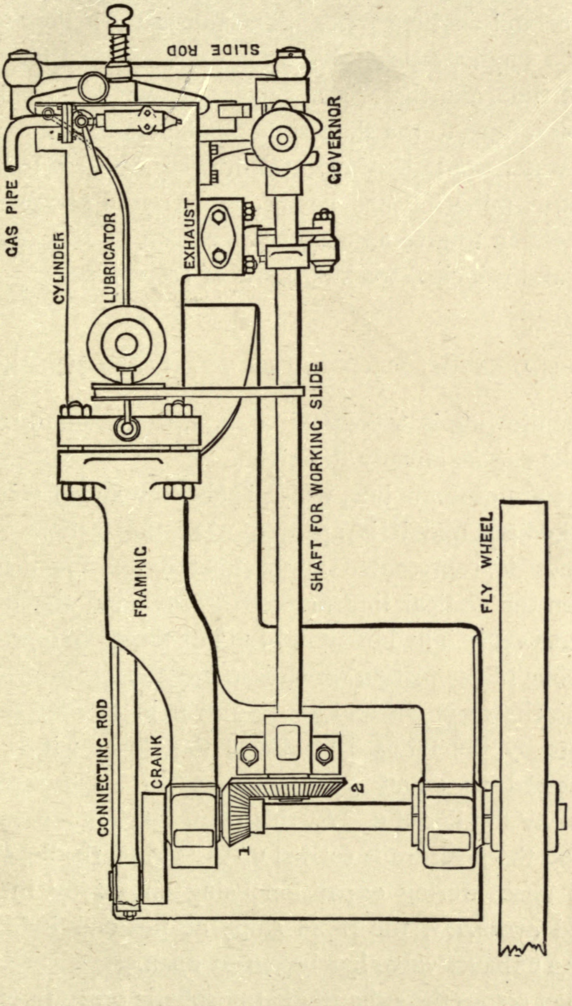

GAS PIPE
CYLINDER
LUBRICATOR
EXHAUST
SLIDE ROD
GOVERNOR
SHAFT FOR WORKING SLIDE
FRAMING
CONNECTING ROD
CRANK
FLY WHEEL
1
2

Fig. 20.

for operating the exhaust valve is indicated. There is a lubricator, having a mechanical feed for distributing oil to the slide and working parts. The lubricator is kept working by a small strap running upon the shaft used for working the slide, and there is a gaspipe shown for admitting a supply of gas to the slide and cylinder; a pipe for circulating water would appear in the drawing, but this, together with other minor fittings, has been omitted in pursuance of the intention to give a general conception of the arrangements and principal working parts of the engine.

21. Indicator Diagram of the Otto Engine.

The drawing is a copy of an indicator diagram taken from the engine already described.

The atmospheric line, which is also the line of volumes, is marked C B, and it is apparent that the volume of the clearance is represented approximately by the distance between the vertical line marked *ignition* and the line of pressures C D. The horizontal full line therefore represents the stroke of the piston, which is 9 inches.

The charge of gas and air is drawn in at atmospheric pressure by the forward stroke of the piston; it is then compressed to about 35 lbs. above the atmosphere, as shown by the line B E. At this point ignition takes place, whereby the pressure is carried up to 150 lbs., the behaviour of the gases during expansion being shown by the line marked *expansion*, the rapid slope at the end indicating that the exhaust valve has begun to open.

Then comes the exhaust at atmospheric pressure, whereby the indicator pencil runs along the horizontal line and returns again, retaking in a fresh charge, as shown by the arrow vertically under the point E.

While this card was being taken the fly wheel was making 180 revolutions per minute, and the length of stroke of the piston being, as stated, equal to 9 inches, and the diameter of the cylinder being $4\frac{1}{2}$ inches, it is easy to calculate the indicated horse-power from the diagram.

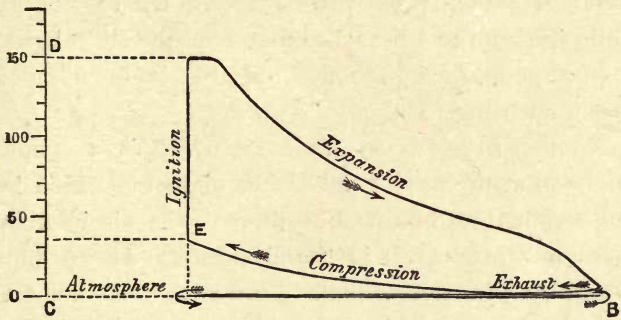


FIG. 21.

This has been done, and it appears that the mean effective pressure on the piston = 60·975 lbs.

$$\text{Hence I.H.P.} = \frac{60{\cdot}975 \times \frac{\pi}{4}(4\frac{1}{2})^2 \times \frac{9}{12} \times \frac{180}{2}}{33{,}000} = 1{\cdot}98$$

$$= 2 \text{ H.P. very nearly.}$$

22. FITTINGS OF THE ENGINE.

There are certain fittings which we proceed to describe by reference to the engine of $\frac{1}{2}$ H.P. Taking, first, the supply of gas, it will be found that precautions are necessary in order to prevent the disturbance produced by successive explosions from extinguishing or making unsteady other lights in the building which are fed from the same pipe as that which supplies the engine when at work.

For this purpose the gas passes through a regulator valve and a gas bag before it reaches the engine. If it be desired to measure the quantity of gas consumed, a meter may be placed between the main pipe and the regulating valve. A $\frac{5}{8}$ inch pipe will suffice for the engine, and a small pipe with two branches may feed the slide light and the passage marked *gas inlet* in fig. 11, the function of the latter inlet being to supply *ff* with gas.

Another fitting is an *air valve*, which is a cylindrical box, open at the base, 7 inches in diameter and 8 inches long, terminating in a neck leading to the air inlet in the inner cover marked D in the drawings. The cylinder is divided by 5 transverse plates having $1\frac{1}{4}$ inch holes alternately in the top and bottom of each plate.

There is also the *exhaust pipe*, which is $1\frac{1}{2}$ inches in diameter, and passes first into a strong cast-iron cylinder $5\frac{1}{2}$ inches in diameter and 16 inches long, after which it leads on to a cylindrical box 10 inches in diameter and 14 inches deep, filled with beads or small pebbles, whereby the noise caused by the escaping gases is reduced as much as possible. The jacket surrounding the cylinder must be supplied with *circulating water*, which is here provided by a $\frac{3}{4}$ inch pipe and regulating tap, the escape pipe being the same size as that for the supply.

The *starting* of the engine is a simple matter. The sleeve of the governor is raised and supported by a catch the object being to bring T opposite to S in order that the cylinder may take in a charge of gas together with air. The gas is turned fully on, the slide light is set burning, and three or four rapid turns are given to the fly wheel, which are generally enough to commence an action in the cylinder and to start the engine.

23. Comparative Efficiency of Engines.

The methods of working a gas engine have been discussed, and it may be interesting to apply the principles laid down in that portion of the Text-Book on the Steam Engine which relates to the theory of heat in order to institute some sort of comparison between the theoretical efficiency of a non-compression engine such as that of Lenoir and a compression engine such as that of Otto.

Inasmuch as coal gas is a complex substance and the exact amount of heat developed by burning its different constituent parts is uncertain, and as, moreover, the only purpose of the present inquiry is to obtain a general estimate, it is proposed to deal with air, and to simplify the problem by assuming that air alone is admitted into the working cylinder, where it is suddenly heated at a constant volume—no matter how—from a temperature of 60° F. to a temperature of 2,800° F., and is then allowed to expand adiabatically and to drive the piston of an engine.

It is of course impossible to carry out this idea in practice unless the air be mixed with an inflammable gas; but for the purpose of applying analysis in an elementary manner we may be allowed to make an hypothesis which relieves us of many difficulties, and whereby we obtain a result which is to a considerable extent true for a mixture of coal gas and air.

24. Diagram of Lenoir Engine.

Recurring to the diagram of the Lenoir engine in art. 9, it will be seen that the gas and air are drawn in at the pressure of the atmosphere, that the pressure is then rapidly raised by explosion or combustion, after which the heated gas expands and does work, as shown by the expansion curve, and that finally the products of combustion are expelled into the atmosphere.

The successive steps may be understood from the following sketch of a normal indicator diagram given by Tresca, and taken from a Lenoir engine.

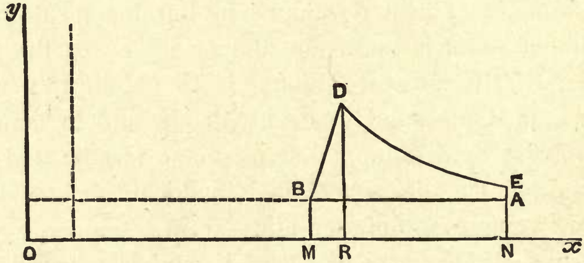


Fig. 22.

Here the clearance is assumed to be 10 per cent. of the whole capacity of the cylinder.

A volume of air and gas represented by O M is drawn in at a pressure equal to that of the atmosphere, and is fired at B, whereby its volume increases to O R, and its pressure rises, as shown by the oblique line B D; the heated products then expand, doing work along D E, until the volume is represented by O N. At this point the exhaust begins, whereupon the pressure falls through E A, and remains equal to that of the atmosphere during the return stroke.

25. EFFICIENCY OF AIR ENGINE WORKING AFTER LENOIR.

This method may be imitated theoretically by an air engine working according to the diagram annexed, which

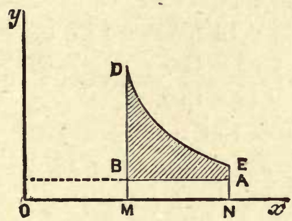


FIG. 23.

differs only from the Lenoir type in respect that the rise of pressure B D takes place at a constant volume, the line B D being vertical, an assumption which simplifies the calculation.

Take O x, O y, the lines of volume and pressure. Let $OM = v_1$, $BM = p_1$, and conceive that a mass of air at temperature 60° F., and of volume and pressure indicated by the position of B, is drawn into the cylinder of the engine, and is suddenly heated at a constant volume until its temperature is raised to 2,800° F., whereby its pressure rises to M D. Let now the heated air expand adiabatically, doing work in the engine, as shown by the curve D E, until its volume is doubled, and finally let the exhaust be fully opened, whereby the pressure falls to A N. The return stroke of the piston is now made, the contents of the cylinder being expelled into the atmosphere. We proceed to calculate the efficiency of such a theoretical engine.

1. To find the volume in cubic feet of 1 lb. of air at pressure 14·7 lbs., and temperature 60° F.

As above stated, volume $= v_1$, pressure $= p_1 = 14{\cdot}7$.

$$\text{Then } p_1\, v_1 = \text{R}\, t,$$

$$\text{or } 144 \times 14{\cdot}7 \times v_1 = 53{\cdot}2\ (460 + 60),$$

$$\therefore v_1 = \frac{53{\cdot}2 \times 520}{144 \times 14{\cdot}7} = 13{\cdot}0688 \text{ cub. feet.}$$

2. To find M D. Let M D $= p$.

$$\text{Then } \frac{p\, v_1}{p_1\, v_1} = \frac{\text{R}\,(2800 + 460)}{\text{R}\,(60 + 460)},$$

$$\text{or } p = p_1 \times \frac{3260}{520} = 14{\cdot}7 \times \frac{163}{26}$$

$$= 92{\cdot}16 \text{ lbs. per square inch.}$$

3. Let the heated air expand through D E, doing work represented by the shaded area D E A B, by reason of a back pressure equal to 14·7 lbs. during the return stroke. Let E N $= p_2$, O N $= v_2$, and assume that $v_2 = 2v_1$.

$$\text{Then } p_1\, v_1^{\gamma} = p_2 v_2^{\gamma}, \text{ where } \gamma = 1{\cdot}408,$$

$$\text{or } \frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^{\gamma} = \left(\frac{2v_1}{v_1}\right)^{\gamma} = 2^{\gamma}.$$

Also $2^{\gamma}=2^{1\cdot408}=2\cdot6537$,

$$\therefore p_2=\frac{p_1}{2\cdot6537}=\frac{92\cdot16}{2\cdot6537}=34\cdot73 \text{ lbs.}$$

4. Work done in forward stroke

$$=\text{area MDEN}$$

$$=\frac{p_1 v_1-p_2 v_2}{\gamma-1}$$

$$=\frac{144\, v_1}{\cdot408}(92\cdot16-2\times34\cdot73)$$

$$=104705\cdot7,$$

$$\therefore \text{mean pressure}=p_m=\frac{104705\cdot7}{144\times v_1}=55\cdot637 \text{ lbs.}$$

5. Effective work per 1 lb. of air $=(p_m-14\cdot7)\,v_1\times144$

$$=40\cdot937\times13\cdot069\times144$$

$$=77040\cdot8 \text{ ft. lbs.}$$

Effective work per 1 cub. ft. of air $=\dfrac{77040\cdot8}{13\cdot069}=5894\cdot9$ ft. lbs.

Expenditure of heat

=specific heat at const. vol. × difference of temp.

$=130\cdot25\times2740$

$=356885$ ft. lbs.

$$\therefore \text{Efficiency}=\frac{\text{effective work}}{\text{expenditure of heat}}$$

$$=\frac{77040\cdot8}{356885}$$

$$=\cdot216.$$

Tabulating the results we have

Vol. of 1 lb. of air at temp. 60° F. and press. 14·7

=13·069 cub. ft.

Pressure after heating = 77·46 lbs. above atmosphere
Terminal pressure = 20·03 „ „
Mean pressure = 40·94 „ „
Effective work per 1 lb. of air = 77037·7 ft. lbs.
Effective work per 1 cub. ft. of air = 5894·9 ft. lbs.
Efficiency = ·216.

26. Diagram of Otto Engine.

In the Otto engine the air and gas are admitted at atmospheric pressure, the mixture is then compressed to (say) 40 lbs. pressure, the charge is fired and work is done, after which the products of combustion are expelled into the atmosphere.

Dr. Slaby, of Berlin, has written an elaborate report on the performance of the Otto engine, from which the following normal indicator diagram is taken.

Here the position of A gives the pressure and volume of the charge of gas and air upon admission. The charge

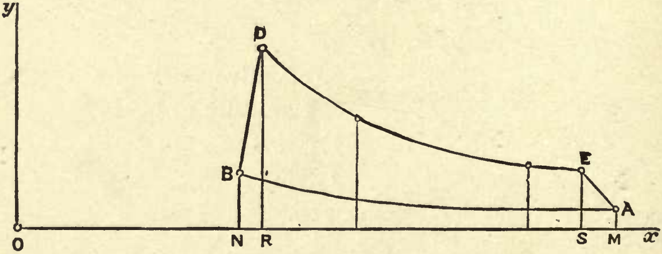


Fig. 24.

is then compressed as shown by the position of B; it is fired, and expands somewhat, as shown by the inclined line B D; it then does work, as shown by D E; and is finally exhausted into the atmosphere, as shown by E A.

The numbers given by Dr. Slaby are in millimètres 1 mm. = ·03937043 inch) and

O N = 60·6 mm.
O R = 66·5 „
O S = 152·5 „
O M = 161·6 „

and the intermediate volumes as shown by the intersection of two vertical lines with O *x* are represented respectively by 90·7 and 138.

The pressures are given in millimètres, and are as follows:

B N = 15 mm.
D R = 50 „ = maximum pressure
E S = 15·6 „
A M = 5·6 „

The intermediate pressures being 37·2 and 17·5 millimètres.

The atmospheric pressure being (on this scale) 4·7 mm. or 14·7 lbs., we have D R = 156 lbs. approximately.

27. Efficiency of an Air Engine Working after Otto.

This state of things may be imitated theoretically, as in the former example, by an air engine working according to the annexed diagram, which resembles that of Otto, except that B D, E A, are vertical.

Let the piston move from N to M, and draw in a charge of air at atmospheric pressure—viz. 14·7 lbs. On the return stroke from M to N the charge is compressed adiabatically, as shown by the curve A B, to the absolute pres-

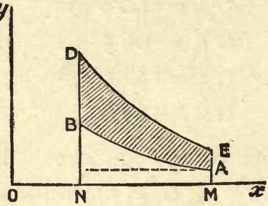


FIG. 25.

sure (say) B N = 54·7. The air is then heated to (say) 2,800° F., whereby its pressure rises to N D; it expands, doing work as shown by D E, and finally escapes into the atmosphere.

As before, we commence with 1 lb. of air at pressure 14·7 lbs. and temperature 60° F., of which

$$\text{volume} = v_1 = 13{\cdot}069 \text{ cub. feet.}$$

1. To find O N.

Let O M $= v_1$, O N $= v_2$, M A $= p_1 = 14{\cdot}7$, N B $= 40 + 14{\cdot}7 = 54{\cdot}7 = p_2$.

$$\text{Then } p_2 v_2^{\gamma} = p_1 v_1^{\gamma}, \text{ where } \gamma = 1{\cdot}408,$$

$$\therefore v_2 = \left(\frac{p_1}{p_2}\right)^{\frac{1}{\gamma}} \times v_1$$

$$= \left(\frac{14{\cdot}7}{54{\cdot}7}\right)^{\frac{1}{\gamma}} \times 13{\cdot}069$$

$$= {\cdot}393 \times 13{\cdot}069$$

$$= 5{\cdot}136 \text{ cubic feet.}$$

2. To find E M.

$$EM = DN \times \left(\frac{v_2}{v_1}\right)^\gamma$$

$$= DN \times \left(\frac{5{\cdot}136}{13{\cdot}069}\right)^\gamma$$

$$= DN \times {\cdot}26847.$$

In order to find D N we must first ascertain the temperature at B.

Let t_2 = temperature at B

t_1 = „ A = 60 + 460 = 520.

$$\text{Then } \frac{t_2}{t_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{54{\cdot}7}{14{\cdot}7}\right)^{\frac{\gamma-1}{\gamma}},$$

$$\text{or } t_2 = 520 \times 1{\cdot}463 = 760{\cdot}968.$$

$$\text{Hence } \frac{DN}{BN} = \frac{2800+460}{760{\cdot}968},$$

$$\text{or } DN = \frac{3260}{760{\cdot}968} \times (40 + 14{\cdot}7)$$

$$= \frac{3260}{761} \times 54{\cdot}7$$

$$= 234{\cdot}7 \text{ lbs.}$$

It follows that $EM = 234{\cdot}7 \times {\cdot}26847$

$$= 63{\cdot}009 \text{ lbs.}$$

We can now find the work done in one stroke which is represented by the area D E A B.

$$\text{Thus area } NDEM = \frac{ND \times ON - EM \times OM}{\gamma - 1}$$

$$= \frac{144 \times 13{\cdot}069}{{\cdot}408}(234{\cdot}7 \times {\cdot}393 - 63{\cdot}009)$$

$$= \frac{144 \times 13{\cdot}069}{{\cdot}408}(29{\cdot}228).$$

$$\text{Also area NBAM} = \frac{144 \times 13{\cdot}069}{{\cdot}408}(54{\cdot}7 \times {\cdot}393 - 14{\cdot}7)$$

$$= \frac{144 \times 13{\cdot}069}{{\cdot}408}(6{\cdot}7971),$$

$$\therefore \text{area DEAB} = \frac{144 \times 13{\cdot}069}{{\cdot}408}(22{\cdot}4309)$$

$$= 103465 \text{ ft. lbs.}$$

Let p_m be the mean pressure, then

$$144 \times p_m (13{\cdot}069 - 5{\cdot}136) = 103465,$$

$$\therefore p_m = 90{\cdot}572.$$

Also expenditure of heat

$$= \text{spec. heat at const. vol.} \times \text{ rise of tem.}$$

$$= 130{\cdot}25 \times 2499$$

$$= 325494{\cdot}7,$$

$$\therefore \text{efficiency} = \frac{103465}{325494{\cdot}7}$$

$$= {\cdot}318.$$

This result shows a large balance of efficiency for 1 lb. of air when working according to the compression system instead of according to Lenoir.

APPENDIX.

I. General View of the Engine.

This Appendix has been written in order to present an outline of a new device for firing the charge in Otto gas engines, and it will appear that this improvement has led to considerable changes in the details of construction of the engine.

For the purpose of comparison it will be convenient to examine, in the first instance, the drawing given in fig. 1, which shows a section, horizontal through the cylinder, and inclined downwards through the valve and ports, the piston being at one end of its stroke, and on the point of drawing in a fresh charge of gas and air.

So far as the cylinder and piston are concerned there is no alteration, and there is the usual water jacket surrounding the cylinder; but, upon referring to fig. 9, at page 28 of Part I., it will be seen that the essential difference consists in the construction of the valve for admitting the charge. In place of a slide valve working to and fro at the end of the cylinder, there is a cylindrical valve V, which rotates continuously in one direction, with the advantage of substituting circular for reciprocating motion.

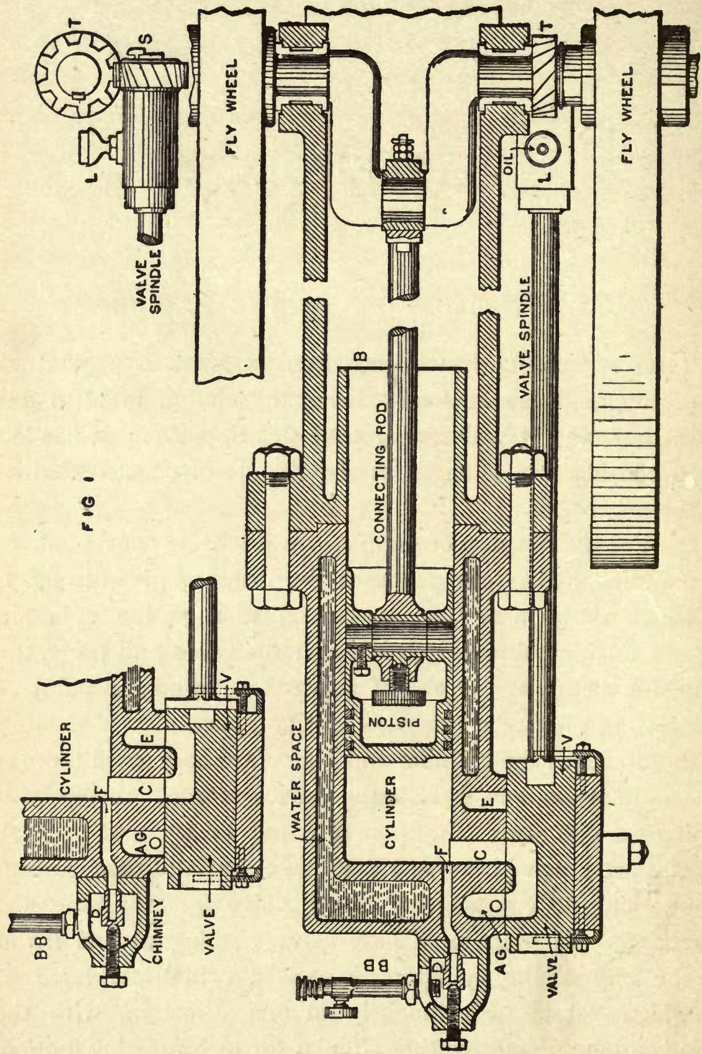

T
S
L
VALVE SPINDLE
FLY WHEEL
OIL
L
T
FLY WHEEL
B
CONNECTING ROD
VALVE SPINDLE
PISTON
WATER SPACE
CYLINDER
E
C
F
A G.
V
VALVE
BB
D
CYLINDER
E
C
F
AG
V
VALVE
CHIMNEY
D
BB

FIG I

This valve is provided with passages which enable the cylinder to communicate (1) with the supply of gas and air, and (2) with the exhaust.

There is no separate exhaust valve, as in the old engine, but the valve V both admits and gets rid of the charge, and in this respect operates like a slide valve in an ordinary engine. It will require careful study to comprehend the precise arrangement of ports and passages by which this result is arrived at.

The new method of igniting the charge is so simple that it will be understood without any difficulty. Instead of carrying a small flame of lighted gas by means of the slide to the open mouth of the port which admits the charge into the cylinder, there is a passage, marked F in fig. 1, which leads to the so-called tube igniter, the operation of which will be fully explained.

It is, of course, an advantage to free the admission valve from its former function of carrying the flame to the cylinder, and, except for the difficulty of obtaining tubes of such material as to be capable of resisting the long-continued action of intense heat, no improvement could be more desirable than that resulting from tube ignition.

It has been stated that a rotary valve replaces the former slide valve, and bearing in mind the cycle of operations, namely, (1) admission of charge, (2) compression, (3) firing, (4) exhaust, each of which occupies the period of one stroke of the piston, it is obvious that, just as the slide valve in the former engine made one complete stroke to and fro while the piston made two double strokes, a like action must take place in the new engine, and the valve must rotate once for two revolutions of the crank shaft. This is the first movement to be provided for, and it is effected by a pair of screw wheels, which, in light mechanism, are now coming into use in the place of bevel wheels.

2. THE CYLINDER AND ROTARY VALVE.

In order to obtain a general idea of the nature of the valve V, and of its motion, the student should again refer to fig. 1, where the rotary valve V is shown in two positions: (1) admitting the charge of gas and air into the cylinder; (2) allowing the gases after firing to escape into the exhaust passage. In the drawing the gas and air passage is marked A G, and the exhaust passage is marked E. The valve is connected by a cheese coupling to its spindle, one end of the spindle terminating in a screw wheel S, which is in gear with a second screw-wheel T on the crank shaft. The pair of screw wheels, which are formed on cylinders of equal diameter, are also set out in a separate sketch in the diagram, where L is a small ordinary lubricator for the bearing of the valve spindle.

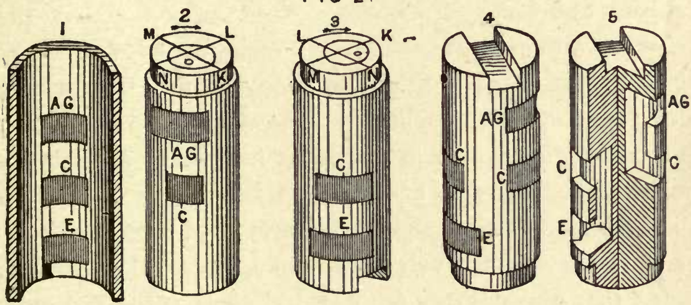
It is indicated in the drawing, and will appear from an examination of the screw wheels, that the number of threads on the wheel S is twice that upon T, whereby S makes one revolution for two revolutions of T, and we have practically the same motion as with a pair of bevel wheels in the old engine where the numbers of teeth were as 1 to 2. In the particular engine described, there are 9 threads upon T and 18 threads upon S. Hence the rotary valve makes one complete rotation for two complete revolutions of the fly wheel or crank shaft.

3. Construction of Valve.

The next point is the construction of the valve, and this is determined by the arrangement of ports in the casing, which lead (1) to the supply of gas and air, (2) to the cylinder, (3) to the exhaust.

It appears that the valve V is in part embedded in a

FIG 2.



recess in the casting, and in part covered by a metal envelope. In fig. 2, at the extreme end marked (1), there is a perspective view of the recessed part of the casting wherein V works. The port A G leads to the supply of gas and air, the port C leads directly into the cylinder, and the port E opens to the exhaust. These ports are placed one over the other, in a vertical line in our present drawing, where the valve is looked at apart from the engine, and it is the function of the valve to connect A G and C together, or to connect E and C together, at the proper times.

Sketches of the valve are also given at (2) and (3), whereof (2) shows the valve ports concerned in the admission of the charge, and (3) shows the exhaust ports.

In an engine of $\frac{1}{2}$ H.P., which has been selected for illustration, the diameter of the valve is 3 inches.

At (4) and (5) the valve is inverted so as to indicate the position of the cheese coupling by which it is connected with the valve spindle. Diagram (4) shows that, speaking generally, the charging and exhaust passages are on one face of the cylinder, the object being to reserve the period of one-half of a rotation of the valve for the compression and firing.

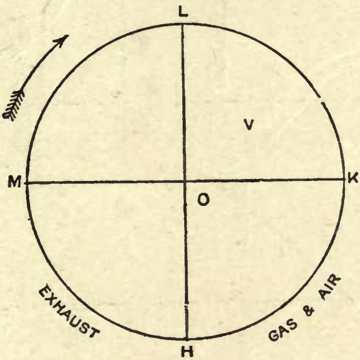
At (5) there is a section as made by two planes at right angles to each other, or nearly so, and intersecting along the axis of the cylinder. The object of this drawing is to show the manner in which the interior of the valve is hollowed out so as to enable it to act like an ordinary D slide. This drawing should be compared with the transverse sections of the valve given in fig. 1, and it should be noted that the passage for gas and air is at the end most remote from the attachment to the valve spindle.

It may now be convenient to examine more particularly the reason for putting the charging and exhaust passages on the same face of the cylindrical valve.

Conceive that fig. 3 represents the circular end of the valve V at the part most distant from the attachment to the valve spindle. Let two diameters H L, K M intersect at right angles in the axis O, while the valve itself rotates about an axis through O, perpendicular to the plane of the paper, in the direction shown by the arrow.

On considering the cycle of operations it appears that the passage to the cylinder is first opened to receive gas and air, that the same passage is closed during compression, and closed during the firing, but opened to the

FIG 3.



exhaust immediately afterwards. It follows, therefore, that if the gas and air passage lies in one quadrant, as H O K, the exhaust passage must lie in the adjacent quadrant H O M.

For convenience, the diameter K M, which cuts off the working part of the valve, is drawn in position in fig. 2, the diameter at right angles being marked N L, the letters N and H indicating the same point on the valve, as explained in the next article.

4. How the Valve Operates.

In order to simplify the explanation, the valve is represented in fig. 4 as if a sheet of paper marking the several ports were unwrapped from the cylinder and spread out upon a plane surface, the ports A G, C, E, in the bearing of the valve being treated in the same way.

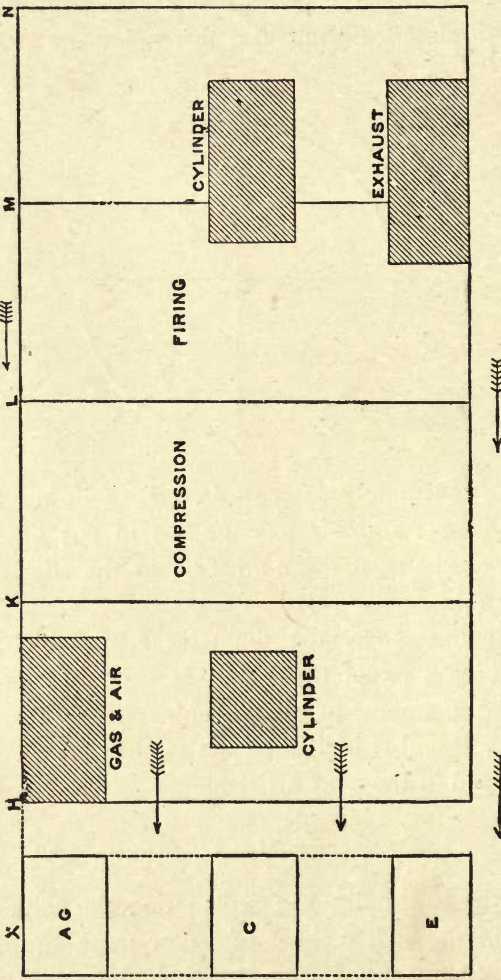


FIG 4.

The spaces H K, K L, L M, M N represent the four equal portions into which we have already supposed the circumference of the plane end of the valve to be divided, and the rotation of the valve upon its axis will be imitated by the passage of the unwound sheet over the openings A G, C, and E, in the rectangle marked X.

Inasmuch as a movement through H K, in the direction indicated by the arrow, corresponds to one passage of the piston through the whole length of the cylinder, it is apparent that while the sheet travels over the distance H K the cylinder becomes charged with gas and air. It may be noted that when the crank is horizontal the rectangle marked 'gas and air' has begun to overlap A G, preparatory to the opening of the cylinder port, which commences just after the crank has passed the dead centre.

In like manner the exhaust can be traced out by observing the passage of the other rectangles over C and E.

During the passage of K L over X the charge is confined in the cylinder and undergoes compression. While L M passes over X the charge is still confined, inasmuch as the cylinder port remains closed, and during this period of the motion the charge is fired. During, and somewhat before, the passage of M N over X the exhaust port is connected with C, and the gases escape after combustion, just as in the former engines.

As soon as the exhaust stroke is completed the cylinder takes in a fresh supply of gas and air, and we may imitate the action by supposing this diagram to be repeated any number of times.

The reason for placing the charging and exhaust ports on two contiguous quadrants M N and N K (see fig. 2) is now apparent, and of course M N in this diagram corresponds to M H in fig. 3, the points H and N being identical.

The rotary valve has now been described, and the student will understand that the reciprocating slide valve discussed in Part I. will gradually disappear, and that the future of the rotary valve is uncertain, inasmuch as the makers may prefer to allow the charge to enter the cylinder and to be exhausted by separate lift valves. This is a detail of construction, but at any rate a considerable number of engines have been fitted with rotary valves.

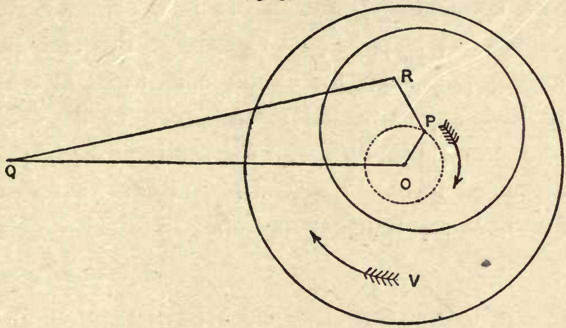
5. Principle of the Pendulum Motion.

In order to regulate the speed of the engine, a so-called pendulum, or swinging bar, is provided, which is made to oscillate through a small angle by the rotation of the valve C.

Before describing the construction of the pendulum regulator it will be useful to examine the principle upon which the circular motion of the valve produces a reciprocating motion in the swinging bar. Looking at the question simply as a problem in pure mechanism, let a point Q in the plane of the paper be the centre of motion of a rod Q R, and let O be the centre of the large circle V, representing a section of the valve made by a plane perpendicular to its axis. Let a small circular plate, whose centre is at P, be set eccentrically in the valve circle, and carry a socket into which a pin R, attached to the bar, is inserted.

We have from this construction, (1) two fixed centres at O and Q, (2) a line Q R of invariable length, (3) a line of constant length from R to P, (4) a line of constant length from O to P; forming, in fact, an ordinary four-bar motion.

FIG 5.



If the proportions of the parts be properly chosen, it will follow that when the valve circle V is made to rotate uniformly about the axis through O, the point P will also describe a circle about O, as indicated by the dotted line in the diagram, while Q R and R P each oscillate through definite angles.

This method of deriving the motion of Q R from the rotation of the valve V, by simply inserting a small circular disc eccentrically into the end of the valve, becomes very apparent upon constructing a model according to fig. 5, and is well worth studying. It will appear that the small circular disc is carried round by the rotation of V in such a manner that P describes a circle round O, and that the disc itself oscillates upon the point R. The movement required in the engine is an oscillation of Q R through an angle during each rotation of the valve, and the extreme positions of Q R are set out in fig. 6, and are in this way provided for.

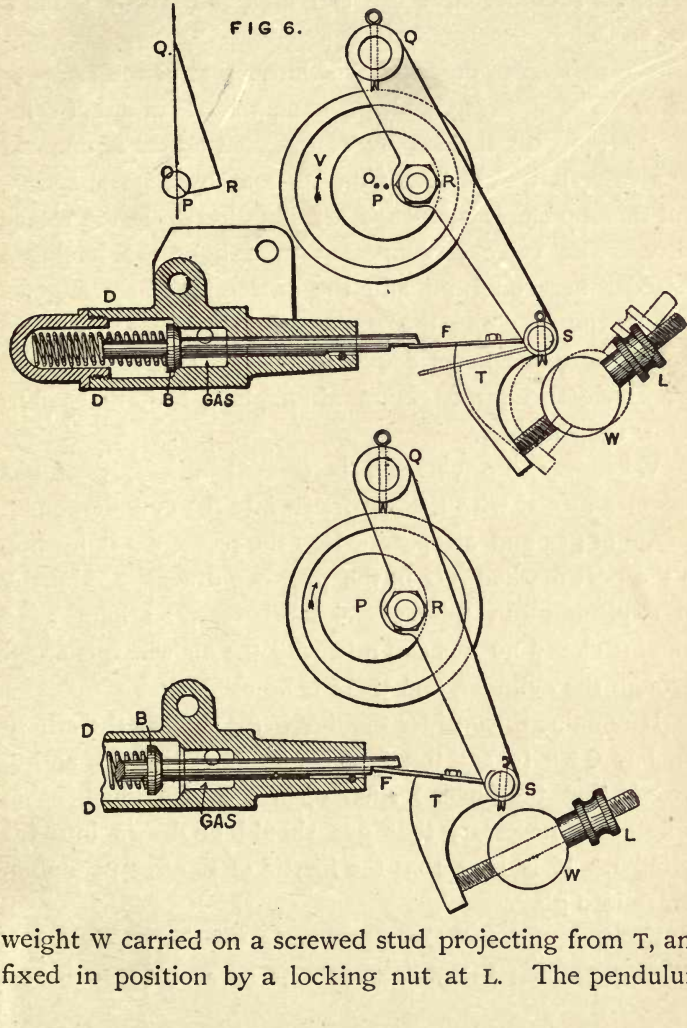
The student who has read the appendix to the author's 'Mechanism' will see that this is a combination of 4 turning pairs, viz., those at P, O, Q, and R. The fixed link is the framework connecting Q and O. It is a common device, as is pointed out at page 347, to enlarge the elements of each turning pair, such, for example, as those at P and O, so as to lose any outward resemblance to an ordinary crank and crank pin, although the motion is still present in the disguised form. The combination is therefore one form of an ordinary four-bar motion.

6. Construction of Regulator.

In the regulator, as now constructed, there is (1) a swinging bar Q R S, which derives its motion directly from the rotation of the valve V, and (2) a free pendulum T, carrying an adjustable weight W, and hung upon a pin S at the end of the bar Q R S. The complete regulator is shown in fig. 6, where it is apparent that the plane end of the valve V carries a circular disc, whose centre is P, and that this disc is represented as connected with Q R S by a pin at R. The result, as already stated, is that the rotation of V upon its axis causes Q R S to swing through a small angle on one side of the vertical in the manner indicated by a comparison of the upper and lower diagrams. The motion of Q R S is therefore a constrained motion derived directly from the valve V.

The free pendulum consists of a curved metal slab T suspended upon a pin at S, and provided with an adjustable

FIG 6.



weight W carried on a screwed stud projecting from T, and fixed in position by a locking nut at L. The pendulum swings freely upon the suspending pin S, and the slab T carries a finger F arranged to strike at the proper times against a shoulder near the end of a rod which opens a gas valve.

We pass on to describe this latter part of the arrangement. The drawing shows a chamber D D in direct communication with the supply of gas, and closed at one end by a valve B, which is kept on its seat by a spiral spring, and thereby closes a passage leading directly to the rotary valve. The valve is connected to a light rod, having a shoulder near one end, and the extremity of the finger F runs to and fro along the prolongation of the rod beyond the shoulder, but never comes to the end, so that it cannot rise above this prolongation although it sometimes falls below the shoulder.

Whenever the valve B is opened a supply of gas becomes mixed with the air drawn into the cylinder, and a charge of gas and air passes into the passage A G, leading to the port marked A G in the previous drawings, whereby an explosion can take place. Whereas, so long as B remains closed no gas can mix with the air which is swept through the cylinder, and there is no explosion.

It remains to consider the device for causing the swinging bar Q R S to set the free pendulum in motion and to provide that the finger F shall open the valve B whenever it becomes necessary that gas should be drawn into the cylinder. It is here that the inertia of the free pendulum comes into play.

Upon examining the construction of the pendulum, it will appear that the weight W acts as a sort of counterpoise to the bar T and the finger F, and that the immediate consequence of screwing the weight W outwards, along the stud which supports it, is to bring the end of the finger F to a higher level. It follows that by adjusting the position of the weight W we can cause the engine to run permanently at different rates of speed, and that whenever the engine gets beyond the normal rate to which W is set the finger F will not rise quite high enough at the end of the swing of QRS, and will fail to strike the shoulder and thereby to open the valve. Such a state of things is indicated by the dotted lines in the upper diagram, the amount of the movement being exaggerated in order to make it clear to the eye.

When the weight W is at the greatest distance from T the rate of the engine is the greatest possible, and the speed will be reduced by bringing W nearer to the base of the screwed stud upon which it is carried. In this way the rate of the engine is controlled. Whenever that rate tends to get beyond the limit assigned by the position of W, the free pendulum will lag behind in consequence of its inertia, the finger F will for a short interval fail to open the valve B, and there will be no explosion until the engine has gone back to the normal rate.

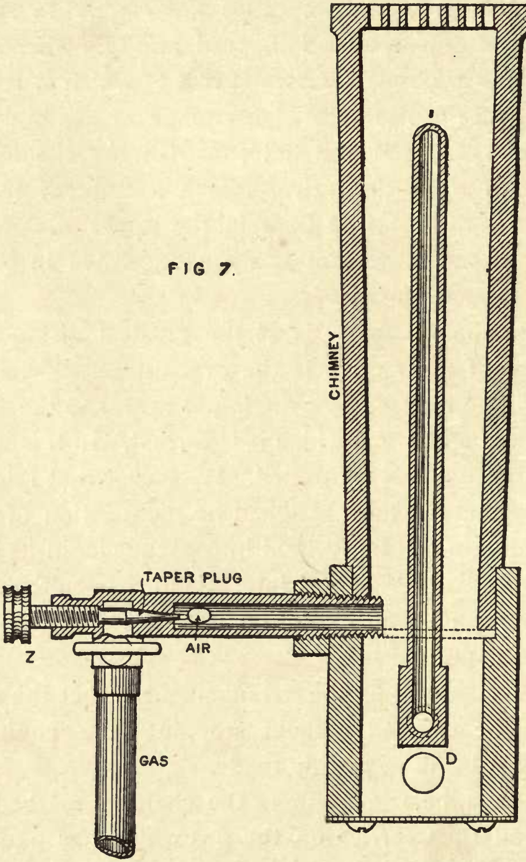
One advantage of the arrangement is that the regulation can be effected without stopping the engine, the adjustment being so readily made.

The gas-pipe which enters the chamber marked AG in fig. 1, and thus carries on the gas which has passed the valve B, is closed at the end, but perforated by holes which regulate the supply.

7. THE TUBE IGNITER.

The method of firing the charge by tube ignition is set out in figs. 1 and 7. In fig. 1 there is a passage FD

FIG 7.



terminating in a metal chamber D, held in position by a screw. The chamber is shown in section in fig. 7, and terminates in a closed vertical metal tube I, the middle portion of which is kept at a temperature sufficient to ignite gas by the flame of a Bunsen burner, directed against it.

The Bunsen burner is also shown in fig. I, and enters the chimney above the plane of the section, as drawn. The supply of gas for the burner is regulated by a screwed taper plug Z, and there are the usual air holes for the admission of air.

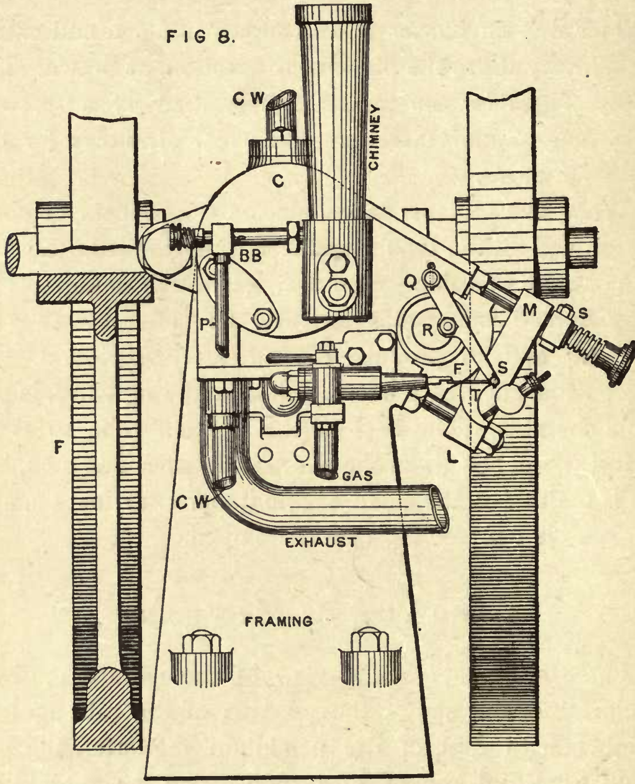
When the exhaust takes place, the products of combustion will fill the tube I, and it is only towards the end of the period of compression that gas which is capable of being lighted is forced sufficiently far along the tube to take fire and to produce the necessary explosion. In larger-sized engines a valve, called a timing valve, is put into a chamber at the base of the ignition tube so as to control the period when the gas could enter the tube, but this is omitted in the small engine under examination, and the passage FD (see fig. I) is quite open.

8. END VIEW OF THE ENGINE.

Fig. 8 represents an end view of the cylinder C, given in elevation, and shows the position of the tube igniter, together with that of the pendulum regulator, the gas supply pipe, and the exhaust pipe. The student will no doubt compare this drawing with some of those previously examined, and it will be seen that the tube igniter, the Bunsen burner, and the chimney are placed just outside the cylinder cover at one end, as previously indicated in fig. 1. The gas-tube for the supply of the Bunsen burner B B is marked P in the sketch.

Below the chimney and on one side of it is the pen-

FIG 8.



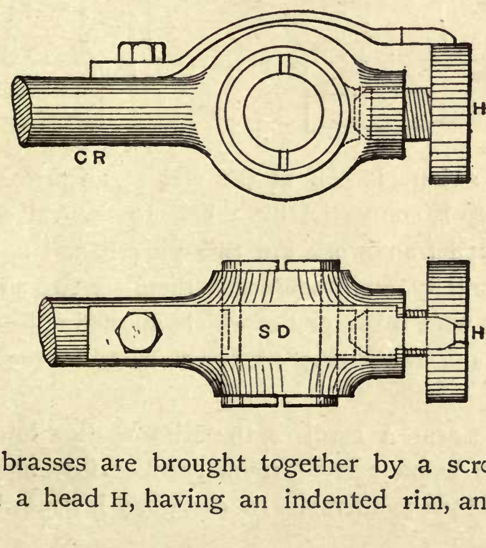
dulum regulator Q R S T, which has already been fully described. The gas-pipe, marked 'GAS,' leads directly into a chamber attached to a bracket underneath the base of the chimney, the chamber being provided with a stopcock for turning on the supply of gas, as well as the valve B, held on its seat by a spring, and opened each time that the finger F strikes against the end of the valve rod.

A block L M, secured at the end L by a nut and bolt, and pressed forward at M by a spring, as shown, keeps the rotary valve V in close contact with the facing in which it works. The exhaust pipe is also marked, and the lower of the pipes C W is the water circulating inlet, the upper one being the outlet for the water as it leaves the cylinder jacket.

9. Connecting Rod End.

A method of taking up the wear of the brasses at the end of the connecting rod is sketched in fig. 9.

FIG 9.

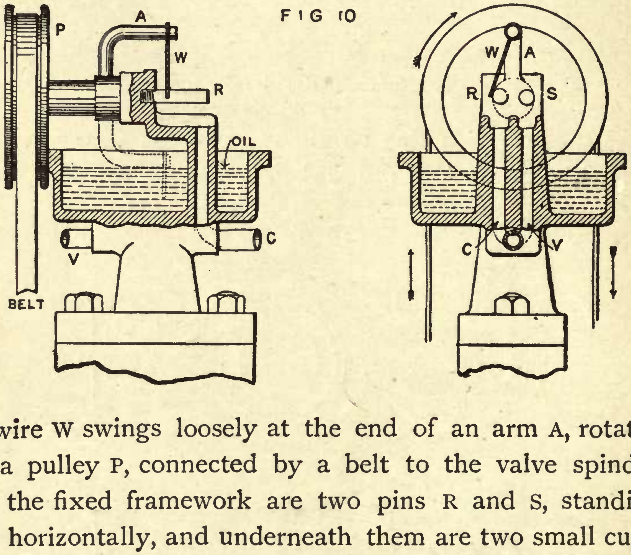


The brasses are brought together by a screw terminating in a head H, having an indented rim, and held in position by a spring detent S D. The connecting rod end is sketched in elevation and plan, and the nature of the contrivance is at once apparent from the drawing.

10. THE LUBRICATOR.

The lubricator, secured to the top of the cylinder, is shown in fig. 10, and is simple in construction and effective.

FIG 10



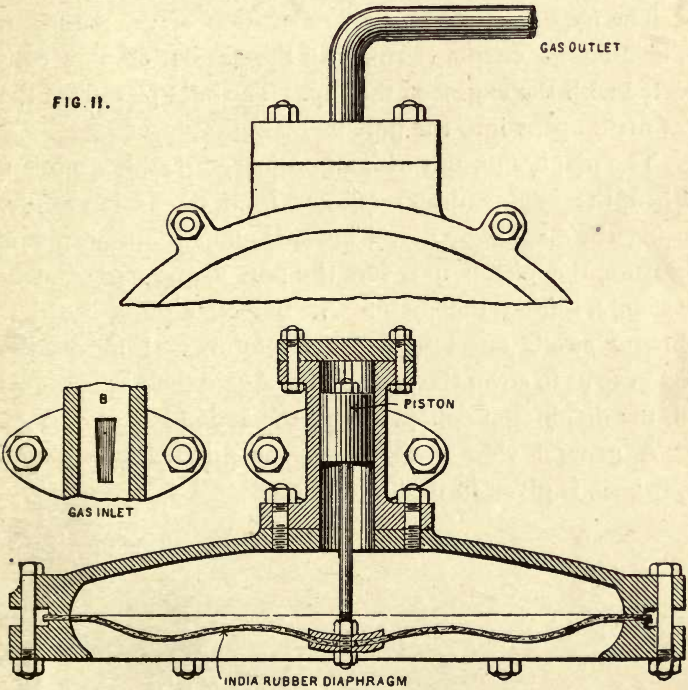
A wire W swings loosely at the end of an arm A, rotated by a pulley P, connected by a belt to the valve spindle. On the fixed framework are two pins R and S, standing out horizontally, and underneath them are two small cups, connected with tubes, one of which, marked C, leads to the cylinder, and the other, marked V, leads to the rotating valve.

As the arm A revolves, the wire W dips into the oil, and, while being carried round, strikes first against the pin R and then against S. In doing so it deposits a little oil on each pin, but a greater amount on R which leads to the cylinder, and such oil drips off into the respective passages open to receive the same, and the lubrication is therefore made continuous. The dotted lines in the drawing show the wire W passing down into the oil during the revolution of the arm A round the axis of the wheel P.

11. The Gas Regulator.

The gas regulator is a casing, provided with a gas inlet port, and a piston valve which is automatic in its action.

FIG. 11.



A horizontal section of the casing and piston is shown in the lower part of fig. 11, from which it will be understood that one side of the casing is a somewhat convex plate of metal carrying the piston valve and cylinder, and that the other side is a sheet of indiarubber attached at the centre to the valve rod, and free to swell out or contract as the pressure of the gas inside increases or diminishes.

In the drawing the gas inlet port is covered by the piston valve and valve rod, and accordingly a section of the cylinder is drawn at one side, showing the inlet valve, marked B.

The upper sketch is a side elevation of the regulator, indicating its circular form, with the gas outlet pipe connected with the engine at the top. The inlet pipe from the gas main opens into the port B.

The diaphragm acts with an ordinary breathing motion. When the engine draws off gas from the inside of the casing, the diaphragm moves inwards under the atmospheric pressure, the piston uncovers the port B, and immediately gas enters from the main. As the casing fills, the diaphragm swells out into a convex form, and moves the piston so as to cover the inlet port. Again the gas is drawn off, the diaphragm collapses, and the action is renewed.

A general view of the engine, as fitted with a single fly-wheel, is given in the frontispiece.

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