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GAS ENGINES
FOR
THE FARM

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PREFACE.

THERE are numerous books devoted to the operation and care of farm gas engines but contact with agriculturists has shown the authors that there is a very real need for a publication which will serve as a guide when contemplating the purchase of such an engine. The following pages represent an attempt to produce a book of this character.

The theory underlying the operation of these engines has been discussed only to the extent necessary to enable the reader to appreciate the conditions which must be met by any successful engine. The greater part of the book has been devoted to a discussion of the weak and strong points in the various designs, to the features which give long and useful life and those which tend to cause early failure, and to the characteristics which best adapt different types to different uses.

The material given in the chapter devoted to prices at which engines are sold and to the things which affect those prices should, when combined with the discussion which precedes it, materially assist a prospective purchaser in deciding which one of the numerous engines available will best meet his needs.

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FARM GAS ENGINES

CHAPTER I.

THE POWER PROBLEM.

As civilization has progressed and the agricultural and manufacturing industries have developed, man has been forced to the use of more power than human beings or draft animals can develop.

The days when the plow was drawn by hand were succeeded by those in which it was drawn by one, two and three draft animals, and these in turn are now being replaced by *mechanical power*, that is, by steam and gas tractors.

So, too, there was a time when threshing was universally and very economically done by hand but, as labor has become more and more scarce and therefore higher priced, the agriculturist has been forced toward the use of mechanical power.

Turn as one will, the same thing is everywhere evident; human time and human labor are becoming more and more valuable, and mechanical power producers are being substituted for the human being and for the animal which must be guided, controlled and cared for by the human being.

It so happens that Nature has put little mechanical power directly at man's disposal. It is true that the *moving winds* and the *moving waters* can be harnessed by windmills and water wheels; but winds are uncertain and a single windmill develops very little mechanical power even in a high wind, while moving water in quantities sufficient to yield a reasonable amount of power is not often found where it is needed, particularly in agricultural districts. Both these sources of mechanical power are also handicapped by the fact that, in general, the windmill and the water wheel must be stationary — they cannot be brought to the work — the work must be brought to them.

On the other hand Nature has presented man with enormous stores of *fuel* of various kinds. By burning fuel man liberates *heat* and he has been fortunate enough to discover various means of *converting* this *heat into mechanical energy* or power.

This changing of heat into mechanical power is done by means of what the engineer calls *heat engines.* It is to the study of one form of heat engine that this book is devoted, but before we can enter upon this study it will be necessary to look over the various fuels and make a brief study of those which are most important in connection with the gas engine.

CHAPTER II.

FUELS.

The principal natural fuels are

(1) *Vegetable tissues*, such as brush, wood, grasses and straw, mosses and the like;

(2) *Coals*, ranging from anthracite, or hard coal, through bituminous, or soft coal, to the material known as peat which is scarcely a coal at all;

(3) *Natural*, or petroleum, *oils*, and

(4) *Natural gas*.

The vegetable tissues are very extensively used for fuel but, with the exception of straw and similar wastes, they can generally be used to better advantage in other ways. So far as gas engines are concerned, they are not available as fuel unless treated in apparatus of such cost and character as to prohibit their use for agricultural purposes except in isolated instances which we need not consider.

The coals are extensively used under steam boilers producing steam for traction and other engines, but they, too, need great modification before they can be used in gas engines. The apparatus in which they are prepared for such use is known as a *gas producer* and its cost and complexity have so far prevented any wide application to agricultural purposes. It does, however, offer possibilities for the future.

Natural gas is an excellent fuel for gas engines but is not, in general, available in agricultural communities. It requires no preparation and can be fed directly to the engine as it comes from the pipe line.

The natural or petroleum oils are by far the most important fuels at the present time so far as the agriculturist is concerned and will therefore be considered in more detail than the others.

Petroleum oil is obtained from driven wells exactly like those used for obtaining water. The character of the oil as it comes from the well varies in different localities but is approximately constant in any one district. In the United States the oils are generally heavy brown or dark greenish brown liquids, which give off gases when exposed after leaving the well.

These oils are generally transported to refineries where they are treated in such ways as to produce a large number of different products. Some of these products are intended to be used as fuels, others as lubricating oils, and still others for medicinal and household purposes.

The simpler part of the refining is done by heating the crude oil in large vessels so that it boils off. The vapors boiling off at different stages of the process are caught, cooled and liquefied, and after further purification become the various products sold by the refinery.

The first part of the oil boils off at very low temperatures and when cooled becomes a very light liquid which vaporizes or evaporates very quickly when exposed to the air. It is not used as a fuel.

The next part boils off at slightly higher temperatures and after cooling forms a light liquid like the other but one which does not evaporate so quickly. It is sold under the name of *gasoline* and is the fuel most extensively used in gas engines by the agriculturist. When exposed to the air it gives off vapors which can be very easily ignited and which readily mix with the surrounding air to form explosive mixtures. This property makes it more or less dangerous but it is because of the readiness with which the vapors are formed and mix with the air to form explosive mixtures that it is such an ideal gas-engine fuel.

The part of the oil which boils off after the gasoline is liquefied by cooling and sold as *kerosene*. This is a watercolored or slightly yellow liquid, not quite as light as gasoline and much less volatile; that is, it does not as readily give off vapors when exposed and there is much less chance of its forming an explosive mixture with the air. These properties make it a more difficult fuel to use in gas engines but it is, nevertheless, extensively used in such engines because of the greater safety and because it costs much less than gasoline.

The vapors distilling off immediately after the kerosene also condense to light liquids. These resemble kerosene in a general way but are still heavier and less volatile. They are sold under numerous names, the most common probably being *distillate.*

The history of the oil after the removal of these distillates is of little interest to the agriculturist so far as fuels are concerned because there are few engines adapted to his needs which can utilize any of the heavier liquid fuels.

The heavier distillates are, however, worthy of notice because it is from them that the lubricating oils are made, by various more or less complex refining processes.

CHAPTER III.

THE INTERNAL-COMBUSTION ENGINE.

THE gas engine is known to the engineer as an *internal-combustion heat engine* because the fuel which supplies the heat that is to be converted into mechanical power is burned *inside* of the engine cylinder. It is given this name to distinguish it from such engines as the steam engine which requires the fuel to be burned *outside* of a boiler. Such engines are for this reason called *external-combustion engines.*

The easiest way of acquiring a knowledge of the method of operation of an internal-combustion or gas engine is to first consider one of its very near relatives, namely the rifle. While this is not commonly looked upon as an internal-combustion engine, it really is one.

Gunpowder is merely a carefully prepared, *artificial fuel* so made that it will burn very quickly and form large quantities of gas which are heated to a high temperature by the burning or combustion. When such powder is burned in the breech of a gun behind a bullet or similar projectile, the heat liberated makes the gases expand very rapidly and the bullet is thus driven out of the gun at very high velocity.

If there were any method of harnessing this bullet in the way that a moving horse is harnessed, we could get mechanical power from it. As a matter of fact, some of the earliest experimenters with internal-combustion engines tried to do what was exactly equivalent to harnessing the bullet in the case considered. They built engines so arranged that they could explode, or burn, gunpowder in the closed end of a cylinder and let the gases drive out a piston just as they drive a bullet out of a gun.

This could have been done, for instance, by using an arrangement like that shown in Fig. 1. The piston corresponds to the bullet, the cylinder to the breech and barrel of the gun, and the connecting rod is the arrangement for harnessing the moving piston to the crank shaft as shown. Powder exploded in the closed end of the cylinder would drive out the piston and rotate the crank shaft just as it is rotated in any other engine.

It is now but a simple step to substitute a combustible (burnable) mixture of gasoline vapor and air in the end of the cylinder in place of the gunpowder. When this is done, however, we have a modern gas engine. This engine operates by taking into its cylinder, at regular intervals, a combustible (burnable) mixture of fuel and air, and burning this mixture within the cylinder against the face of the piston, just as the powder in a gun burns against the end of the bullet. The *heat* liberated by the burning gases *causes these gases to expand* and drive the piston out toward the other end of the cylinder.

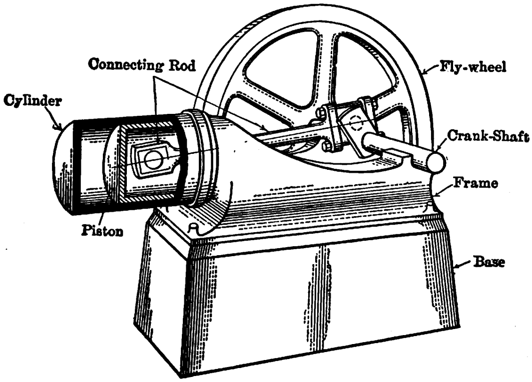


Fig. 1.

It will be observed that in this engine the fuel is burned *inside* of the cylinder just where the heat is to be utilized and therefore all the heat is available for conversion. This is quite different from the case of the steam engine in which fuel is burned *outside* of a boiler and only part of its heat passes into the steam to be carried by that steam to the engine piston for conversion into work. The internal-combustion engine, therefore, has just that much better chance at the start and is enabled, because of this and other facts which we cannot here consider, to give a *much larger return* in the form of useful power from a given amount of fuel and hence from a given fuel cost.

An idea of the *advantage possessed by the internal-combustion engine* may be obtained from the following figures. In small steam outfits it is not at all unusual to find that only 2 per cent of all the heat supplied in the fuel is converted into useful mechanical power and in the best small plants we seldom find more than 5 per cent converted. On the other hand, the small gasoline farm engine generally converts into useful mechanical power at least 15 per cent of all the heat supplied and in exceptional cases over 20 per cent may be converted in these engines.

There is one *disadvantage* of the internal-combustion principle which should be recognized. In external-combustion engines practically anything which will burn can be used for fuel. This is not true of the internal-combustion engine. It must be possible to mix the fuel with air and use this mixture in the cylinder. Solid fuel cannot be successfully handled in this way for several reasons and practice has settled down to the use of fuels which are already gases, or which are easily vaporized liquids, such as gasoline, excepting in such cases as warrant the expense and complication of apparatus to gasify solid fuels, that is, gas producers.

CHAPTER IV.

THE MECHANICAL CONSTRUCTION OF THE ENGINE.

Before we discuss the method of operation of gas engines in greater detail, it will be best to briefly describe the principal parts of these engines in order that we may become familiar with their names and their appearance.

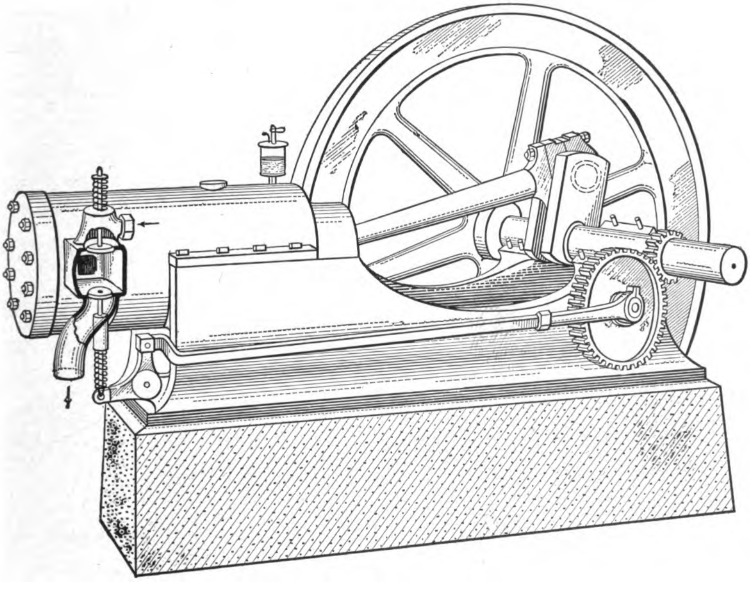


Fig. 2 (*a*). — Horizontal, Single-acting, Trunk-piston Engine.

Practically all gas engines with which the agriculturist has to deal are what are known as *single-acting, trunk-piston engines*. Two such engines are illustrated in Figs. 2 (*a*), (*b*) and (*c*) and 3 (*a*) and (*b*) with their principal parts shown assembled and separately. The engine shown in Fig. 2 is

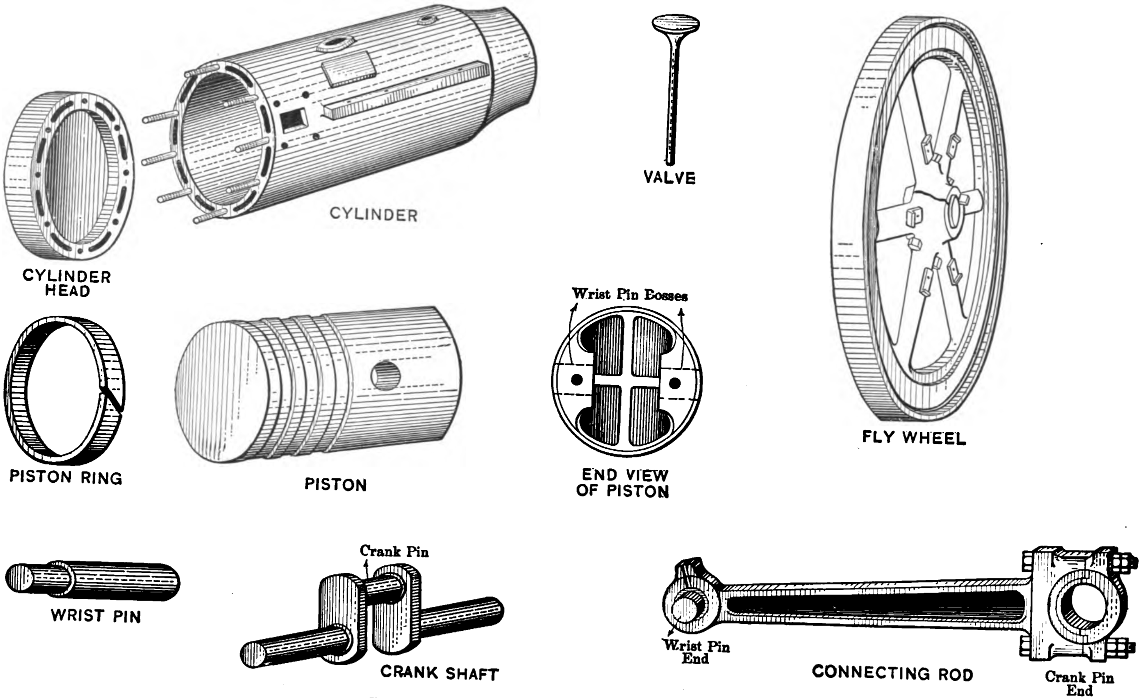


FIG. 2 (*b*).—Parts of Horizontal Engine.

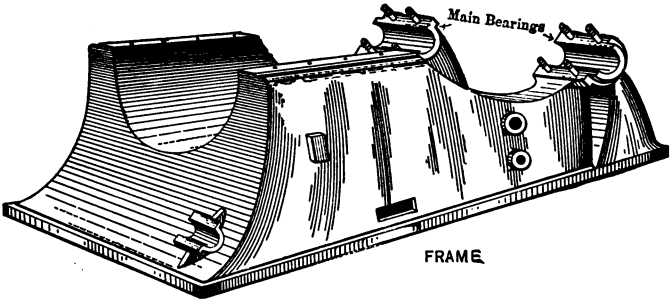


FIG. 2 (*c*). — Frame of Horizontal Engine.

called a *horizontal*, single-acting, trunk-piston engine; that in Fig. 3 is known as a *vertical*, single-acting, trunk-piston engine.

In Figs. 4 and 5 are given sections taken vertically through the centers of engines similar to those shown in Figs. 2 (*a*) and 3 (*a*).

It has already been explained that the engine is made to operate by "exploding" or burning a mixture of some kind of fuel and air in the closed end of the cylinder between the cylinder head and the face of the piston. This *burning raises the temperature and pressure* of the gases in the cylinder and the high pressure on the face of the piston drives that member out just as a bullet is driven out of a gun. The piston, through the connecting rod and crank, rotates the crank shaft as it moves out, and power can be taken from the shaft by means of a belt or other convenient arrangement.

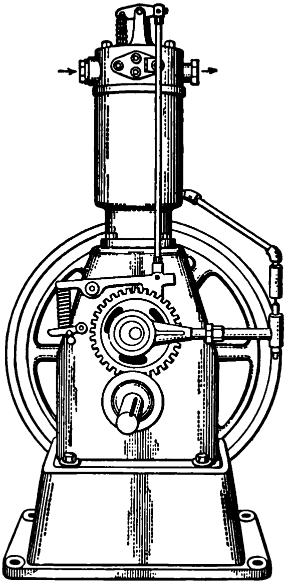


FIG. 3 (*a*). — Vertical, Single-acting, Trunk-piston Engine.

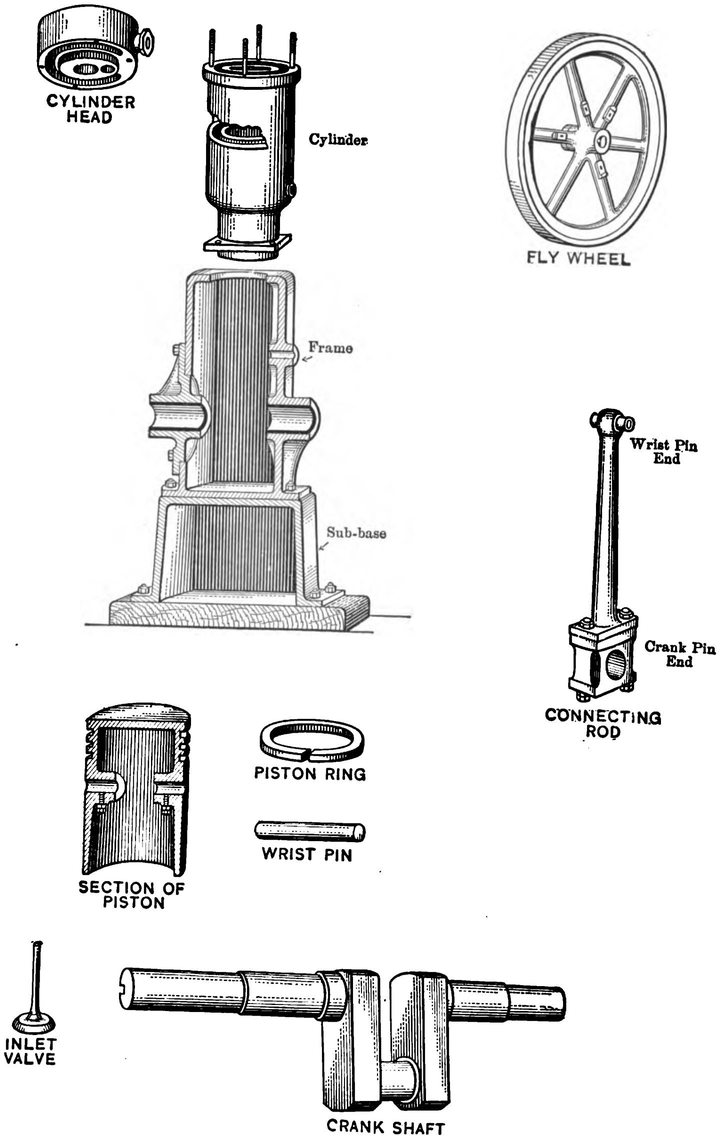


Fig. 3 (b). — Parts of Vertical Engine.

It is commercially impossible to make the piston fit perfectly inside of the cylinder so as to prevent the high-pressure gases leaking by it and blowing out into the atmosphere use-

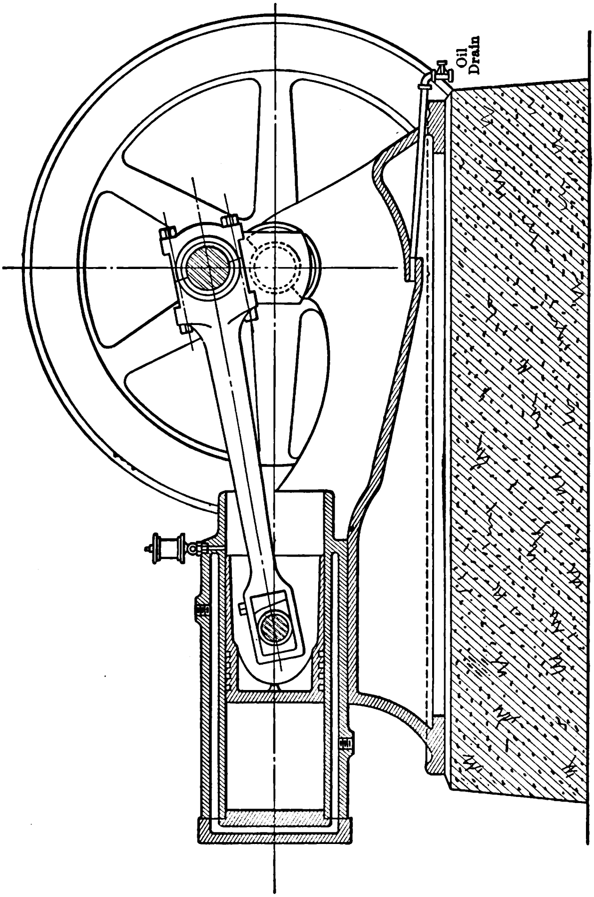


Fig. 4.—Section of Horizontal Engine.

lessly. To prevent such loss the *piston rings* are used. When out of the cylinder they are a little bigger than that cylinder; that is their outside diameter is greater than is the inside diameter of the cylinder. When they are forced into the cylinder, they are sprung together and therefore press out against the inner wall of the cylinder so that they more or less completely prevent gas leakage. The rings fit in grooves in the piston as shown in the figures, so that they travel with the piston as it moves.

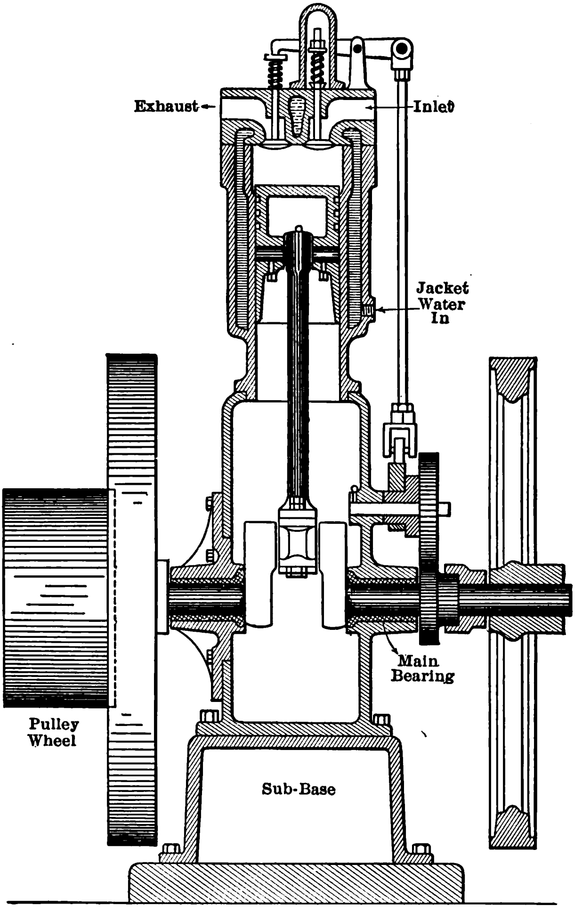


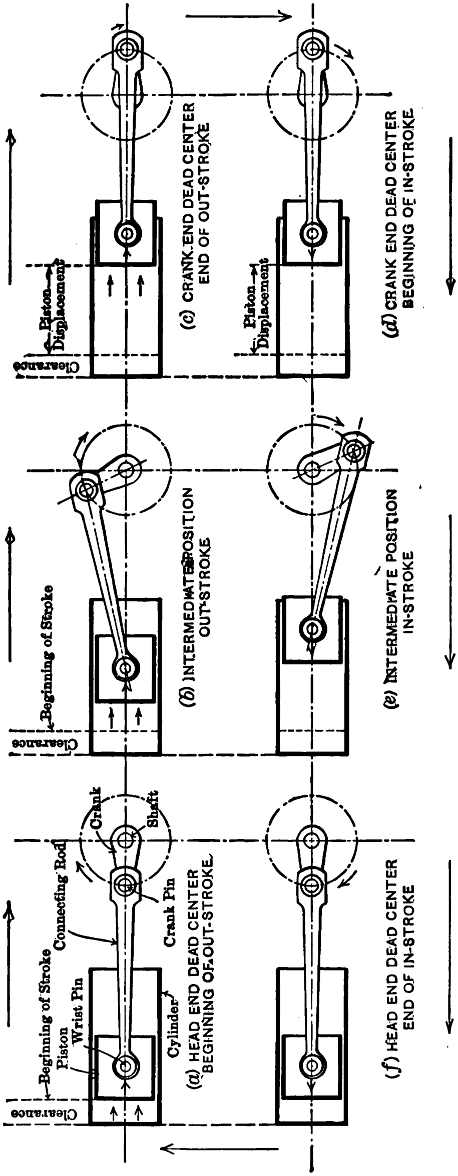
FIG. 5.—Section of Vertical Engine.

When the engine is in operation the piston moves back and forth within the cylinder. As it is guided by the walls of the cylinder it can move only in a straight line. It is seldom that such motion can be utilized for driving machinery of any kind, a "rotary" motion, that is, the motion of a rotating shaft or pulley, being commonly required. To get such rotary motion from the straight-line motion of the piston it is necessary to make use of the *connecting rod* and *crank*. This mechanism operates as shown in Fig. 6. It will be observed that the piston end of the rod which is fastened to the piston pin moves back and forth in a straight line while the crank-pin end travels around in a circle. While the piston moves out, that is, during the "outstroke," the crank pin passes through one half of a revolution; while the piston moves back, "return" or "instroke," the crank pin passes through another half revolution. Thus the crank pin, traveling in a circle comes back to its starting point every time the piston, which travels in a straight line, comes back to the position from which it started.

Quite contrary to popular belief, there is *no great loss in this system.* If it were not for friction of the piston on the cylinder walls and for friction at the pins and bearings there would be absolutely no loss of power in this mechanism. As it is, there is a small loss because of this friction—it may be as low as 5 per cent of the power given the piston by the hot gases and it is seldom as much as 15 per cent of that power. This means that in the best case we would receive at the shaft about 95 per cent of the power which the cylinder could generate, the other 5 per cent being lost in friction.

The *main bearings* hold up the weight of the shaft and flywheels which are fastened to that shaft, absorb various pressures to which the shaft is subjected when in operation and form surfaces in which the shaft may rotate with minimum friction loss.

The *frame* serves to hold up all parts of the engine and to fasten all parts of the engine to whatever foundation is used



(a) HEAD END DEAD CENTER BEGINNING OF OUT-STROKE

(b) INTERMEDIATE POSITION OUT-STROKE

(c) CRANK END DEAD CENTER END OF OUT-STROKE

(d) CRANK END DEAD CENTER BEGINNING OF IN-STROKE

(e) INTERMEDIATE POSITION IN-STROKE

(f) HEAD END DEAD CENTER END OF IN-STROKE

FIG. 6.

under it. It also keeps the parts in the proper relative positions during operation; for instance, it prevents the cylinder and bearings from being blown apart by the high pressures which exist between the piston face and the inside of the cylinder head.

The *flywheels* act as storers of energy in several ways. It will be discovered later that on the outstroke of the piston, which occurs under the action of high-pressure gases, the piston delivers to the shaft more power than is taken from that shaft by the machinery which is being driven. It will also be discovered that at certain times (as, for instance, during a return stroke when gas is being compressed by the piston) energy must be supplied the piston. The flywheels store the surplus energy given to the piston when necessary and give this back when required. They store the surplus energy by speeding up during the working outstroke and they return it by slowing down. This variation of speed is not generally visible when an engine is operating properly at full speed but it can easily be seen when the engine has just been started and is still turning over slowly.

It will also be shown later that, in order to keep the engine operating, fresh supplies of combustible (burnable) gas must be put into the cylinder at periodic intervals and the burned gases must be similarly removed. The gases are introduced and removed through the *valves*, which are opened and closed at the proper times in ways which will be considered later.

CHAPTER V.

PRINCIPLES OF OPERATION.

We must now consider what occurs inside of the cylinder of a gas engine, so that we may explain how and why the piston is driven back and forth.

There are two distinctly different ways in which gas engines may operate. One is called *Four-stroke Operation* or *Four-cycle Operation* and the other is known as *Two-stroke Operation*, or *Two-cycle Operation*. They get their names from the number of strokes which the piston must make in order to complete a cycle, that is, to complete one set of operations inside of the cylinder.

Four-stroke Operation.

This method of operating will be described with the aid of Fig. 7 which shows the principal moving parts of such an engine in various positions assumed during one cycle or set of operations. In this figure, drawing (*a*) represents the condition of things just before the first stroke of the cycle starts. The *exhaust valve E* is closed, the *inlet valve I* is just opening, the piston is as far to the left as it ever gets, and the crank is on the *head-end dead center*.

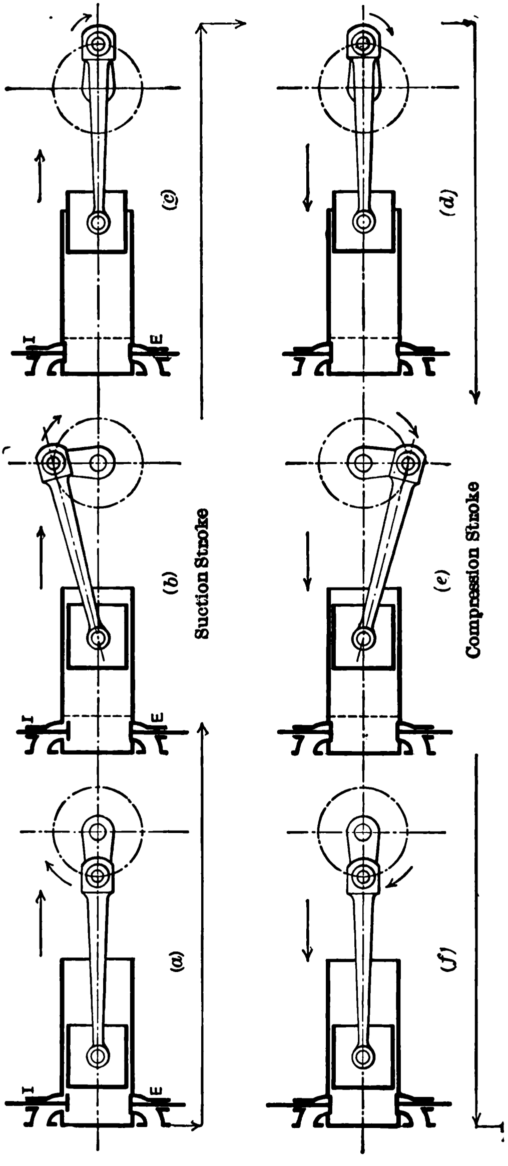
Starting with the parts in this position, the inlet valve is opened wide and the piston is drawn to the right by rotation of the crank. The pipe shown leading to the inlet valve is arranged to supply a combustible or burnable gaseous mixture in ways which will be discussed in later chapters. As the piston moves out this mixture flows through the valve and fills the space left by the piston so that when the piston gets to the outer end of its stroke, as shown by drawing (*c*) in ~~Fig.~~ 7, a full *charge* has been drawn into the cylinder and the inlet valve can be closed. This stroke of the piston is called the *suction stroke.*

The rotation of the crank is continued, driving the piston back to the innermost position in the cylinder while both valves remain closed. As there is no way for the gases inside the cylinder to escape, their *volume is decreased* and their *pressure rises;* that is, they are *compressed* by the piston. This stroke is therefore called the *compression stroke.* The parts of the engine are shown in three positions assumed during this part of the cycle by drawings (*d*), (*e*) and (*f*) in Fig. 7.

After the charge has thus been compressed it is *ignited;* that is, it is set on fire or combustion is started. For present purposes this may be assumed to occur at the instant when the piston reaches the innermost position, (*g*) in the figure, and the burning may be assumed to occur so rapidly that it is completed before the piston has a chance to move. This results in a very great *increase of pressure* within the cylinder and the piston is driven out by the high-pressure gases. As the piston moves out, the volume occupied by the gases constantly increases; that is, the gases *expand,* and this stroke is therefore sometimes called the *expansion stroke.*

This stroke is the only one of the four strokes of the cycle during which power is generated within the cylinder; that is, it is the only stroke during which the gases in the cylinder *do work on the piston* and make the crank shaft revolve. It is therefore also called the *working stroke.* Successive positions of the mechanism are shown in (*g*), (*h*) and (*i*) of the figure.

At the end of the working stroke the cylinder is filled with burned gases which are useless so far as the engine is concerned and which must be removed from the cylinder in order that a fresh charge may be introduced. The burned gases are driven out by holding the exhaust valve open while the piston is driven back into the cylinder. This stroke is called the *exhaust stroke* because during it the


I
E
(a)
(b)
(c)
(d)
(e)
(f)
Suction Stroke
Compression Stroke

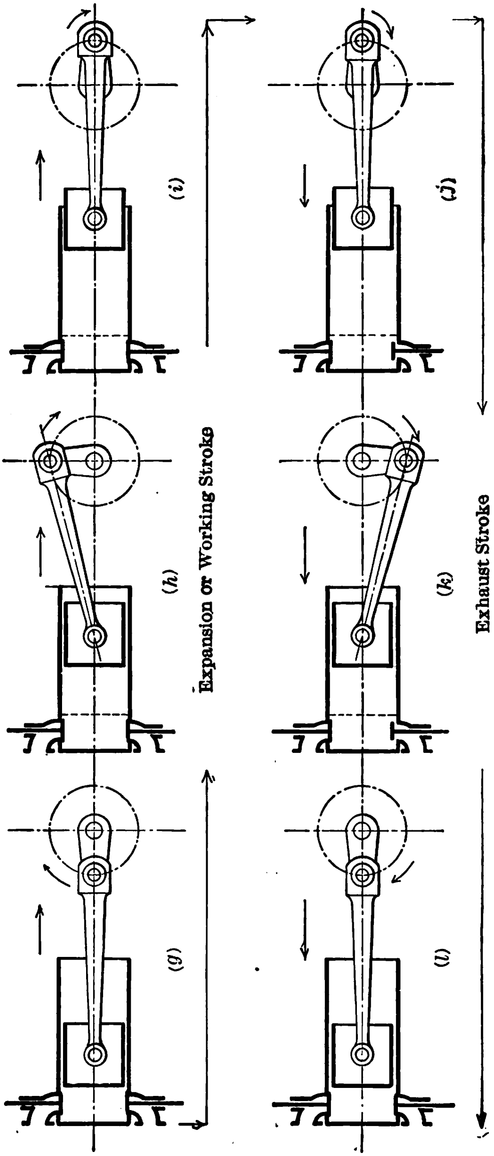


FIG. 7.— Four-stroke Operation.

burned gases are exhausted from the cylinder. Successive positions are shown in (*j*), (*k*), and (*l*), Fig. 7.

Closing the exhaust valve and opening the inlet valve now brings us back to the beginning of the suction stroke. We have completed *one cycle of operations* and can start another similar cycle. It will be observed that there were *four strokes* required to complete the cycle and that only one of these was a working stroke. That is, during only one stroke out of the four did the gases in the cylinder give energy to (do work upon) the piston. During the other three the flywheels of the engine, when in regular operation, must drive the piston, supplying any energy which is needed to overcome resistance offered to the motion of the engine. Such resistances are friction of engine parts, friction of gases passing through valves, work of compression previous to ignitions, and the load which the engine is carrying.

It should also be noted that all of the burned gases are never exhausted in this type. When the piston has reached its innermost position there is still a distance between it and the cylinder head. This space is called the *clearance space* or simply the *clearance.* This clearance space must remain full of burned gases at the end of the exhaust stroke. During the suction stroke the fresh charge entering the cylinder mixes with these burned gases and it is this mixture which is compressed.

The suction and exhaust strokes are often spoken of as *pumping strokes* because the gases are pumped into and out of the cylinder during these strokes.

TWO-STROKE OPERATION.

The two-stroke method of operating is so devised that the two pumping strokes needed in four-cycle operation are not necessary ; that is, the strokes used in drawing the charge into the cylinder and in exhausting the burned gases from the cylinder are omitted. The same things must, however, be accomplished in two-stroke operation as in the four-stroke method; that is, the burned gases which have driven the piston out must be exhausted, a new charge must be made to flow into the cylinder, must be compressed, burned and expanded.

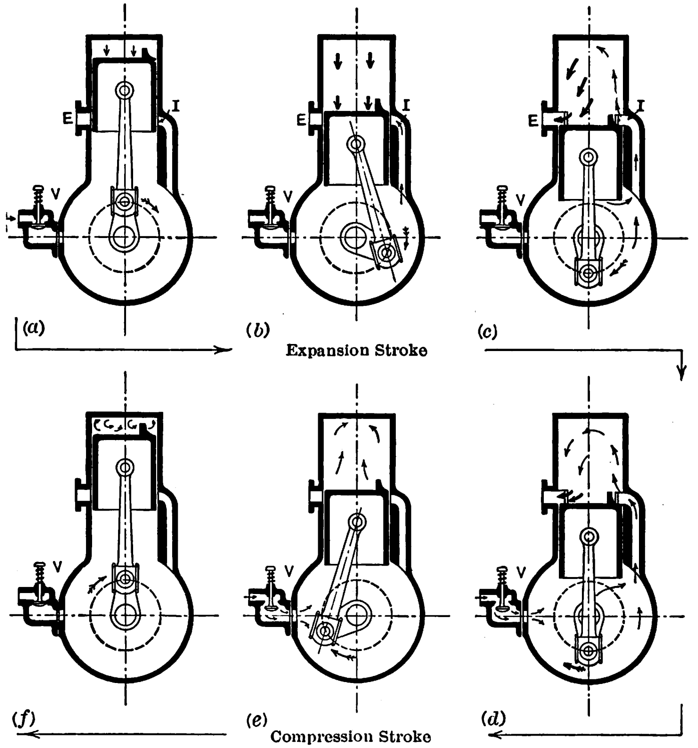


FIG. 8.—Two-stroke Operation.

We shall consider the operation of the two-stroke engine with reference to Fig. 8. In this figure the drawing (*a*) represents the position of the parts of the engine at the instant when ignition occurs. In the working end of the cylinder, between the inside of the cylinder head and the face of the piston, is a compressed charge of combustible mixture. The way in which it is brought to this position and condition will develop later. On the other side of the piston, within it and the walls of the closed crank case, is a charge of combustible mixture. The way in which this charge comes to occupy this position will also be explained later.

With the parts as shown in (*a*) ignition is effected in the cylinder and the resulting high pressure drives the piston outward, that is, downward in the figure. As the piston moves out it compresses the charge of combustible mixture contained in the crank case.

When the piston finally gets to the position shown in (*b*) its further motion uncovers an opening *E* in the lower part of the wall of the cylinder. This opening is known as the *exhaust port* and it leads directly into the exhaust pipe. When this port is uncovered the burned gases in the cylinder which are still at a fairly high pressure begin to rush out into the exhaust pipe.

Shortly after exhaust starts in this way the further motion of the piston uncovers the opening *I* on the other side of the cylinder. This opening is called the *inlet* or *admission port* and is connected with the crank case by the pipe shown. At the time when the inlet port is uncovered by the piston the charge in the crank case has been compressed to a pressure of several pounds above that of the atmosphere and the pressure within the cylinder has dropped to very nearly atmospheric. The fresh charge therefore rushes into the cylinder, strikes on the *deflecting plate* shown on the top of the piston, turns and travels up the length of the cylinder driving the exhaust gases before it. It then turns on the inside of the cylinder head and, still driving the exhaust gases, it travels down toward the open exhaust port. The condition of things during this part of the process is indicated in drawing (*c*). While this combined charging and exhausting operation is occurring the piston moves out until the ports are entirely uncovered and then it starts on its return stroke from (*d*), finally covering the exhaust port at just the instant when the fresh charge, returning down the length of the cylinder, reaches, and is about to pass out of, that port.

The cylinder is now filled with a combustible mixture at about atmospheric pressure and the crank case is filled with a similar mixture at similar pressure. The positions for this point in the operation are shown in (*e*) of Fig. 8. It will be observed that the mixture previously contained in the crank case (when the piston was approaching outer dead center) is now partly in the cylinder and partly in the crank case.

As the piston moves upward from the position shown in (*e*) it compresses the charge in the cylinder and leaves behind it an ever-increasing volume in the crank case. To fill this volume the mixture outside valve *V* shown in the figure pushes open that valve and flows into the crank case, thus taking the place of that which has just been trapped, and is being compressed, in the cylinder. The continued upward motion of the piston finally brings things to the positions and conditions shown in (*f*) which are the same as those with which we started, as shown in (*a*). The clearance is filled with a compressed combustible mixture and the inside of the piston and crank case are filled with combustible mixture at about atmospheric pressure.

It will be observed that the entire cycle of operations has required *two strokes only*, expansion occurring during almost the entire outstroke and compression during almost the entire instroke. The charging and discharging operations have been made to occur at the outer end of the stroke and to require but a short time for completion. More careful analysis will show, however, that the two pumping strokes of the four-stroke engine have not really been eliminated; the operations have merely, in a way, been shifted to the other side of the piston. On the upstroke the crank-case side of the piston really performs a suction stroke and on the return this same side of the piston, by compressing the mixture in the crank case, performs what is equivalent to an exhaust stroke. It is really because of this preliminary compression that the fresh charge can blow the burned gases out of the cylinder through the exhaust port.

The type of two-stroke engine shown in Fig. 8 is called a *two-port engine* for very obvious reasons. It will have been noticed that these ports take the place of inlet and exhaust valves as used in the four-stroke engine. The type shown is not, however, devoid of valves, an admission valve to the crank case being used.

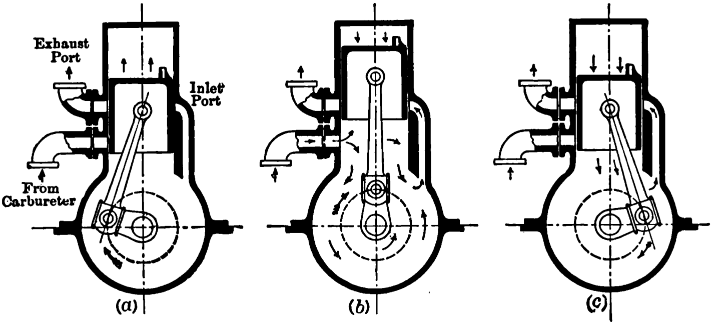


FIG. 9. — Three-port Engine.

To completely eliminate valves a different type, known as the *three-port, two-stroke engine,* is sometimes used. This is shown diagrammatically in Fig. 9. The third port opens into the crank case and serves to bring in the mixture just as the pipe and inlet valve did in the engine in Fig. 8. This third port is so placed that it is covered by the piston until that member travels almost to its head-end dead-center position. From that time until the piston reaches dead center and returns the third port opens into the crank case and the new charge can enter that chamber. Several positions of the piston during this period are shown in (*a*), (*b*) and (*c*) in the figure, the arrows indicating the direction of motion. The third port as shown is lower than it would be in a real engine as too much of the charge would escape during the downward motion of the piston and not be compressed in the case. With the exception of the action of the third port the operation of this engine is exactly similar to that of the type shown in Fig. 8.

Four-port engines are also constructed, but as this design is used only when exceptionally high speed is required it is not found in agricultural engines and will not be considered here.

CHAPTER VI.

INDICATOR DIAGRAMS.

Engineers have developed a means of drawing pictures or diagrams showing what happens inside the cylinders of heat engines. These diagrams are obtained by means of an instrument called an *indicator* and are therefore called *indicator diagrams.* It is outside the province of this book to consider the instrument, but the diagrams may well be studied as they are a great help in explaining what takes place within the cylinder of a gas engine.

To show what an indicator diagram is, we will assume a small cylinder, *A* in Figs. 10 and 11, to contain a small piston which is pushed downward by a spring as shown. If this small cylinder is connected with the inside of the engine cylinder, whatever pressure is exerted by the gas on the engine piston will also be exerted on the small piston. Obviously the greater the pressure inside of the cylinder the higher will the small piston be pushed up, so that by watching the movements of the end of the rod fastened to the small piston we can actually see the way the pressure inside the engine cylinder varies. We will hereafter designate the end of this rod by the letter *x*.

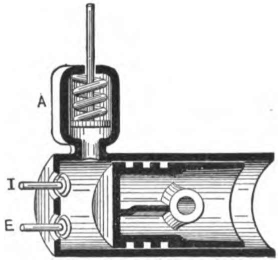


Fig. 10.

Suppose the engine cylinder to operate on the four-stroke principle and to have compressed a charge into the clearance when the piston is in the position shown in Fig. 11 (*a*). The pressure in that clearance will be indicated by the height of point *x* on the end of the rod protruding from the small cylinder. To show that this is the pressure when the piston is in this particular position, we will draw a vertical line *aa* and put a point x' on that line opposite to the point x.

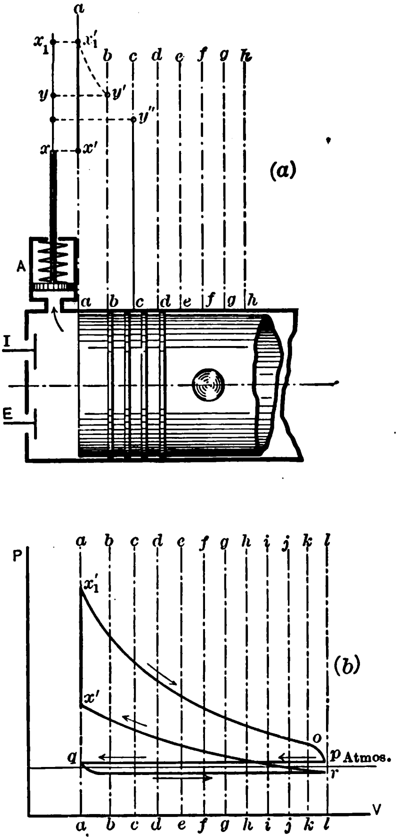


Fig. 11.

Assume now that ignition occurs. There will be a very *sudden rise of pressure* within the cylinder and the small piston will rapidly rise carrying the end of the rod x up with it until it gets to some new position x_1. The engine will, however, be on dead center and its piston standing still so that the line *aa* will still show its position. If we put the point x_1' on the line *aa* and opposite to x_1, we obtain a line $x'x_1'$ which shows how the pressure in the engine cylinder changes while the engine piston remains stationary.

Assume now that the engine piston moves out and the high-pressure gases expand. When the piston gets out to such a position that its face lines up with *bb*, the end of the rod fastened to the small piston will have dropped to a point y. If we put y' on *bb*, opposite to y, we have a point which indicates the pressure in the cylinder corresponding to that piston position.

In this way we can get a series of points on *aa, bb, cc, dd,* etc., each one showing the pressure in the cylinder when the engine piston reaches a certain position. If we connect these points by means of a smooth curve we get a line showing the variation of pressure with piston position during the entire expansion stroke of the piston. This is called the *expansion curve.*

We could carry out this process for the four strokes required to complete one cycle and it would give a diagram like that of Fig. 11 (*b*). The arrows indicate the direction in which the piston moves as the various changes occur.

The line $x'x_1'$ represents rise of pressure during combustion. The curve $x_1'o$ represents expansion behind the piston with drop of pressure as shown. At *o*, that is, when the piston has reached position *kk*, the exhaust valve opens. In the ideal engine the exhaust valve would not open until the piston reached the end of the cylinder but in the real engine it opens earlier in order that the burned gases may be more perfectly exhausted. From point *o* to *p* the gases blow out through the exhaust valve while the piston moves out; obviously, the pressure in the cylinder continues to drop.

Then the piston starts back on its exhaust stroke and the burned gases are driven out of the cylinder through the open exhaust valve. The pressure in the cylinder remains constant during this stroke and the line *pq* which represents this part of the process is therefore horizontal.

When *q* is reached the piston has arrived at the end of its stroke; the exhaust valve is closed and the inlet valve is opened. The piston then starts back and a new charge is drawn into the cylinder with pressure remaining practically constant as shown by *qr*. When the point *r* is reached the inlet valve is closed and the piston then returns, the pressure inside the cylinder rising as shown by rx' as the combustible charge is compressed. This brings us back to the point at which we started and ignition again causes the sudden pressure rise $x'x_1'$.

It will be observed that this diagram gives a very good picture of what happens inside the cylinder and it will be found very useful later on in picturing various things which will have to be discussed.

DIAGRAM OF TWO-STROKE OPERATION.

A diagram showing the pressure variations within the cylinder of an engine operating on the two-stroke principle is shown in Fig. 12.

Starting at the same point as in the last case, we will assume the piston at head-end dead center at the end of the compression stroke. The pressure is as shown at *m*. Ignition is produced and the pressure rises to *n* as indicated by the line *mn*.

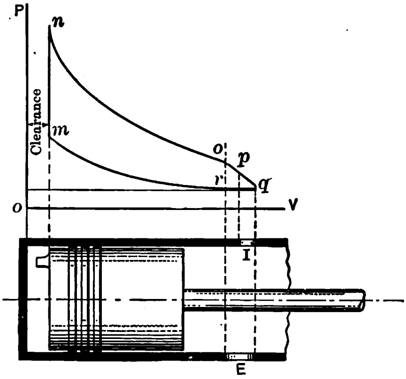


FIG. 12.

The piston is then driven out by the expanding gas and the pressure of the gases drops as shown by *no*. When the point *o* is reached the exhaust port is uncovered and the gases begin to flow out into the exhaust pipe while their pressure drops rapidly as shown by *op*.

When *p* is reached the piston begins to uncover the inlet port allowing the fresh charge to blow into the cylinder while the burned gases continue their outflow. This combined charging and discharging continues until the piston reaches a position directly under *p* on the return stroke. At that instant the inlet port is closed but gas continues to blow out through the exhaust until the piston reaches a position directly under *o* at which instant the exhaust port is completely covered. From *r* to *m* the pressure within the cylinder rises as the mixture is compressed.

A complete picture of two-stroke operation would involve the drawing of still another diagram showing the variation of pressure on the crank-case side of the piston. For the purposes of this book it is, however, unnecessary to consider this other diagram.

CHAPTER VII.

POWER OF GAS ENGINES.

ENGINES are bought and sold on the basis of the power they can develop. This power is measured in *horse power*. Historically, one horse power was supposed to be equivalent to the power of one horse as the name indicates, but as a matter of fact the power of horses is so variable that it is necessary to use a more exact definition.

The engineer uses the term one horse power to mean the doing of work at the rate of 33,000 *foot pounds of work in one minute*. A foot pound of work is the work one would have to do in raising a one-pound weight one foot against the action of gravity. If one raises 33,000 pounds one foot in one minute he develops one horse power, or if one raises one pound 33,000 feet in one minute he develops one horse power.

Similarly, if one does work equivalent to twice 33,000 foot pounds in one minute he is developing two horse power, and work at a rate of half of 33,000 foot pounds per minute is equivalent to half a horse power.

To determine the horse power developed by any piece of mechanism it is therefore only necessary to find the foot pounds of work which it does in a minute and divide this value by 33,000.

Suppose, for instance, that we determine in some way the fact that an engine is delivering 148,500 foot pounds per minute. The horse power developed by the engine is 148,500 divided by 33,000 which gives $4\frac{1}{2}$ horse power.

The way in which the output of an engine is measured need not be considered in this book. We must, however, devote our attention to what it is that determines the amount of power which an engine can develop. For this purpose we must first discover what it really is that causes a gas engine to develop power.

The combustible mixture which is taken into a gas-engine cylinder and there burned has stored in it that which is going to appear later as power at the crank shaft of the engine. That which is stored in the mixture is called *heat energy.* It is a matter of experience that when such a combustible mixture is burned heat appears. It is beyond the province of this book to explain why or how it appears but it is necessary to bring out the idea that the burning of the mixture does liberate heat energy.

Another very important thing to note is the fact that if one cubic foot of a combustible mixture liberates a given quantity of heat energy two cubic feet of the same mixture will liberate twice as much heat energy when burned.

This heat energy is liberated inside the cylinder of the engine when the charge is burned therein. Some of it, by a very complicated series of transformations, appears later as mechanical energy at the shaft of the engine. The part which appears in this way can be determined and engineers have discovered that the equivalent of about 15 to 25 per cent of all the heat energy liberated in the cylinder finally appears at the crank shaft of the engine as useful mechanical power.

The problem of building an engine to deliver a certain power is then merely the problem of building an engine which *can liberate the necessary amount of heat energy in its cylinder.* Since one cubic foot of mixture is able to liberate a given quantity of this heat energy when burned it is only necessary to build a cylinder which will *take in the requisite number of cubic feet of mixture.*

The horse power of an engine is, therefore, really determined by the number of cubic feet of mixture which can be taken into its cylinder and burned in a given time, say one minute, or one cycle, or one hour, as may be convenient.

The number of cubic feet of mixture which can be drawn into a cylinder are measured by what is called the *piston displacement*, that is, the volume which the piston opens up or leaves open as it moves out of the cylinder. This obviously depends upon the diameter of the piston or cylinder, and the length of the stroke of the piston. Since this volume of material should be drawn in every time a suction stroke occurs it will also be necessary to consider the number of suction strokes per minute or else the speed of the engine.

We should, therefore, be able to express the horse power of an engine in terms of the *cylinder diameter*, the *length of stroke* and the *number of revolutions per minute.* This can be done in a general way, but there are so many other things associated with the design and manufacture, which also affect the power of the engine, that formulas worked out in this way must be considered to give approximate results only.

It is also a fact that equal volumes of different kinds of mixture liberate different amounts of heat in the cylinder and cause other differences which necessitate a different formula for each kind of fuel. The formula given below has been developed by examining several hundred American engines of the agricultural types and gives very good average results.

In this formula, the letter d stands for cylinder diameter measured in inches; the letter l stands for the stroke of the engine in inches; and the letter n stands for revolutions per minute, that is, the number of times the crank pin makes a complete circle in one minute.

For four-stroke gasoline engines

$$\text{Horse power} = \frac{d^2 \times l \times n}{16{,}600}.$$

This means simply that if we square the diameter, that is, multiply it by itself, and then multiply this by the stroke and the resultant product by the number of revolutions per minute and then divide the value so obtained by the number given in the formula we will get a number equal to the horse power of the engine in question. For example, suppose it is desired to find the horse power which a 6 × 8 gasoline engine running at 400 revolutions per minute will develop. The numbers 6 × 8 are read "six by eight" and mean that the cylinder diameter is 6 inches and the stroke is 8 inches. To calculate the horse power of this engine we square 6, that is, multiply 6 by itself, giving 36; we then multiply this by 8 giving 288 and multiplying this by the revolutions, 400, gives 115,200. This number divided by the numerical constant 16,600 gives approximately 7.0 as the horse power which this engine might reasonably be expected to give when run on gasoline.

Similar formulas for other fuels and for other types of engines could easily be developed in a similar way. They would, in general, differ only in the value of the numerical constant.

It will be observed that these formulas would indicate that an engine with small diameter and small stroke but running at a high speed ought to be able to deliver as much power as an engine with larger diameter and stroke but running at a lower speed. Within certain limits this is true, but in every case there is a certain limit beyond which it is useless to carry the speed. This results from the fact that beyond a certain speed the volume of gas which can be made to flow into the cylinder in the very short time available decreases very rapidly because of the choking or throttling at the valves, so that the power of the engine decreases because it is not supplied with the material necessary to liberate the required amount of heat in the cylinder.

This is of considerable importance to the buyer of engines because the smaller the cylinder diameter and stroke for a given horse power, the smaller and lighter is the whole engine and therefore the smaller the price for which the engine can be sold if other things are equal. There are a number of other considerations, however, which affect the cost of the engine and the cost of power which can be obtained from that engine but these will be left for a later chapter.

The formula just given applies only to four-stroke gasoline engines, but it is desirable that we should also be able to predict the performance of two-stroke engines. In theory the two-stroke engine would give just twice as much power as would an engine of the same size operating on the four-stroke principle and giving the same number of revolutions per minute. Practically, however, this is not true for several reasons, the more important being:

(1) Part of the work developed during the outstroke of the piston is used in compressing the charge contained in the crank case, so that only the remainder is made available at the shaft.

(2) The real stroke of the piston is not all used as in the four-stroke engine. In the four-stroke engine the cylinder is supplied with a charge which fills that cylinder when the piston is on the outer dead center. In the two-stroke engine the charge fills the space in the cylinder when the piston has returned far enough to just cover the exhaust port. The charge in the cylinder of a two-stroke engine in actual practice generally only measures about eight-tenths to nine-tenths of that in the cylinder of a four-stroke engine of the same size.

(3) The charge entering the cylinder of a two-stroke engine never really pushes the burned gas out ahead of it in any such perfect manner as we assumed in the earlier description. There is always considerable mixing, so that when the exhaust port is finally closed the gases left in the cylinder consist of a mixture of burned gases and fresh charge. A similar thing was noted in a previous chapter regarding the charge in the four-stroke engine, but the relative amount of burned gases retained in the two-stroke

cylinder is generally greater than in that of the four-stroke engine and therefore there is less volume to be occupied by new charge.

It therefore happens that the two-stroke engine *gives much less than twice* the power of a four-stroke engine of the same size, running at the same speed. Experience shows that real two-stroke engines give anywhere from one and one-fourth to one and three-fourths times the power of similar four-stroke engines. The higher value is reached only in the very best designs and it is generally not safe to figure on more than one and a half unless one has very good reason for choosing a higher value.

In a subsequent chapter we are going to consider several things which involve a slight knowledge of how the power travels through the engine from the time it is given to the piston by the gas until it is finally taken off the shaft or belt pulley of the engine.

The gas operating within the cylinder of an engine delivers to the piston of that engine a certain amount of power. The piston passes this on through the mechanism of the engine toward the shaft. In order to pass it on in this way, however, the piston and all connected parts have to move continuously in certain definite ways. But all motion is resisted by friction and so some of the power given the piston by the gas in the cylinder is used up in moving the parts of the engine against their own frictional resistance. The remainder may finally be taken from the shaft of the engine.

The power given to the piston by the gases in the cylinder we will call the *cylinder horse power;* that lost in friction we will call the *friction horse power;* and that which may be taken from the shaft of the engine we will call the *developed* or *shaft horse power.* From what has preceded, it is evident that the developed horse power must equal the cylinder horse power minus the friction horse power. Real gas engines generally waste considerable power in friction of the principal working parts and of the valve-operating mechanisms, so that the developed horse power is generally only from 75 to 85 per cent of the cylinder horse power.

The formulas previously mentioned in this chapter give developed or shaft horse power.

CHAPTER VIII.

THE COOLING SYSTEM.

About one third to one half of all the heat liberated in a gas-engine cylinder is given to the surrounding metal, that is, to the cylinder walls, cylinder head and piston face. If this heat were not removed from the metal as fast as supplied by the gas it would not take long to raise the entire cylinder to so high a temperature that further operation would become impossible. The hot metal would decompose the oil used for lubricating the piston and cylinder walls so that their surfaces would be rapidly destroyed; the expansion of the piston might become so great as to cause it to stick (freeze or grip) in the cylinder; and the high temperature might ignite (set fire to) the combustible mixture during compression, thus giving a high pressure at the wrong time. It thus develops that *some method of cooling these metallic walls is necessary.*

There are two distinct methods in use; they are,

1. Cooling by means of a liquid, generally water but occasionally oil, and
2. Cooling by means of air.

Each system has its advantages and its disadvantages, and it should be understood at the outset that it is impossible to make a flat statement to the effect that the one method or the other is the better. Certain conditions call for air cooling, certain others for liquid cooling.

In general, *liquid cooling is the more flexible* of the two methods and is by far the more common.

Liquid-cooled engines are always constructed with double-walled cylinders as shown in Figs. 13, 14, 15, 16 and 17, the liquid filling the space between the two walls or cylinders. This space is called the *jacket space* or simply the *jacket.*

The cylinder head is similarly made with double walls, either wholly or in part, so that it also contains a jacket space and is liquid cooled. The piston is never cooled by means of liquid in small engines such as are used for agricultural purposes. Part of the heat it receives is passed through the cylinder wall to the cylinder jacket and part of it passes through the face and barrel of the piston to the air on the open or crank-case side. Thus the piston is partly air cooled even in a liquid-cooled engine.

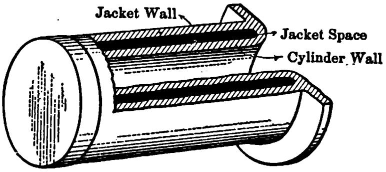


Fig. 13.

In two-stroke engines in which the charge is compressed in the crank case this charge itself serves to cool the piston.

There are a number of different types of liquid cooling in use, the more common being shown in Figs. 13, 14, 15, 16 and 17.

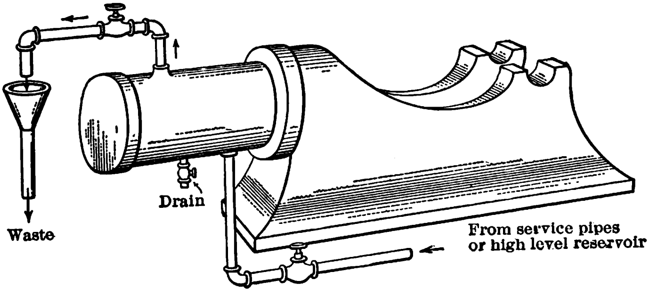


Fig. 14.

The type illustrated in Fig. 14 is that commonly used on stationary engines when water is available under pressure, as from service pipes, or from an elevated tank, or from a reservoir on a hill. The cooling liquid generally runs to waste and this method is therefore only applicable when large quantities of water are available at low cost. It is obviously unsuited for use with oil.

In Fig. 15 is shown what is commonly called the *tank method* of cooling which may be used with water or with oil. The temperature of the liquid in the jacket is raised by the heat given it by the hot gases in the cylinder. This causes the liquid to expand and therefore to weigh less than a corresponding volume of cool liquid in the tank. Some of the latter, therefore, flows downward into the jacket and replaces the warmer liquid which rises into the tank. In this way a constant circulation is maintained in the direction indicated by the arrows in the illustration.

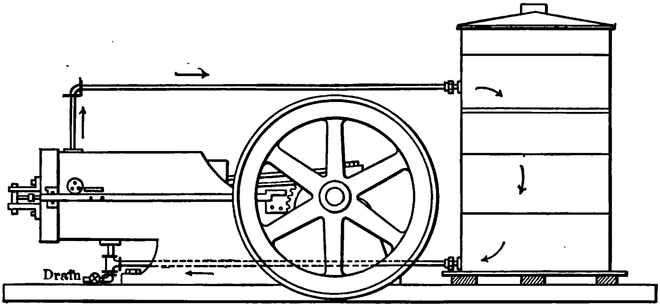


Fig. 15. — Tank Cooling.

When an engine which is cooled in this way is first started the liquid in the system is naturally cool, generally at a temperature near that of the air. As operation continues the liquid brings into the tank more and more heat and thus the temperature of the liquid within the tank and the temperature of the tank walls are increased. But as the temperature of the walls is raised they lose heat more and more rapidly to the surrounding air. It thus results that a temperature is finally attained at which the tank loses just as much heat as is brought in by the liquid, the liquid dropping from the top to the bottom as its temperature is decreased. If the tank is too small for the engine its walls will have to be heated to too high a temperature before they can lose heat fast enough to balance that brought in. They will, therefore, not cool the liquid to a sufficiently low temperature and the engine will be imperfectly cooled. It is, therefore, obvious that large tanks are desirable and that they must vary with the size (horse-power capacity) of the engine. If the engine is to be readily transportable, however, the tank must be of small size in order to decrease the weight of the outfit.

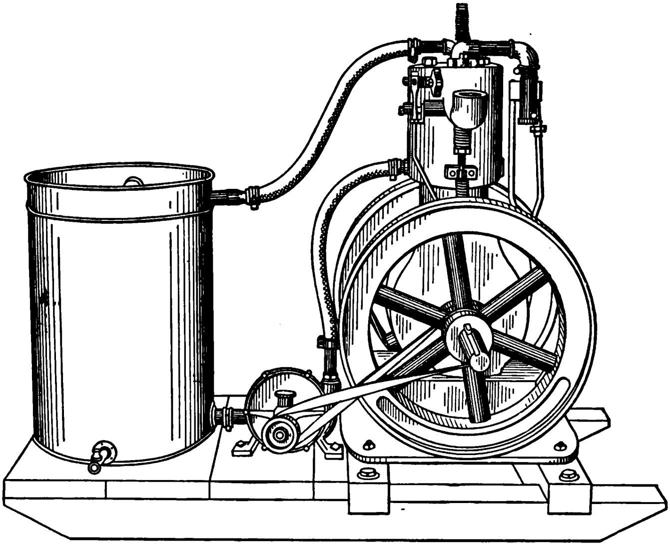


Fig. 16 (*a*).

In Figs. 16 (*a*) and (*b*) are shown two examples of somewhat similar types which are very commonly used in agricultural work. The circulation is maintained by a pump which is driven by the engine itself so that the amount of liquid circulated varies with the speed of the engine. The type illustrated by Fig. 16 (*a*) might be used with oil or water since none of the cooling liquid need be lost. The type illustrated in

Fig. 16 (*b*) should, however, only be used with water because some of the liquid will always be lost by evaporation at the point where it flows over the screen. In fact, the cooling is largely due to evaporation at this point. Water and all other liquids absorb large quantities of heat when evaporating, and in the case in question the greater part of this comes from that part of the liquid which does not evaporate. The latter is, therefore, cooled by the evaporation of the rest.

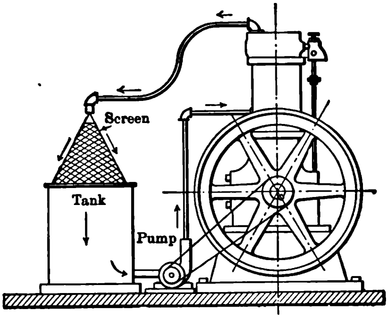


Fig. 16 (*b*).

The method shown in Figs. 17 (*a*) and (*b*) is the simplest of all liquid-cooling systems and is particularly adapted to give a water-cooled engine which is readily portable. There are no pipes and pipe joints and there is no auxiliary tank, the entire system being part of the engine and therefore self-contained. This method is called *hopper* or *open-jacket cooling* and an engine so fitted is called a *hopper-cooled* or an *open-jacket engine*.

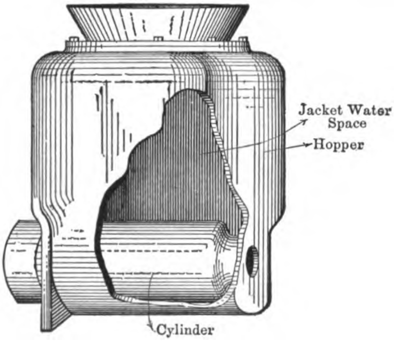
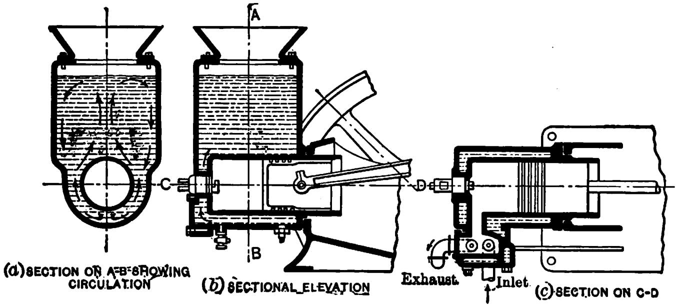


Fig. 17 (*a*).

In the same way engines fitted with cooling arrangements such as those previously discussed are sometimes spoken of as *closed-jacket* engines.

When an engine of the hopper-cooled type is working at light loads the water is heated only to a moderate temperature, but as this warm water is exposed in the hopper there will be a gradual evaporation from its surface. When the engine is working at maximum capacity the water generally boils in the hopper and the loss is fairly rapid. In a way, this is a disadvantage, as the water has to be replaced, but, from another point of view, it is a good feature, as it *requires a very large amount of heat to convert water into steam* in comparison with what is required simply to heat the water. Each pound of water which leaves the hopper as steam carries with it about fifteen or more times as much heat as would be required merely to raise its temperature, so that it



(a) SECTION ON A-B SHOWING CIRCULATION (b) SECTIONAL ELEVATION (c) SECTION ON C-D

FIG. 17 (*b*).

rose up around the cylinder, found its way into the hopper, was gradually cooled and returned to start again as indicated in the sketch in Fig. 17 (*b*).

It is obvious that the smaller the volume of water contained in the jacket and hopper of an engine of a given horse power the sooner will the water boil away to such an extent that it will be necessary to refill the system. Engines are generally supplied with jacket spaces and hoppers of such a size that they can operate at full load for several hours without requiring refilling.

The liquid-cooled engine has several *advantages*, principal among which are the easy control of engine temperatures and sure prevention of overheating excepting in case of the greatest negligence. They have the *disadvantages* of being heavy, of involving the necessity of supplying liquid, and of being subject to breakage, in the case of some water-cooled types, if the water in the jacket is allowed to freeze. In connection with the last statement it should be observed that a hopper-cooling system can be so constructed that no damage will result from freezing.

When water-cooled engines with closed jackets are to be used in very cold weather or must be allowed to stand idle for periods of time when the air temperature is below freezing it is customary to use "nonfreezing" or "antifreezing" solutions in the jacket.

A mixture of one part of alcohol to eight parts of water does not freeze above fifteen degrees above zero.

By the addition of glycerine the freezing temperature can be lowered still further, some mixtures of this character remaining liquid at twenty degrees below zero.

Calcium chloride dissolved in water gives solutions which can be subjected to very low temperatures and which are therefore often used in water-jacketed engines. By the use of about three and three-fourths pounds of commercial calcium chloride per gallon of water a solution which does not freeze at a temperature of thirty-two degrees below zero can be obtained.

There is one characteristic of water-cooled engines which should be noted. It is a matter of common experience that vessels in which water is heated or boiled gradually become coated with a *scale.* This scale is really formed of baked metallic compounds or "salts" which were originally present in solution (dissolved) in the water and were thrown out of solution as the water was heated or boiled.

The same sort of thing will occur in the jacket of the engine if the water used contains any such compounds in solution. Practically all water available, except rain water, does contain such compounds and hence scale may be expected to form in the jackets of most gas engines. This scale is a very poor conductor of heat and when deposited on the jacket side of the walls surrounding the burning gases it very materially interferes with the cooling of those walls. In cases where the scale is allowed to accumulate it may be responsible for serious trouble in the form of preignitions or even broken cylinders and pistons.

To guard against difficulties arising from the deposit of mud and scale in the jacket space, the engine should be so constructed that the interior of this space is easy to get at. An example of the method used is shown in Fig. 134, the open handhole giving access to the jacket space.

AIR-COOLED ENGINES.

When an engine is to be air cooled, provision is made to create a draft of air about the cylinder end of the engine, the cylinder and head being so arranged as to most readily give up heat to the air. Air-cooled engines may be roughly divided into two types: those which have natural draft or circulation of air and those which have forced draft or circulation. An example of the latter type is shown in Fig. 18, the natural-draft type being similar but not being supplied with a fan.

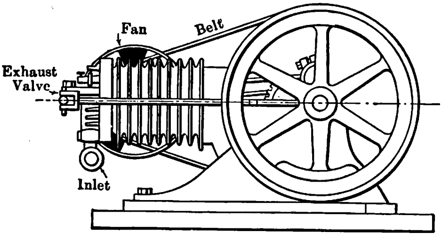


FIG. 18.

The ribs shown are generally cast on the cylinder. Their functions are twofold — they expose considerably more surface to the cooling air than would a plain cylindrical surface and they serve to guide the cooling air and to break it up into thin streams which can be most effective in cooling.

Air cooling possesses several *advantages*, giving a lightweight and simple engine and one which can be operated in regions where water is very scarce or heavily laden with impurities. It is also impossible to damage an air-cooled engine by frost.

On the other hand, the degree of cooling is not in general so well under control as in the case of water-cooled engines, being, to a great extent, dependent upon the load carried and upon the weather. Experience has shown that air cooling can be applied to small cylinders only, seldom being used on cylinders with a diameter of more than about eight inches.

Air-cooled engines, when properly constructed and not of too large a size, may be made to operate perfectly satisfactorily, but they are very apt to overheat and to lose power if required to run for long periods at full load, particularly in inclosed spaces and on hot days. The loss of power is due to two causes.

(1) It has been shown that the power of a gas engine depends upon the amount of heat-carrying mixture which can be taken into the cylinder per cycle. Now it is a matter of common experience that gases expand when heated. A charge which would just fill the cylinder of an engine when cold will more than fill that cylinder when heated. If the cylinder of an engine operates at a high temperature the charge entering it is heated and hence less actual material, and therefore less heat, is taken in per cycle and less work is done. This appears as a loss of power in the real engine.

(2) As an engine heats up, the diameter of the piston and the diameter of the cylinder both increase, but experience shows that the diameter of the piston increases more rapidly than does that of the cylinder. As a result the piston becomes a tighter fit in the cylinder and the friction loss increases. This loss is also often increased by failure of the lubricating oil at high temperatures. As the friction horse power increases the developed or shaft horse power decreases.

One may argue for water cooling or for air cooling with good arguments on both sides. The water-cooled engine must be regarded as standard, that is, as the more commonly accepted type, and it is most universally applicable. However, where only a small engine is required, where first cost is a weighty consideration, where the temperature often goes below freezing or where water is particularly bad the air-cooled engine should be considered. This is especially true if the work which the engine is to do is of an intermittent character so that it will not be necessary to operate at full load for long periods of time.

It is advisable to use engines with forced-air circulation only, as this insures more certain cooling. Some of the more recent models have ribbed cylinders inclosed in light metal jackets through which the fan forces air. This is obviously advantageous.

It should be noted that two-stroke engines cannot be as advantageously air cooled as can four-stroke engines with the same sized cylinders operating at the same speeds. This is because there are twice as many cycles in a given time in the two-stroke engine and therefore there is more heat to be carried away in a given time.

CHAPTER IX.

THE VALVE SYSTEM.

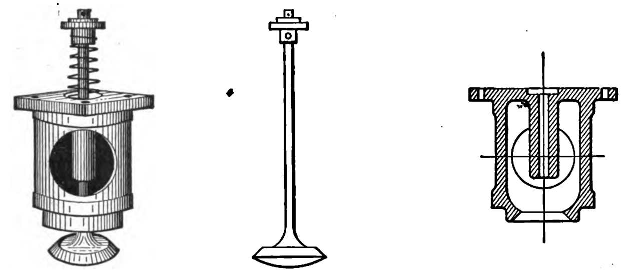
A FOUR-STROKE engine requires at least two valves, an *inlet valve* and an *exhaust valve,* as has already been shown.

These valves are practically always of what is called the *poppet* or *mushroom* type. They consist essentially of a circular plate or disk fastened to the end of a cylindrical rod or stem. They are held to their seats by springs which press against some fixed part on the engine and against a washer, plate or nut on the end of the valve stem. Several different arrangements are shown in Fig. 19.

Inlet valves may be opened "automatically" in which case they are called *automatic inlet valves,* or they may be opened by the pressure of mechanically operated levers or arms, in which case they are spoken of as *mechanically operated inlet valves* or simply *mechanical valves.*

The so-called automatic valve is really not automatic in a strict interpretation of that word. It is really pushed open just as is the mechanically operated valve. In this case, however, it is air pressure which does the pushing instead of metallic parts of the engine. An explanation of the way in which this occurs is best given in connection with some of the lines of an indicator diagram. We shall start with the piston at the outer dead center just after the completion of an expansion stroke, as shown dotted in Fig. 20. The exhaust valve is open and the cylinder is filled with burned gases which must be expelled. It will be found in the case of any real engine that the pressure inside of the cylinder during the exhaust stroke which follows is *higher than the pressure of the atmosphere outside.* This is shown in the indicator diagram of Fig. 20 by drawing a horizontal line *hi* at the proper height to represent atmospheric pressure and then drawing an exhaust line *de* higher up.

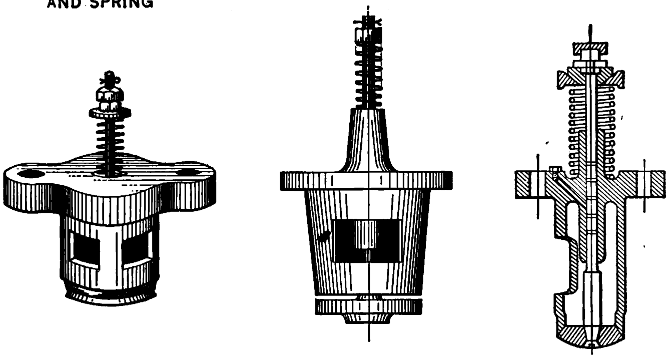
The reason for this difference of pressure is easily explained. It is a matter of common experience that it requires a difference of pressure to force liquid or gas through a small opening. Thus the pressure inside a hose must be higher than the pressure of the atmosphere outside to force a stream of water to flow out through a nozzle on the end of that hose, and the smaller the nozzle the greater must be the pressure difference to discharge the same amount of water. Or, when a bellows is used to make a jet of air issue from a



(*a*) ASSEMBLY OF VALVE, CAGE AND SPRING

(*b*) VALVE

(*c*) VALVE CAGE



(*d*) FLAT PLATE CONICAL SEAT

(*e*) FLAT PLATE AND SEAT

(*f*) DOMED PLATE CONICAL SEAT

FIG. 19. — Types of Valves and Cages.

nozzle the sides of the bellows are pressed together, raising the pressure within to a value greater than that outside, *i.e.*, that of the atmosphere.

It thus happens that when the piston arrives at the end of the exhaust stroke (shown by full lines in Fig. 20), and the exhaust valve closes, the clearance space within the cylinder is filled with burned gases at a pressure above that of the atmosphere. When the piston starts out again on the suction stroke this gas expands, its pressure dropping as the piston moves. This is shown by the short curve *ef* in the diagram. When the pressure has dropped far enough below that of the external atmosphere the automatic inlet valve is pushed open, against the action of its spring, by atmospheric pressure acting on the outside. This should occur just as soon as the pressure of the atmosphere outside of the valve becomes the least bit greater than the pressure of the spring combined with the pressure of the gas within the cylinder, both of which tend to keep the valve

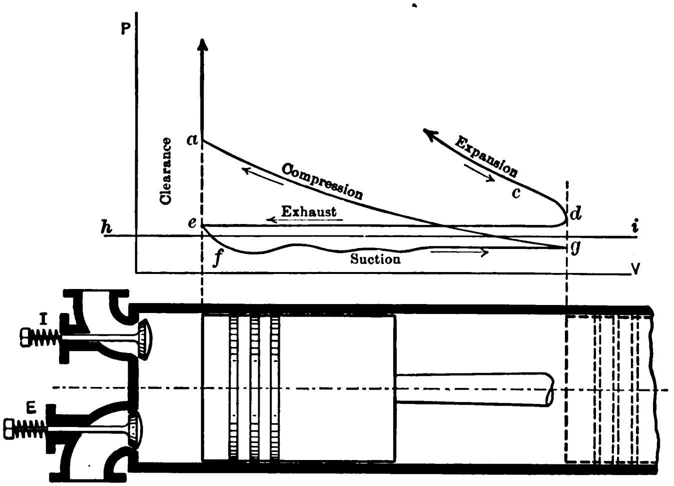


FIG. 20.

closed. In reality the valve has to be moved against friction, and it also takes a little time to start it moving, so that it never opens as soon as it should on theoretical grounds. After the valve is finally opened the charge can flow in.

It is found in real engines that such automatic valves do not open full and then stay wide open until the end of the stroke. Instead they "chatter," as it is called; that is, they open full, then close partly or entirely, then open wide again, then close once more, and so on. If they remained wide open during the entire suction stroke the opening through which the charge flowed would always be as large as possible and a very small difference of pressure on the two sides of the valve would be required to make the charge flow in. When the valve chatters, however, it is constantly changing the size of the opening, and when this is small it requires a greater pressure difference to cause flow. The net result is that the pressure varies, as shown by the wavy line in the figure, and the average pressure inside the cylinder during the suction stroke is lower than it should be. When the piston completes the stroke the cylinder has been filled with a mixture with pressure lower than it ought to have.

It is obvious that the greater the amount (weight) of any gas which is packed into a given space the greater will be the pressure in that space, and, hence, the less the pressure in a given space the smaller is the amount (weight) of gas that has been put into it. In the real engine, therefore, *the lower the pressure of the mixture within the cylinder at the end of the suction stroke the smaller is the amount of mixture that has actually entered that cylinder.*

It would seem as though this could be overcome by running the engine at a higher speed but this is only a partial, and a faulty, remedy. In the first place, the higher the speed of the engine the more imperfect will be the action of the automatic valve, so that the increase of power which is theoretically possible with increase of speed could be only partly realized. In the second place, there is some best speed for an engine of a certain size, the speed depending upon the size and weight of the parts of the engine. To run the engine at a greater speed may give increased power but it will also give more rapid wear and imperfect mechanical operation.

For reasons such as these the automatic-inlet valve is now generally used on the smaller and cheaper engines in which first cost and simplicity are more weighty considerations than power and efficiency. In such cases its use is amply justified.

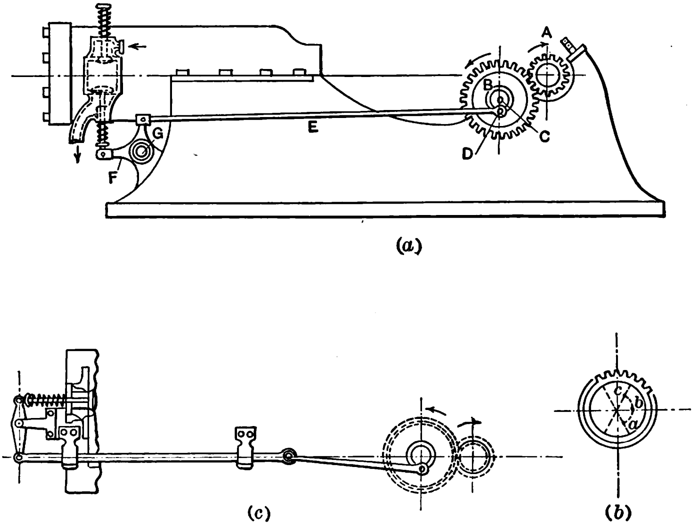
In the more expensive and the larger engines both inlet and exhaust are mechanically operated.

HALF-TIME MECHANISMS.

It is next necessary to note that in the case of four-stroke operation each of these valves is required to open but once in two revolutions. As the motion for mechanically operated valves is generally obtained from the crank shaft of the engine it is necessary to use some mechanism which, with two revolutions of the shaft, will cause but one (and not two) openings of each valve. This is accomplished by what is called a two-to-one mechanism or reduction, or a *half-time mechanism.*

One simple arrangement of two-to-one mechanism is shown in Fig. 21 (*a*) as applied to an exhaust valve. A small "spur" gear *A* is keyed to the crank shaft of the engine so that it revolves at the same speed as that shaft. Another gear *B*, with twice the diameter and twice the number of teeth possessed by gear *A*, is arranged, as shown, to mesh with *A* and to revolve about a pin *C* fastened to a convenient point on the frame of the engine. The large gear will obviously rotate only half as many times per minute as does the smaller. By means of a pin *D*, a rod *E* and a bell crank *F* pivoted at the point *G*, this gear can be made to operate the valve.

Suppose, for instance, that the pin *D* occupies a position shown by *a* in Fig. 21 (*b*), and that the arm of the bell crank is just touching the end of the valve stem. Further rotation of the gear, taking pin *D* from *a* toward *b*, will result in pulling the rod toward the crank end of the engine and will therefore pull the bell crank in such a way as to push the valve open. When the pin *D* gets to point *b* the valve will have been opened as far as possible because further motion of the pin (from *b* to *c*) will push the rod back toward the cylinder allowing the spring to gradually close the valve.



(*a*)

(*c*) (*b*)

Fig. 21. — Half-time Mechanism.

This is a very simple and very effective mechanism and is used in one form or another on a large number of engines.

A simple modification of this same general principle is used on another large group of engines. In these the pin *D* is not used, its place being taken by what is called a *cam*. Diagrammatic representations of this system are shown in

Figs. 22 (*a*), (*b*) and (*c*). The cam *D* may be regarded as a circular piece of metal with a raised portion or bump on its surface, as shown. In this case it is fastened to the larger gear so as to revolve with it. The operation should be evident from the illustrations without further explanation.

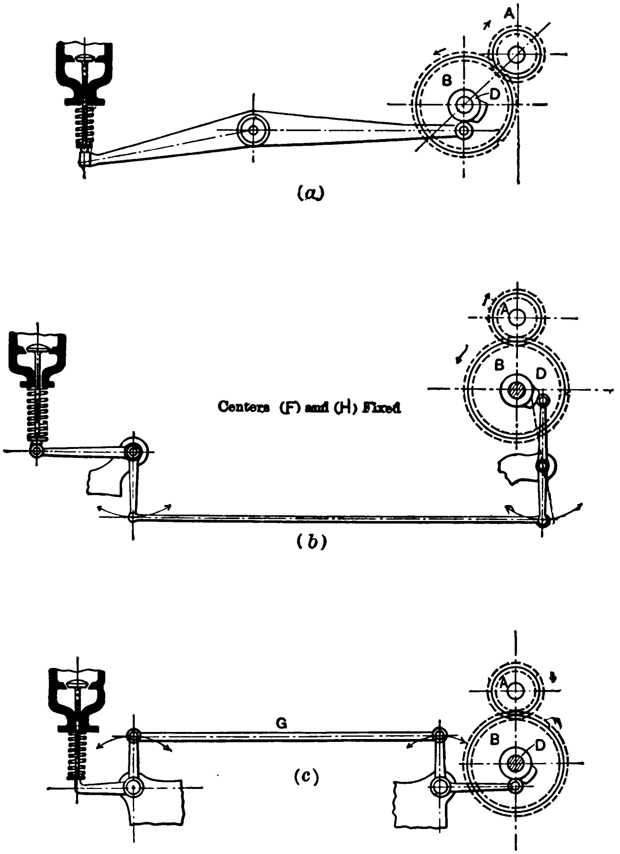


Fig. 22. — Half-time Mechanism.

Nearly all four-stroke gas engines which do not have one or other of the above types of valve-operating mechanisms or some simple modification of them are fitted with a "cam shaft," "lay shaft" or "*half-time shaft*" driven by what are called "spiral" gears. Such an arrangement is shown in Fig. 23.

The cam shaft runs along the side of the engine, being rotated at half the speed of the crank shaft by means of the gears. At the cylinder end it carries the necessary cam or cams to operate the valves. These cams are keyed or otherwise fastened to the cam shaft and rotate with it so as to operate on the valves through bell cranks or levers as shown.

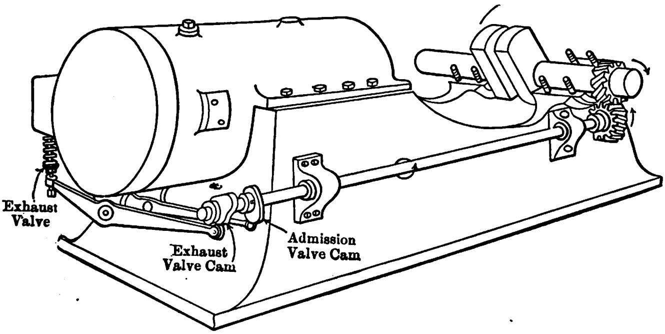


FIG. 23.—Showing Spiral Gear and Cam Shaft.

In Figs. 24 (*a*), (*b*) and (*c*) are shown valve-operating mechanisms for vertical engines which are similar to those just considered.

LOCATION OF VALVES.

The valves must, of course, always open into the clearance or combustion space of the engine. They may be so set that their *axis* is *vertical*, Fig. 25; *horizontal*, Fig. 26; or *inclined*, Fig. 27. In all cases vertical valves are best, although it often happens that because of convenience of arrangement or cheapness of construction horizontal or inclined valves are used instead.

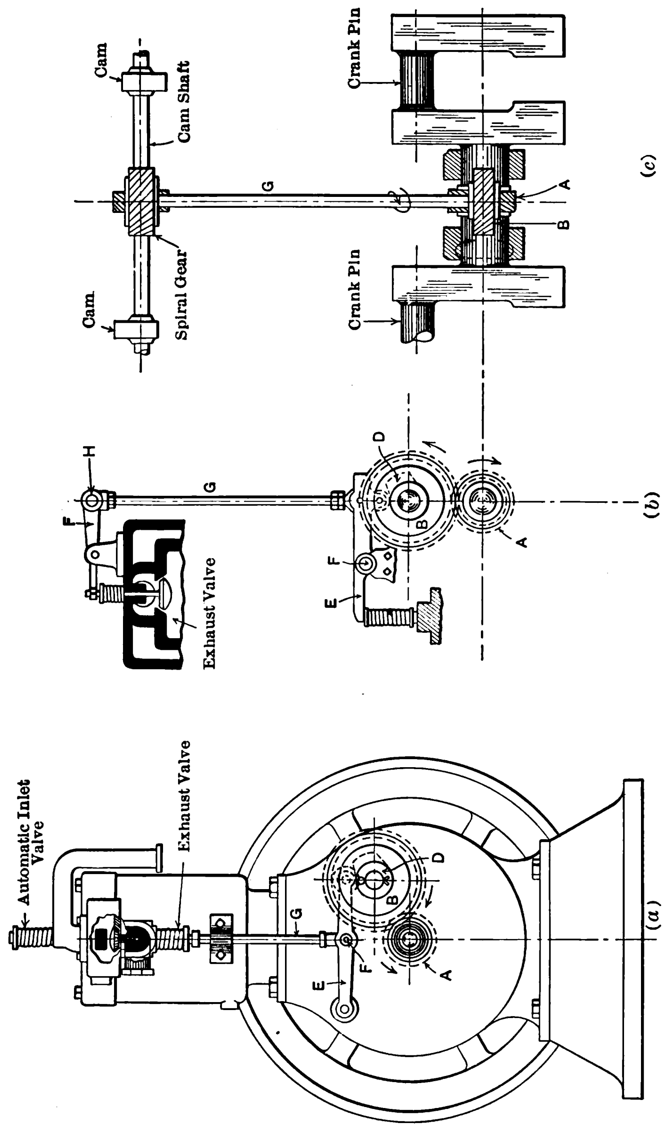


FIG. 24.—Types of Valve Mechanism for Vertical Engines.

The principal objection to horizontal valves is due to their tendency to rapidly wear out of true as shown in Fig. 28, so that they fail to seat properly under the action of the spring, the valve disk first striking one side of its seat.

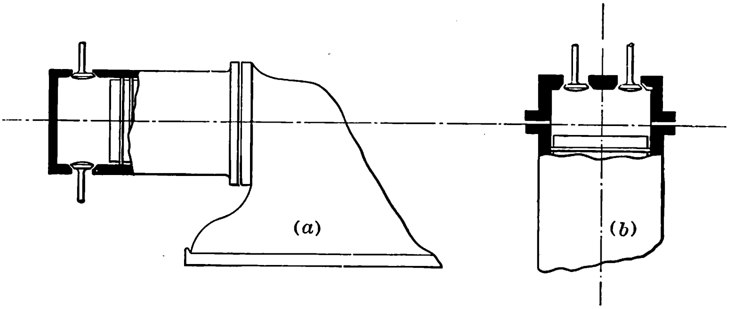


Fig. 25. — Vertical Valves.

The inclined valve is obviously midway between vertical and horizontal in properties as well as position. If it is not too greatly inclined it does not wear badly and is almost, if not quite, as satisfactory as one with vertical axis.

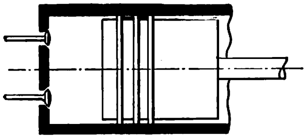


Fig. 26. — Horizontal Valves.

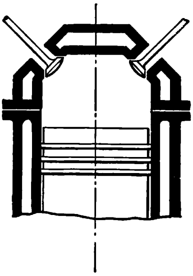


Fig. 27. — Valves set at an Angle.

As a general principle the farther the inlet and exhaust valves are separated the better. This is true chiefly because in real engines the inlet valve should be opened before the exhaust valve closes. The exhaust gases move by the exhaust valve at very high velocity and if this valve is allowed to remain open after the end of the stroke the gases will continue in motion for a while because of their own inertia (momentum). If the inlet valve is open at the same time the new charge may be coming in while the burned charge is blowing out with the result that the clearance space will be more or less completely filled with fresh charge instead of remaining full of burned gases.

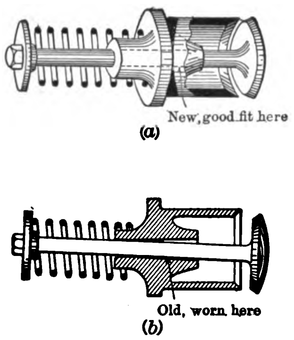


FIG. 28. — Horizontal Valve showing Wear.

Thus in Fig. 29 the new charge follows the burned gases toward the exhaust valve and if the latter is closed just as the first part of the fresh charge reaches it the action will be ideally perfect.

On the other hand, if the valves are arranged as in Fig. 30 it is obvious that there must be more mixing of new and old charges and that the cleaning or "scavenging" of the clearance cannot be as perfect as in the preceding case.

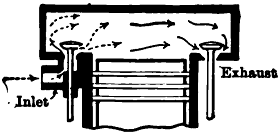


FIG. 29.

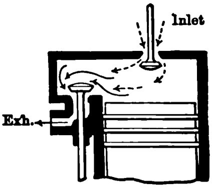


FIG. 30.

The arrangement shown in Fig. 31 is still worse, as practically no scavenging can be effected because the incoming charge would blow out through the exhaust valve as shown.

Unfortunately, separation of the valves generally leads to more expensive construction and is therefore not common in the lower priced engines. It generally involves a complication of the valve-operating mechanism, often necessitating duplication throughout, and the advantages of the arrangement are therefore obtained at the expense of simplicity as well as of added cost. For agricultural engines, which are generally of small power, too great weight should not be attached to the separation of the valves but if other things are equal that engine in which the valves are the more widely separated is the better.

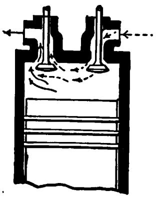


FIG. 31.

What is known as an *auxiliary exhaust* is occasionally used with four-stroke engines, particularly with those which are air cooled. This auxiliary exhaust is really an additional exhaust valve consisting of ports in the cylinder wall which are uncovered by the piston at the end of the stroke in just the same way as the ports are uncovered in two-stroke engines. The arrangement is shown in Fig. 32. It has the advantage of allowing the greater part of the hot gases to blow out of the cylinder at the end of the exhaust stroke through the large ports instead of requiring all of these gases to pass the exhaust valve. The quantity of hot gases passing the exhaust valve and the quantity and temperature of the gases in contact with the cylinder walls during the return (exhaust) stroke are therefore decreased and there is less tendency to heat the valve and cylinder.

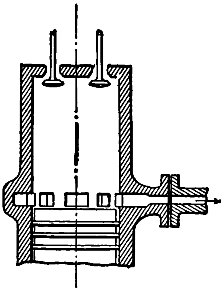


FIG. 32.

Water-cooled engines with auxiliary exhausts always give slightly less power (5 to 8 per cent less) than do ordinary engines of the same bore and stroke running at the same speed. This is probably due to the sort of thing that has already been considered in the case of two-stroke engines (see p. 37); the effective stroke is less than the real stroke by the amount of the latter which is used in covering the exhaust ports.

In air-cooled engines, however, the case may be reversed. The cooling effect is sc great that it may overbalance the loss above mentioned and result in giving greater power for the same piston displacement. This is particularly apt to be the case with comparatively small engines operating at high speeds.

VALVES IN TWO-STROKE ENGINES.

The simplest two-stroke engines have no valves of the type used in those operating on the four-stroke principle, all valve events being controlled by the uncovering of ports by the piston. In reality the piston serves as a huge slide valve similar to the slide valves used on steam engines. An engine in which all events are controlled by the piston (three-port engine) was shown in Fig. 9.

The next simplest arrangement is that already shown in Fig. 8 in which inlet to and exhaust from the cylinder are controlled by the piston, and the inlet to the crank case is cared for by an automatic poppet valve.

There is still another type of valve arrangement for two-stroke engines which is shown diagrammatically in Fig. 33, the arrows in which indicate the movement of gases at various parts of the cycle and should not be understood to represent conditions existing at the same time. In this case the exhaust only is controlled by the piston. Inlet to crank case is effected by an auto-

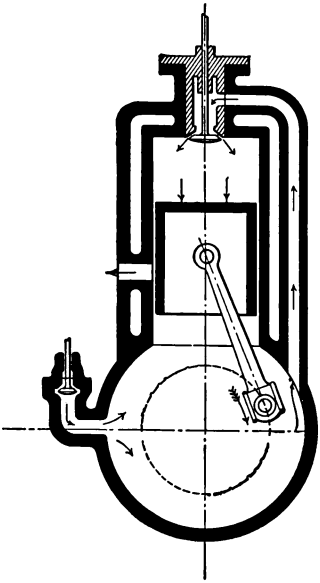


FIG. 33.

matic inlet valve as before. Inlet to the cylinder also occurs through an automatic-inlet valve at the head of the cylinder. This arrangement is naturally a little more expensive than those which have already been described but it possesses a certain advantage. The incoming charge has to travel the entire length of the cylinder before any of it can blow out through the exhaust ports and it travels approximately like a solid piston of fresh gas driving the burned gases before it.

CHAPTER X.

COMPARISON OF TWO-STROKE AND FOUR-STROKE OPERATION.

In general, the two-stroke engine is cheaper and mechanically simpler than the four-stroke engine because of the following:

(1) A given power can be obtained with smaller piston displacement (hence with a smaller and cheaper engine) because there are twice as many cycles per minute as there are in four-stroke operation. It has already been shown that a two-stroke engine will give from 1.3 to 1.7 as much power as a four-stroke engine with the same bore and stroke when operating at the same speed. For the same power the piston displacement will be from

$$\frac{1}{1.3} = 0.77 \quad \text{to} \quad \frac{1}{1.7} = 0.59,$$

or, say, from about eight tenths to six tenths that of a four-stroke engine.

(2) There is no half-time mechanism necessary, even if mechanically operated valves are used and this is seldom the case.

(3) No valve-operating cams, levers and such are commonly used.

(4) No poppet valves with springs are necessary, and even if used they are of the very simplest type.

(5) There is little to wear as the engine is reduced to the very smallest number of parts.

(6) There is little to get out of adjustment, a given setting of valve events lasting practically as long as does the engine.

On the other hand, two-stroke operation is always *less efficient* and often *more sensitive* to improper proportions of mixture than is four-stroke operation.

The lower efficiency, that is, the smaller amount of power from a given quantity of fuel, comes largely from the blowing of unburned fuel through the exhaust ports and from the excessive quantity of burned gases which are retained in the cylinder and remain mixed with the new charge.

The sensitiveness is due to the method of operation, an over-rich mixture (too much fuel) or a weak mixture (too little fuel) almost always registering immediately by "back firing" or even the stopping of the engine. This is due largely to the fact that both rich and lean mixtures burn very slowly and it often happens that the charge is still burning in the cylinder when the inlet port is opened. When this happens the incoming charge is immediately ignited and burns, partly as it enters the cylinder and partly in the crank case. The fact that such burning is occurring is generally made very evident by decided knocking and similar sounds. It is known as "back firing," "crank case explosions," etc. If the engine has a heavy flywheel and is not carrying a very heavy load it may continue to operate if the mixture is not too poor, back fires occurring spasmodically but not so often that the cylinder does not receive sufficient fuel to continue in operation. If the mixture is poorer than this the engine will probably stop, for the simple reason that the charges burn in the crank case and not in the cylinder.

Back firing of this kind can be partly or wholly prevented by the use of wire cloth or other form of perforated metal in the bypass between crank case and cylinder. Obstructions of this kind absorb the heat from any gases which may burn in the bypass and thus prevent the transmission of flame to the charge which is still in the crank case.

The four-stroke engine, if properly built, should always be more complicated, more expensive and more difficult to keep in adjustment than the two-stroke engine. On the other hand, it makes up for these disadvantages by being more efficient and less sensitive to poor mixture and maladjustments of all kinds.

A good four-stroke engine developing the same power as a good two-stroke engine should do so with a fuel consumption of from one-half to three-quarters that of the latter.

When required to run on a variable load the four-stroke engine is, in general, far superior to the two-stroke, as it is less apt to stop because of mixture and similar troubles.

Thus one cannot say that the one or the other type of engine is the better. Each person must decide for himself after studying his needs and the characteristics of the different engines. The way in which such a decision should be made can best be shown by a few samples.

Assume that a small pump is to be operated under absolutely constant conditions as to quantity and head. Either type of engine can do this work satisfactorily. A good four-stroke engine should cost more than a two-stroke engine of equal quality. The four-stroke engine will use less fuel than the two-stroke.

If the pump is to be operated for twenty-four hours a day every day in the year, the four-stroke engine will save enough in fuel in a very short time to more than pay for its additional cost. If the pump is to be operated an hour or two a day for a few weeks per year, the cost of fuel is negligible and the cheaper, less efficient engine will probably give the best financial results.

As another example assume that a man is equipping a tractor with a single-cylinder engine. The engine must be able to operate successfully over a wide range of loads with the minimum of adjustment. For such a case the four-stroke engine is superior to one operating on the two-stroke principle.

CHAPTER XI.

CARBURETERS.

In previous chapters it has been shown that the engine operates because it receives a mixture of fuel and air. When the fuel is a gas the formation of such a mixture is very simple; the gas need only be piped to the engine, and allowed to mix with the air as it enters. When, however, the fuel is a liquid the case is not so simple. A mixture of liquid and air might be made but it would not burn properly. For satisfactory operation the *mixture must consist of air and vaporized fuel.*

It follows that some means of forming this mixture must be used, and all real liquid-fuel engines are fitted with a device for this purpose. Such devices are variously known as *generating valves, vaporizers, carbureters, mixing valves* and such, depending upon their method of operation or the choice of their designer.

We shall consider first the appliances which are used with very volatile fuels, such as gasoline, and shall designate them all as carbureters.

Gasoline Carbureters.

Practically all carbureters now in use with gasoline operate by squirting a jet of liquid gasoline into the air on its way to the engine and they may therefore be called *jet carbureters.* A simple example of a jet carbureter is shown in Fig. 34. The gasoline is maintained at the level shown in the tank *T* by any convenient means and it therefore rises in the nozzle *N* to the same height. This nozzle is located in the air pipe leading to the inlet valve of the engine as shown. During the suction stroke the pressure in this pipe is slightly lowered by the action of the engine piston and the pressure immediately above the nozzle is still further lowered by the air rushing past that nozzle in a way which need not be explained in a book of this scope. As a result the air pressure acting on the surface of the liquid in tank *T* causes a small jet of gasoline to squirt out of the nozzle and into the air on its way to the engine. This jet of gasoline vaporizes (or evaporates) very quickly and the vapor formed mixes with the air to form the combustible mixture. In some cases, particularly when an engine is operated at high speed, the liquid may not be entirely vaporized by the time it passes through the inlet valve and into the cylinder, but this will generally not cause trouble as the hot walls of the cylinder heat the mixture during suction and the temperature is still further increased during the compression stroke. The heat added in this way makes evaporation very rapid and, under ordinary circumstances, all of the gasoline will be vaporized and mixed with the air before the end of the compression stroke.

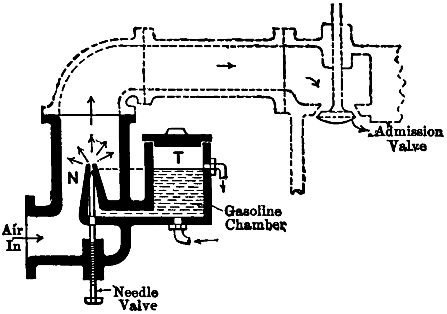


Fig. 34. — Simple Jet Carbureter.

It is a matter of common experience that it takes heat to vaporize water. This is observed every time water is converted into vapor (steam) in a kettle. In the same way it takes heat to vaporize any liquid and the gasoline vaporizing n the carbureter and pipe leading to the inlet valve is no xception to the rule. Under ordinary conditions of tem- erature in moderate climates a large amount, if not all, f this heat can be taken from the air flowing through he carbureter and from the walls of the pipe leading to the ngine. In very cold weather, however, the removal of the ecessary quantity of heat from the air may not be possible nder carbureter conditions and much of the fuel may pass nto the engine unvaporized. As already indicated, this is ot apt to cause trouble unless too much enters in this way ut it is found that for cold weather some method of sup- lying additional heat is desirable. This heat can be sup- lied in two ways; the air may be preheated (heated before ntering the carbureter) by drawing it over the hot exhaust ipe; or, the carbureter and its contents may be heated by unning some of the hot jacket water from the engine through jacket cast around the carbureter. Such devices are par- icularly useful on automobile and similar high-speed engines ut are seldom necessary on well-built stationary gasoline ngines excepting in the coldest weather.

Jet carbureters may be conveniently divided into three ifferent types depending on the method used for feeding e fuel to the needle valve. They will hereafter be called *uction-feed, Pump-feed* and *Float-feed Carbureters,* though should be understood that these names are merely adopted ere for convenience and are not all commonly used by the ade.

A suction-feed jet carbureter is illustrated in Fig. 35 in nnection with an engine. The gasoline is stored in a nk below the level of the carbureter. As a matter of nvenience this tank is often placed inside the frame of e engine as shown but it may be located in any other sirable place.

The air pipe surrounding the gasoline nozzle is generally ntracted (made of smaller diameter) in the neighborhood the nozzle, the smallest diameter being at or just above the nozzle opening. The air rushing through the narrow pipe has to travel at greater and greater speeds as the diameter decreases and this causes a greater lowering of pressure opposite the end of the nozzle. When the parts are properly proportioned the pressure is lowered to such an extent that the air pressure on the surface of the gasoline in the tank can force the fuel up to and through the nozzle. The carbureter then acts as its own pump and is ordinarily said to suck up the gasoline which it needs.

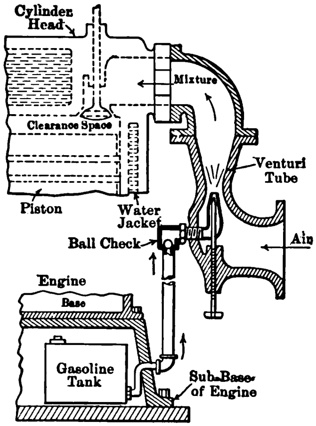


Fig. 35. — Suction Jet Carbureter.

The ball check valve shown near the top of the gasoline pipe serves to keep the pipe full of fuel when the engine is in operation so that only as much as is used by the engine need flow up the pipe each cycle.

The contracted part of the air pipe is called a *venturi tube* and is often used on carbureters of other kinds as a means of obtaining a finer spray and thus assisting vaporization. In practically all carbureters the flow of gasoline is controlled by a needle valve such as shown in Fig. 34 and those which follow. The more nearly this is closed the finer it will break up a given quantity of liquid flowing through it, but the smaller the opening the greater is the pressure difference required to force a given quantity of liquid through. By using a venturi tube a very great drop of pressure can be produced opposite the end of the nozzle and the needle valve can therefore be more nearly closed. The high velocity at the throat (narrow part of venturi tube) also assists in breaking up the liquid, the gasoline being practically torn apart as it is seized and dragged along by the current of air.

A typical example of a pump-feed jet carbureter is shown in Fig. 36 (*a*). The gasoline is stored in a reservoir conveniently located and is forced up to the small reservoir by means of a small plunger pump driven by the engine. The pump raises more gasoline than is required by the engine and the small reservoir is fitted with an overflow pipe so that the excess drains back to the large storage reservoir. In this way the level of gasoline in the small reservoir is maintained constant and just below the level of the top of the nozzle. The flow of fuel from the nozzle is produced by lowering the pressure opposite the tip as already explained and the quantity flowing out is controlled by the needle valve shown.

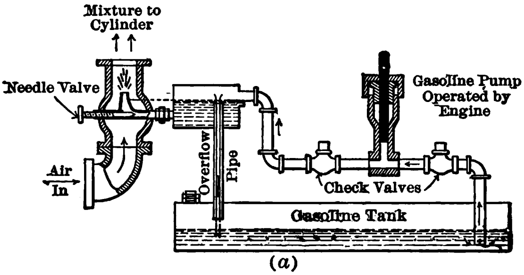


FIG. 36 (*a*).—Forced Feed Carbureter.

The air pipe may or may not be contracted into a venturi tube at the nozzle, but the use of the venturi tube will generally give better results.

Another form of forced feed is shown in Fig. 36 (*b*), combined with a different type of jet carbureter. This form of carbureter is often called a carbureting valve or a generator valve. The gasoline is stored in a tank at higher level than the carbureter, as shown in full lines, or in a tank at lower level with air compressed above the liquid, as shown in dotted lines.

The reservoir is connected to a small opening in the seat of the poppet valve *V* and as long as this valve remains closed no flow can occur. The valve opens "automatically" during the suction stroke of the engine and thus unseals the gasoline opening. Fuel then flows out and mixes with the air on its way to the engine cylinder, the quantity being controlled by the setting of the needle valve shown in the illustration.

Such carbureting valves are most often used with two-stroke engines of the type shown in Fig. 8, being installed in place of the crank-case valve. They are, however, occasionally used with four-stroke engines either as a second valve in the inlet pipe or by making the carbureting valve and the inlet valve one.

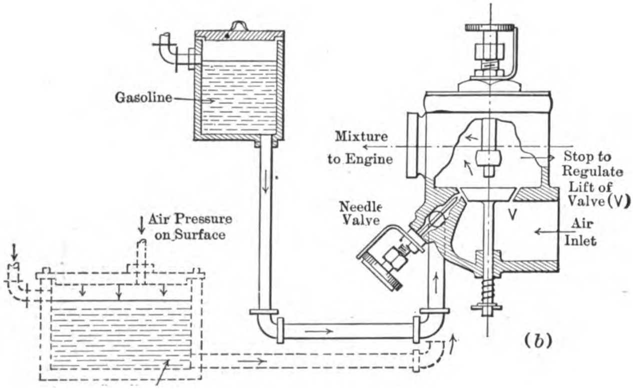
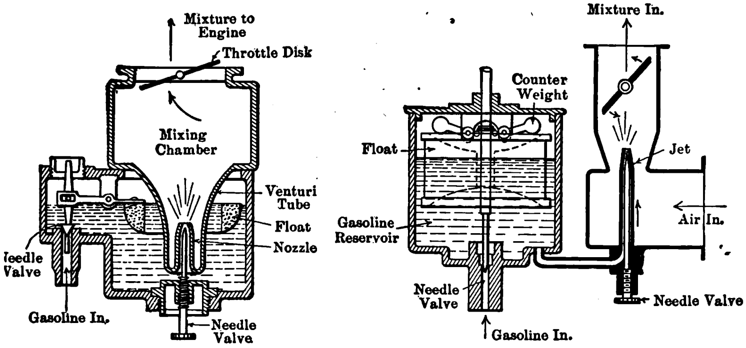


Fig. 36 (*b*).

Typical float-feed carbureters are shown in Fig. 37 (*a*) and (*b*). The fuel is fed to the float chamber through the opening controlled by the float needle valve. It may be supplied from an overhead tank, from a tank under air pressure or by means of an overflow tank such as has already been described. The float serves to maintain the proper level of fuel in the float chamber and hence at the nozzle. It does this by rising and sinking with the level of the fuel in that chamber and thus closing or opening the float needle valve as necessary. The action of the rest of the carbureter will be apparent from what has preceded.

An ordinary stationary gasoline engine generally runs at approximately constant speed and the carbureter is adjusted by closing the needle valve as far as possible without decreasing the speed of the engine when operating at a high load. It will then generally operate satisfactorily, though not necessarily most economically, at other loads. In some cases it may be necessary to again adjust the needle valve whenever the load on the engine changes greatly.



(*a*) (*b*)

FIG. 37. — Types of "Float-feed" Carbureters.

With automobile and similar engines which are required to operate at very variable speeds the adjustment of a carbureter is a far more difficult thing. For instance, if the needle valve of most simple carbureters is properly set when the engine is running at a low speed, it will be found that the engine gets too rich a mixture (too much fuel) when running at a high speed. This is due to the fact that the flow of fuel from the nozzle depends upon the lowering of the pressure opposite that nozzle. When the engine is operating at a high speed much more air flows by the nozzle in a given time than when the engine is operating at a low speed; that is, the velocity of the air around the nozzle increases with speed. But it has been found that the lowering of pressure increases more rapidly than the air velocity, so that as the speed goes up the pressure goes down too fast and too great a quantity of gasoline flows out of the nozzle.

This difficulty is most commonly overcome by the use of what is called *auxiliary air*. This is merely air let into the inlet pipe on the engine side of the carbureting nozzle. Obviously the more air that is admitted in this way the less need flow by the nozzle, and thus the use of auxiliary air decreases the velocity of air around the nozzle and hence decreases the flow of fuel.

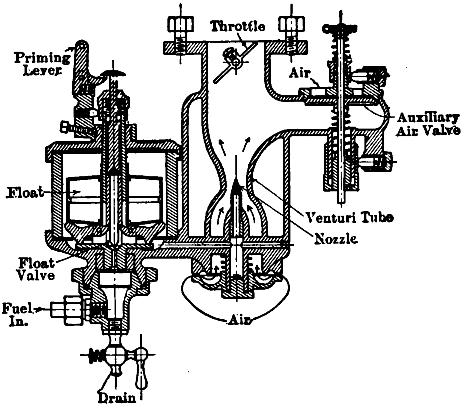


Fig. 38. — Stromberg Carbureter "Type A."

The admission of auxiliary air is generally controlled automatically by the carbureter. There are two characteristic methods of doing this; one may be called the spring-controlled-valve method and the other the ball-valve method.

The first of these as applied in a real carbureter is shown diagrammatically in Fig. 38. When the engine is running slowly the lowering of pressure within the carbureter is not sufficient to cause the atmospheric pressure to push the auxiliary valve open against the action of its spring. At higher speeds, however, the valve opens more and more, thus preventing the excessive flow of air by the needle valve and preventing the formation of an over-rich mixture.

Such carbureters are adjusted by regulating the needle valve for best operation when the engine is running at a low speed, and then regulating the tension of the auxiliary air-valve spring with the engine operating at high speed.

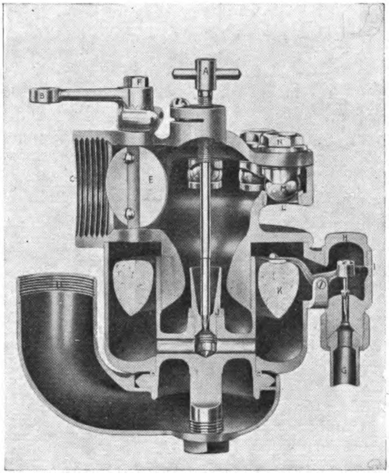


FIG. 39 (*a*). — Section, Kingston Carbureter.

The ball-valve method is shown in Fig. 39. The balls are of different weights, the lightest rising first as the lowering of pressure begins to exceed the desired value and the others rising in succession as the speed increases, so that when running at maximum speed all are open and the quantity of auxiliary air is greatest.

A great number of other forms of carbureters have been designed to meet the conditions imposed by very variable speed and it is impossible to consider all of them in a book of this scope. When met in actual practice they must be studied individually and their characteristics must be determined by more or less accurate experimenting in connection with the engine to which they are attached.

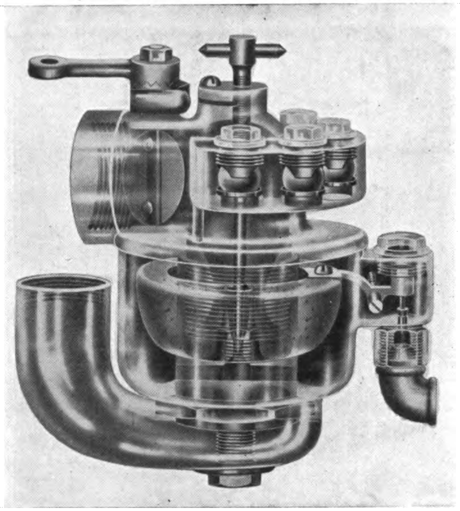


FIG. 39 (*b*). — Ghost View of Kingston Carbureter.

USING KEROSENE AND DISTILLATE.

Gasoline is, in one way, an ideal fuel for internal-combustion engines because it vaporizes so readily, under ordinary conditions, that the required mixture of air and fuel vapor is very easily formed. On the other hand, it is *expensive* in comparison with other available fuels, and the readiness with which it forms an explosive mixture makes it a more dangerous fuel than some of the cheaper petroleum products.

Kerosene and distillates are *low priced* and *much safer* but they are handicapped by the fact that they do not vaporize as easily as gasoline and that it is, therefore, *more difficult to form a proper mixture of fuel and air.*

If kerosene is supplied to an engine by means of an ordinary jet carbureter, operated as it would be with gasoline, very little vaporization of the fuel will occur outside of the cylinder. The liquid will be carried along by the air in the form of small drops. When this mixture finally passes the inlet valve the heating effect of the hot metal walls of cylinder and piston will cause at least a partial vaporization of the drops of liquid. Such vaporization may continue during the entire suction and compression strokes, being assisted during the latter by the heat generated by compression of the air inclosed within the cylinder.

If conditions happen to be just about right vaporization may be practically complete by the time the end of the compression stroke is reached and the engine may operate satisfactorily on kerosene. Most gasoline engines of good design which are fitted with good forms of jet carbureters can therefore be operated on kerosene, provided the conditions are such as to cause satisfactory vaporization within the cylinder.

When engines of this kind are operated on a moderately steady load, which is greater than about one third and less than about three fourths of the rated power, they will generally give satisfactory results with kerosene if the quantity of jacket water flowing is properly regulated. If the load is very variable, or if it is steady but too low, or steady but too high, unsatisfactory operation will generally result.

The difficulties met may be one, or both, of the following:

(1) The engine cylinder, valves and piston become fouled with carbon and tar or pitch and the exhaust becomes very dirty instead of being clean and clear, and

(2) The engine "knocks" violently toward the end of the compression stroke or even slows down and comes to rest.

These troubles come partly from inability to maintain the proper wall temperatures at all loads and partly from certain properties of liquid petroleum fuels which are more marked in kerosene than in gasoline and which result in the breaking up of the fuel within the cylinder to form carbon and the tarry or pitchy materials. In a book of this scope it is impossible to enter into a consideration of the theory of the action of the various fuels within the cylinder, but it is deemed advisable to point out some of the things which experience has taught and to indicate some of the means which have been invented for improving the action of the heavier fuels when used with the carbureting engine.

Past constructions and experiments have shown that if any drops of liquid remain unvaporized at the end of the compression stroke, trouble is sure to follow, because the material composing these drops cannot be properly vaporized and burned during the combustion period. The outer layers of the drops vaporize and burn; the inner layers "crack," that is, break up to form carbon, pitchy or tarry liquids and other products. This results in a fouled engine and a smoky exhaust.

Anything which will prevent the existence of liquid fuel in the cylinder at the end of the combustion period should remove this sort of trouble. Three different methods of doing this have been tried with carbureting engines, either singly or in combination. They are:

(1) *Spraying the fuel much finer than gasoline is ordinarily sprayed,* thus making each drop so small that a small amount of vaporization will suffice to convert all of it into vapor. In the case of a large drop the same amount of vaporization would merely remove the outer layer and would leave the core still liquid.

(2) *Heating the liquid* by means of hot jacket water or exhaust gases before spraying, thus expediting the vaporization of the material. This effect can easily be appreciated if it is remembered that if heated to a high enough temperature the liquid could be made to boil away rapidly in the atmosphere.

(3) *Heating the air supply* by means of the hot exhaust gases, thus expediting vaporization.

When any, or all, of these methods are used it is found that there is apt to be spontaneous or auto-ignition of the charge toward the end of the compression stroke on heavy loads, giving rise to a very distinct knock because of the sudden reversal of pressure at the various bearings. It is also found that the different temperatures should vary as the load on the engine varies but that it is comparatively difficult to control these temperatures with any simple means.

As a result, these methods alone do not insure perfect operation and further modifications are generally resorted to. The most common method of further improving the action is to mix *water vapor* with the charge in the cylinder.

This vapor acts in a number of complicated ways to prevent the formation of carbon and tar and to prevent pre-ignitions. For best operation its *quantity should be varied to suit the load,* experience showing that none is generally required below half load and that a volume sometimes equal to that of the fuel used may be needed at maximum load.

Detailed descriptions of several engines embodying the use of water in connection with kerosene and distillates are given in a later chapter.

CHAPTER XII.

ELECTRIC-IGNITION APPARATUS.

In previous chapters the ignition of the combustible charge after compression within the engine cylinder has been mentioned, but nothing has been said about the means used for producing this ignition. The present chapter is devoted to a consideration of the apparatus used for this purpose.

With the exception of a few types of oil engines which are seldom used for agricultural purposes, practically all agricultural engines use some form of electric ignition. It will, therefore, be advisable to briefly consider some facts with regard to electricity before discussing the various electric-ignition devices and methods.

Flow of Electricity.

That which is called electricity "flows" through suitable conductors (wires, metallic parts of engines, etc.), when proper conditions are maintained to cause such flow. The study of these conditions can be simplified by comparison with the flow of water. When it is desired to make water flow through suitable conductors (pipes, jacket spaces, etc.), we create what is called a head; that is, we raise the pressure of the water at the entering end of the pipe or system. This may be done by means of a pump which we commonly say "forces" the water through the conductors.

To illustrate this in the way most suitable for our purpose, consider the arrangement shown in Fig. 40. The pump forces the water into the air vessel against the pressure of the air inclosed in the upper part of that vessel and this pressure causes the water to flow through the coil against the resistance offered to such flow by the friction between the water and the walls of the coil and by the internal friction of the water itself. By connecting the discharge end of the coil to the suction of the pump the water could be circulated continuously, the pump merely creating sufficient "head" or pressure to cause the flow against such resistance as the various parts offer.

In all electrical systems with which we shall deal there will be found some part which corresponds to this pump and which is present for the purpose of creating sufficient "electrical head" to cause the flow against such resistance as the various conductors offer to flow. This electrical head is called "difference of potential," "electromotive force," and "tension."

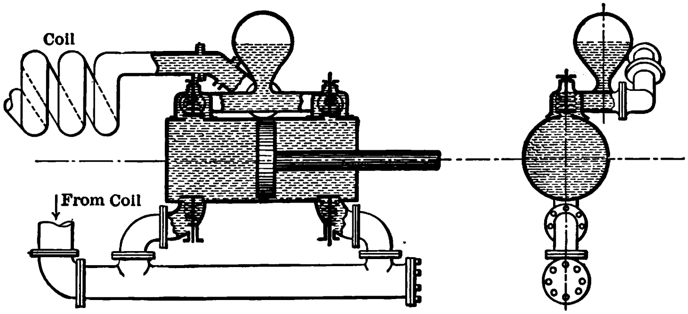


Fig. 40.

Paralleling the arrangement shown in Fig. 40 we might construct an electrical arrangement like that shown in Fig. 41. This consists of a "dry cell" corresponding to the pump and a long wire connecting its terminals corresponding to the coil of pipe. It is not necessary for us to consider in detail the phenomena occurring within the cell; suffice it to say that chemical action within causes a condition at the two terminals (points to which wire is attached) corresponding to the conditions at the discharge and suction terminals or orifices of a water pump. After a certain amount of use the conditions of the materials within the cell become changed to such an extent that the cell is unfit for further use and it is then said to be "dead" or "run down."

The electrical head (called electromotive force, potential, tension or voltage) is measured in a unit called the volt. It is not necessary, for present purposes, to accurately define this unit but it is necessary to observe that it is the same sort of unit as the pound or the foot of head used in measuring the pressure created by a pump.

The ordinary dry cell produces a potential or electrical head of about 1¼ to 1½ volts. This means that if an instrument for measuring voltage were connected to the two terminals of a new dry cell as shown in Fig. 42 it would indicate a potential difference (voltage) of from 1¼ to 1½ volts depending upon the quality and make of the cell.

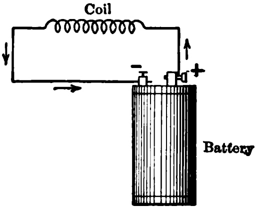


FIG. 41.

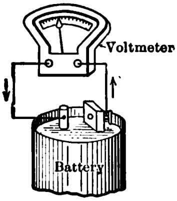


FIG. 42.

It should be noted that when an electric current flows there must be a complete circuit for it to flow through. In the case of the cell and external conductor shown in Fig. 41 the current is supposed to flow through the external circuit from the positive terminal (marked +) to the negative terminal (marked −) and then to flow through the cell from the negative terminal to the positive terminal. This is exactly what happens in the case of the pump and water circuit shown in Fig. 40. The water flows from the discharge pipe through the external circuit and back through the pump to the discharge pipe.

For ignition and many other purposes a voltage of only $1\frac{1}{2}$ is too small to drive the required amount of electricity through the conductors (wires, cables and such) and means must be devised for obtaining a greater electrical head if dry cells are to be used. This is done by using several cells connected in a certain way, known as *series connection.* When several cells are connected together, in this or in other ways, they are spoken of as a "battery."

As before, we will first study this sort of connection in the case of the pumps and then take it up as applied to cells. Assume that it is necessary to pump water against a pressure of 90 pounds per square inch and that the only pumps available are able to produce a pressure of 30 pounds each. If three such pumps are available we can connect them as shown in Fig. 43, the discharge of the first leading to the suction of the second, and the discharge of the second leading to the suction of the third.

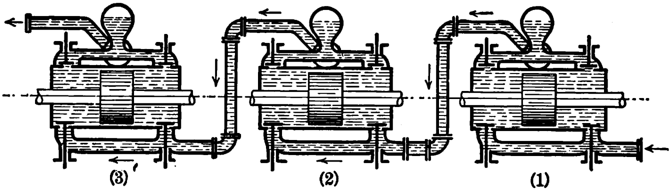


FIG. 43. — Pumps in Series.

The first pump would then raise the pressure to 30 pounds, the second would receive water at 30 and raise it to 60 pounds and the third pump would receive water at 60 and discharge it at the required 90 pounds per square inch.

Three cells connected in series would behave in just the same way. If each cell created an electrical pressure of $1\frac{1}{2}$ volts and the three were connected in series as shown in Fig. 44 the voltage measured between points *a* and *b* would be $1\frac{1}{2}$, that between *a* and *c* would be 3 and that between *a* and *d* would be $4\frac{1}{2}$.

Cells may also be connected in a way known as *multiple* or *parallel connection.* This corresponds to the pump system shown in Fig 45. If both pumps be assumed capable of pumping the same amount of water under the same pressure, it is obvious that this sort of connection will result in pumping twice as much water as would a single pump, but that the pressure at which the water is delivered will be the same as though only one pump were acting. Three pumps connected in multiple would deliver three times the water given by one, four would give four times as much and so on. In Fig. 46 is shown the same sort of connection with dry cells.

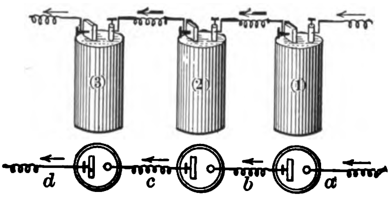


Fig. 44. — Cells in Series.

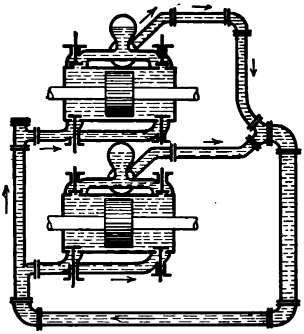


Fig. 45.

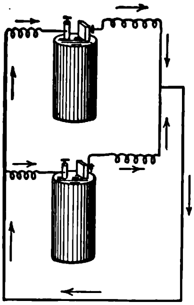


Fig. 46. — Cells in Parallel or Multiple.

Quantity of electricity is measured in units called amperes. A single dry cell, when new, gives between 15 and 30 amperes depending on the make. This means that when the proper instrument is connected between the two terminals it will indicate such numerical values. If the cells in the figure be assumed to deliver a certain number of amperes each (the same as a pump delivers a certain number of cubic feet or gallons in a given time) the result will be to cause the flow of double that number of amperes in the single wire of the external circuit.

It will be observed that connection in series changes the voltage while connection in parallel changes the quantity.

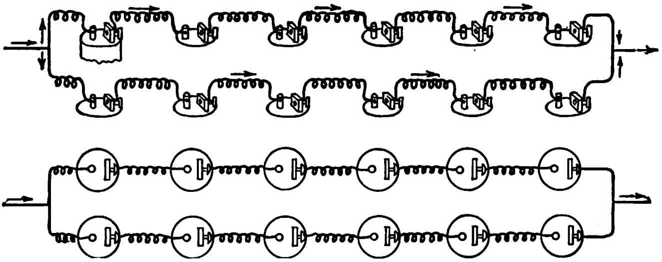


FIG. 47. — Series-multiple Connection.

It is sometimes desirable to obtain both results at the same time, and this can be done by what is called *series-multiple*, or *series-parallel* connection. This corresponds to connecting several pumps in series to obtain the desired head (pressure) and then connecting this combination in parallel with as many similar combinations as are necessary to obtain the desired quantity. The arrangement with dry cells is illustrated in Fig. 47 which shows twelve cells in series-multiple connection, two sets of six cells each (connected in series) being connected in multiple.

The voltage or electrical pressure created by such a combination would be the same as that created by six cells connected in series, but by using the two sets connected in multiple twice the quantity of electricity (twice as many amperes) can be made to flow through the same external resistance. By using three sets of six cells the current flowing could be made three times as great, and so on.

SOURCES OF ELECTRICAL ENERGY.

There are other forms of cells besides the dry cells which have been considered. They are known as *wet cells,* which are sold under various trade names, and as *storage cells.* The wet cells are comparatively seldom used for engine ignition because they are not well constructed for such purposes. Storage cells are very widely used for ignition in automobiles, tractors and motor boats.

Both these varieties owe their activity to chemical changes which take place within them, the changes occurring in wet cells being very similar to those occurring in dry cells. Storage cells are, however, somewhat different. The chemical changes which occur within them may be made to take place in either of two directions and are said to be reversible. When a storage cell is delivering electrical energy (discharging) the change within it causes it to gradually run down or approach the condition of being dead. If the cell, when partly run down, is connected into an electric circuit which will cause a flow of current through the cell in the opposite direction, the change which took place when discharging is reversed, that is, it is undone or made to take place in the opposite direction, so that the cell is charged or again put in condition to deliver electrical energy as before.

A storage cell can be pictured as a storage tank upon a hill. When full, it can discharge a certain amount of water under the head due to its position on the hill. When discharged, it can be pumped full again by a pump able to deliver water at that height and, when full, it is "charged" and ready to discharge once more.

All that has been said about the connections of dry cells applies to wet and storage cells excepting that numerical values of voltage and amperage per cell vary with the kind of cell.

All cells depend upon chemical action for their ability to cause the flow of electricity. There is, however, an entirely different method of causing such a flow. Whenever a wire is moved in the neighborhood of a magnet a difference of potential is created exactly like that created by a battery and if proper connections are made an electric current will flow. Thus if a single coil or turn of wire were rotated (as in Fig. 48) between the ends or the poles of an ordinary horseshoe magnet, a voltmeter (instrument for measuring voltage or electrical pressure) connected between the ends *a* and *b* would indicate the existence of a difference of potential, that is, an electrical head or pressure. By connecting the ends to two cylinders of metal as shown in Fig. 49 and then letting two strips or *brushes* rest upon the rings we can connect an external circuit to the loop of wire just as we connected it to the terminals of the battery.

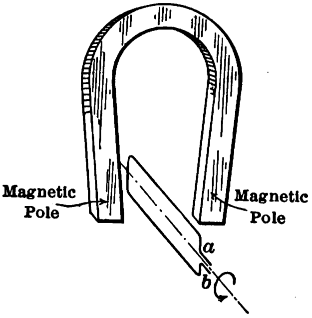


FIG. 48.

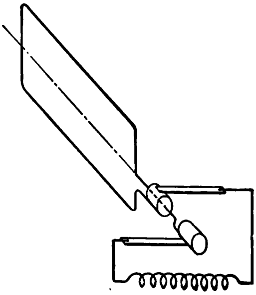


FIG. 49.

The current flowing in the coil and in the external circuit with such an arrangement would change its direction twice in every revolution. It would flow in one direction when one of the long sides of the coil passed before one of the poles of the magnet, would gradually decrease to zero and then begin to flow in the opposite direction and reach a maximum value when the same long side passed before the other pole. It would then decrease to zero as rotation continued and then increase to a maximum value in the first direction as the same side of the coil reached the position from which it started. Such a current is said to be *alternating*, and is spoken of as an *alternating current.*

It is very important to note that it has its maximum values when the wires pass the poles of the magnet. It is sometimes undesirable to have the current alternate in this way and yet it may be necessary to use a coil rotating in a *magnetic field*, that is, near or between magnetic poles, or within the field of influence of the magnet.

The arrangement shown in Fig. 50 makes it possible to connect such a coil, in which the current alternates, to an external circuit in such a way as not to get an alternating current in that circuit. It is merely necessary to connect the ends of the coil to half-cylinders or rings as shown and then to so locate the brushes that, just as the direction of flow in the coil is about to change, one half-ring rotates out from under a brush and the other half-ring comes into contact with it. This results in reversing the connections between the coil and the external circuit so that, despite the change of direction within the coil, the direction of flow in the external circuit is not changed. The arrangement with which the brushes make contact is called a *commutator* and the pieces of which it is constructed are known as *commutator segments.*

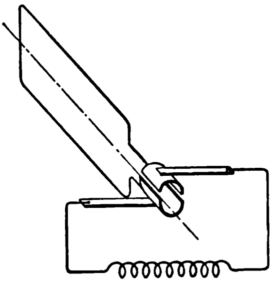


FIG. 50.

In the case of real machines of this type there are generally many coils located like the coil which so far has been considered. In such cases there may be many commutator segments in place of the two which have been discussed, but the action is the same.

The current flowing in the external circuit when a commutator is used is said to be a *direct current,* which means that the direction of flow does not periodically reverse. The current does, however, *pulsate,* that is, get stronger and weaker just as before. The only difference is that after dying down to practically zero it starts up again in the same direction instead of in the reverse direction. The amount of pulsation can be decreased by using more coils and more pieces (commutator segments) to make contact with the brushes. When this is done the brushes can be so placed as to make contact with the segments which are connected to the coil which is just passing under the poles and which will then be generating the greatest difference of potential and therefore will cause the greatest flow of current.

The horseshoe magnet assumed in the above discussion and illustrated in Fig. 48 is called a *permanent magnet.* It is made of steel of such character that it will remain strongly magnetic for many years if properly magnetized in the first place. In real machines using permanent magnets the shape and construction of the magnets is generally somewhat different from the familiar variety shown in Fig. 48 in order to give more perfect operation.

All devices which generate electricity because of the movement of coils within the field of a permanent magnet are called *magnetos.* There are many varieties distinguished by names which indicate their character; thus there are low-potential (voltage) and high-potential alternating-current magnetos, direct-current magnetos, etc.

Since it is only necessary that the coils shall move in the magnetic field in such a way as to pass, in a general way, across the poles of the magnet these coils may be rotated, or may be oscillated (moved back and forth). It thus results that there are *rotating magnetos* and *oscillating magnetos.*

There is another class of devices for generating electricity by the movement of coils of wire within a magnetic field.

This class uses what are known as *electromagnets* instead of the permanent magnets used in magnetos.

When an electric current flows through coils of wire around soft iron that iron becomes a magnet exactly like the permanent magnets which we have just discussed. When the current ceases to flow, however, the iron loses practically all of its magnetism. This phenomenon is made use of in devices known as *electric generators* or *dynamos* which are practically the same, in general principle, as magnetos, excepting that the permanent magnets are replaced by electromagnets.

The current flowing in these coils, which are called field coils, is supplied by the generator itself, part or all of the current passing through the field coils on its way to the external circuit.

IGNITION SYSTEMS.

We have considered the various "electrical pumps" used for creating the "electrical head" or difference of potential which is required to cause a flow of electricity, and are now in a position to take up the ignition systems themselves.

These are broadly divisible into two classes known as *low-tension* and *high-tension* systems. The low-tension system is so-called because it uses a low electrical potential or pressure, while the high-tension systems use potentials very much greater.

LOW-TENSION IGNITION SYSTEMS.

The low-tension systems are so arranged that when two points, located within the cylinder clearance space, are mechanically separated, they break an electric current in such a way as to cause a spark to pass between them. This circuit is made or closed just before the spark is desired and is broken at the time the spark is to pass. Because of this double operation the system is often called *make-and-break ignition.* It is also called a contact system of ignition because of the contact which must be made within the clearance space.

A diagrammatic representation of such a system is shown in Fig. 51.

With the switch closed there is no metallic circuit for the flow of current until the *movable electrode* is rotated in the direction indicated by the arrow so as to make contact with the *stationary electrode.* When this occurs current flows in the direction indicated by the arrows. When the movable electrode is rotated in the reverse direction it breaks the circuit and a spark passes between the two *points;* that is, the current continues to flow through the gap for a very short period of time after the points separate. This flow is due to the action of the coil which is known as a *reactance coil,* a *kick coil,* or an *intensifier coil.* The consideration of the theory of such a coil is beyond the province of this book, but it is essential to point out that the action of the coil is such as to oppose the breaking of the circuit at the points. When properly designed it so strongly opposes the cessation of flow that it causes it to continue for a very short time through the space between the separated points. The more rapidly the electrodes are separated the more intense is the action of the coil, so that it is customary to *make the break as sudden as possible* in order to get the best possible spark.

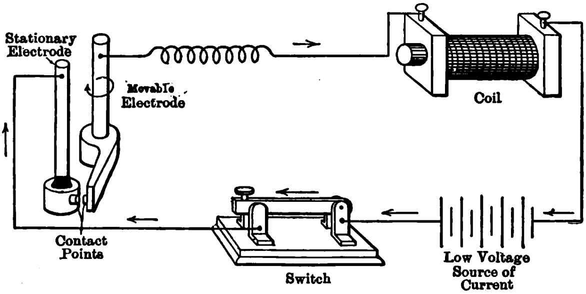


FIG. 51.—Diagrammatic Representation of Low-tension System.

The coil consists only of a bundle of soft iron wires with many coils of fine copper wire wrapped around it. The wires are *insulated* from the *core* (bundle of wires) and from each other; that is, some material which is so poor a conductor of electricity as to conduct practically none at all under the existing differences of potential is placed between the wires and the core and between adjoining turns of wire.

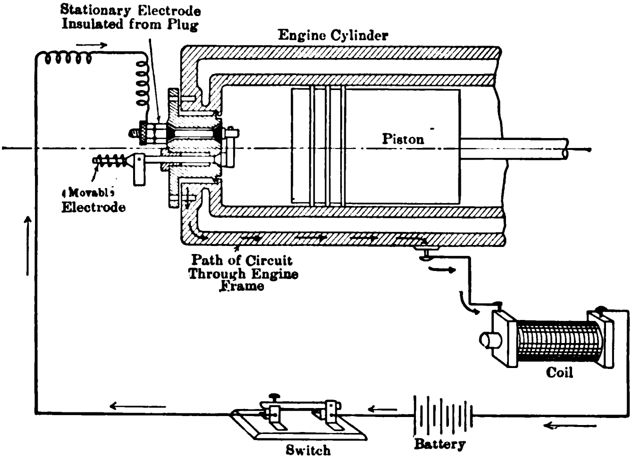


FIG. 52 (*a*).—Low-tension System as actually used.

In Figs. 52 (*a*) and (*b*) are shown a real make-and-break system with the electrodes in place so as to bring the points into the clearance space of the engine. All parts are arranged as in Fig. 51 so as to make the diagram as clear as possible. Since the movable electrode has to rotate back and forth within the plug and still be so arranged that no gas can leak by it even at the highest pressures it is made to fit "metal to metal" with the plug. This means that it is not insulated from the metal of the plug, and as the plug cannot be conveniently insulated from the metal of the cylinder it results that the movable electrode is in electrical contact with the metal of the engine.

Advantage is taken of this fact by making the metal of the engine act as part of the electrical circuit as shown by the arrows in Fig. 52 (*a*).

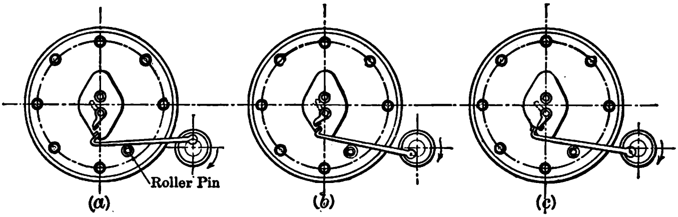


FIG. 52 (*b*).—End View of Cylinder, showing Igniter Block and Operating Mechanism.

An enlarged view of the igniter block is shown in Fig. 53 with all the details in place. It is operated by pushing on the hammer trigger which rotates the movable electrode against the action of spring *S′* until contact is made with the stationary electrode. When the operating mechanism snaps off of the hammer trigger the spring *S′* breaks the contact.

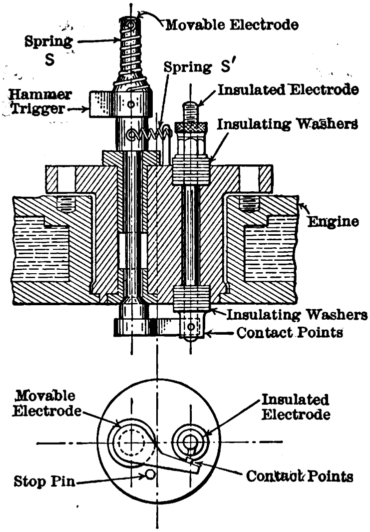


FIG. 53.—Igniter Block.

In order to make the break still more rapid than that resulting from the action of a spring arranged in this way many manufacturers construct the ignition plug with one more piece which acts as a spring-driven hammer. In operation this hammer is released just before a spark is desired and after traveling a short distance under the action of its spring it strikes the movable electrode and breaks the circuit. As the hammer is traveling with a high velocity when it strikes the movable electrode the circuit is broken very suddenly and the spark is therefore very intense. Such arrangements are properly called *hammer make-and-break* plugs.

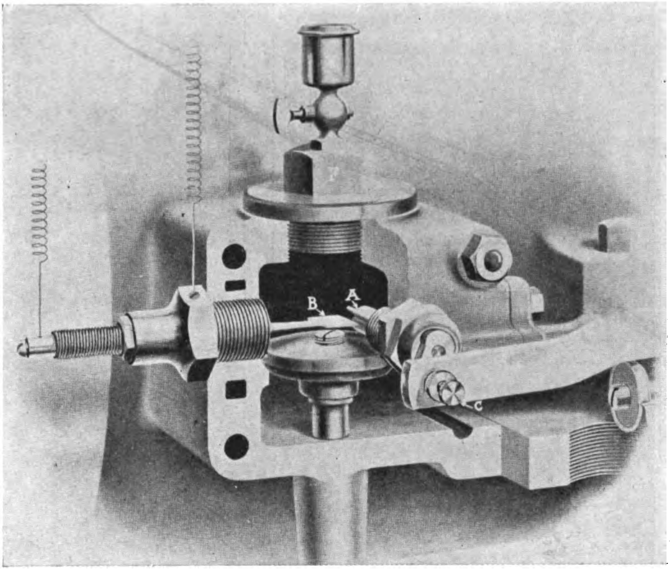


Fig. 54. — Wipe-spark Mechanism.

Another sort of low-tension, make-and-break ignition is shown in Fig. 54. This is known as a *wipe-spark* mechanism, as the movable electrode *A*, which is continuously rotated in one direction, wipes over the face of the stationary electrode *B* when making and breaking contact. The electrical connections are the same as in the other cases already described.

The advantage claimed for this type is that the wiping or rubbing action keeps the electrodes bright and clean so that a spark is always assured. With the hammer type the points are often pounded out of shape and worn away by the mechanical impact, and the point on the stationary electrode is often made inoperative by being pitted by the action of the electric current.

To obviate this latter difficulty the stationary electrode is sometimes enlarged at the cylinder end and the enlargement is then machined so as to give a rounded edge extending all the way around the electrode. When the part of this edge which has been making contact with the movable electrode becomes worn and pitted the stationary electrode is rotated a short distance so as to bring a new part of the rounded edge into service.

HIGH-TENSION SYSTEMS.

The elements of the simplest sort of a high-tension system are shown diagrammatically in Fig. 55. There are two distinct electrical circuits known as the *low-tension* or *primary* and the *high-tension* or *secondary* circuit. The former is shown in the diagram by heavy lines, the latter by light lines.

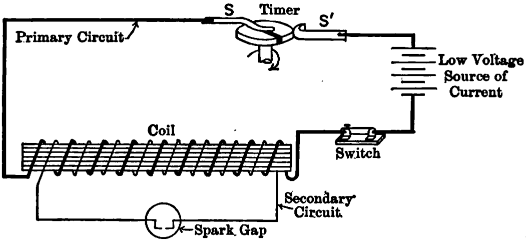


FIG. 55. — Simple High-tension System.

The primary circuit includes a battery or similar electrical pump, a *timer* or *contact maker,* a switch and a comparatively small number of turns of coarse wire on a soft iron core. The secondary circuit includes a large number of turns of very fine wire on the same core and a *spark gap* (opening in the metallic circuit) which is located in the clearance space of the engine.

The timer shown in the illustration is merely diagrammatic but will serve to bring out the essential parts of this apparatus. It is supposed to consist of a disk of insulating material fastened on the end of a shaft which is continuously rotated at the proper speed in the direction indicated by the arrow. It carries a metallic segment (shown in black) on top of which is pressed the metallic spring S. Another spring or brush S' presses against the edge of the disk or of the metal segment, depending upon the position to which the latter has rotated. Whenever the metallic segment comes into contact with the spring S' the primary circuit is closed and the action of the induction or spark coil is such that a high difference of potential (electrical pressure) is brought into being at the spark gap in the secondary circuit. If the parts are properly proportioned this will not, however, be great enough to cause a spark to pass. As the timer continues to rotate the metallic segment will finally pass out from under the spring S' and this will break the primary circuit. The inductance coil again causes a high difference of potential to exist between the points forming the spark gap and, if the break is made to occur quickly and the parts are properly proportioned, this potential difference will be much greater than that caused by the closing of the circuit an instant before. If it is great enough a spark will pass between the two terminals.

It is comparatively difficult to construct a timer which shall be mechanically rugged and yet will give a very rapid break, and other means have therefore been devised for accomplishing this end. It is generally done by what is called a *buzzer*, *trembler*, or *vibrator* in combination with the coil. This arrangement is shown diagrammatically in Fig. 56.

The primary circuit is now made through the contact screw *C* and the vibrator *V* whenever the timer rotates into such a position that the spring *S′* makes contact with the metallic segment. The end of the screw *C* and the vibrator would be touching in a real apparatus with the timer in the position shown in Fig. 56. They are shown separated in the figure in order to indicate the way in which they make contact. But as soon as the primary current flows it magnetizes the core of the coil and this draws the vibrator over and out of contact with the screw *C*, causing a very rapid break in the primary current and hence a spark in the secondary. In the real apparatus the vibrator is located much closer to the end of the coil than is indicated by its position in the illustration which must be considered as diagrammatic and not as a picture of real apparatus.

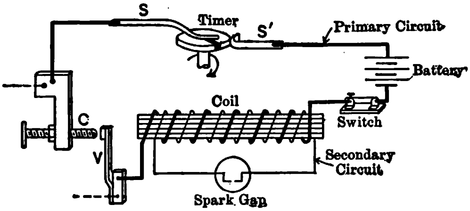


Fig. 56.—High-tension System with Vibrator added.

As soon as the primary current is broken the core of the coil begins to lose its magnetism and the vibrator ultimately flies back and closes the primary circuit again if the timer is still making contact. This again magnetizes the core of the coil, causing a break and a spark as before. The alternate making and breaking in this way will occur very rapidly as long as the timer is in position to close the circuit and there will therefore be a succession of sparks across the spark gap. It is probable that very little, if anything, is gained by this series or shower of sparks, the advantage of the vibrator lying rather in the rapid break which it makes possible.

If the apparatus were used in the simple form illustrated in Fig. 56 there would be considerable trouble caused by sparking between the contact screw and the vibrator. The breaking of the primary circuit at this point corresponds almost exactly to the breaking of the primary circuit at the igniter points in a low-tension system. This sparking would cause rapid pitting and deterioration of the vibrator and screw contacts so that the entire system would soon become inoperative.

To prevent such injurious sparking a piece of apparatus known as a *condenser* is used. This is connected as shown in Fig. 57. A condenser consists of alternate layers of metal foil and insulating material, such as mica or varnished paper in sheet form. The first, third, fifth, seventh, etc., sheets of foil are connected together and to one terminal of the condenser; the second, fourth, sixth, eighth, etc., are connected together and to the other terminal. This is shown diagrammatically in the illustration, in which the horizontal lines represent the metal foil, the insulation between sheets not being shown.

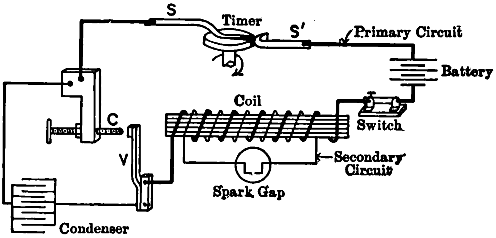


FIG. 57. — High-tension System with Vibrator and Condenser.

It is beyond the province of this book to explain how the condenser prevents excessive sparking but it can be pictured as a sort of storage reservoir to receive the energy which would otherwise be expended in causing a very destructive spark at the trembler contact. It does not entirely prevent sparking but reduces it to such an extent that it does little damage.

The condenser can be, and generally is, connected in such a way as to cause another sort of action as well. It can be made to cause a series of sparks to pass at the spark gap in the cylinder every time the primary circuit is broken by the trembler instead of the single spark which would otherwise result. This series is made up of alternating discharges; that is a spark passes first in one direction and then in the other and this operation is repeated very rapidly. The alternating discharge appears to the eye as a single spark and is generally considered as such.

There are numerous ways in which the various parts of a high-tension ignition system can be connected and it is impossible to discuss the many variations within a book of this size. Connections are nearly always made in such a way that part of the metallic circuit serves to carry both primary and secondary current and that the number of terminals to which wires must be fastened is reduced to a minimum.

One such system of connections is shown diagrammatically in Fig. 58 which is only a slight modification of Fig. 57. When the secondary current flows for the short time during which the spark exists in the spark gap it flows through the battery and part of the wire forming the primary circuit. This does no harm and saves duplication of part of the circuit. It also gives one terminal which serves as a connection to one end of the primary winding and one end of the secondary winding instead of there being two terminals for this purpose as in Fig. 57. In real apparatus the primary and secondary windings of the coil are not separated as shown, but overlap, each set extending the whole length of the core.

It is also very common practice to make the metal of the engine itself act as part of the high-tension and low-tension circuits. This arrangement in combination with the system shown in Fig. 58 is illustrated semidiagrammatically in Fig. 59 (*a*) and details of several different types of spark plugs are shown in Figs. 59 (*b*), (*c*), (*d*), (*e*), and (*f*). The primary and secondary circuits are both completed through the engine. Since the spring which makes contact with the edge of the timer is in metallic contact with the engine and one terminal of the battery is also in such contact, the primary circuit is completed in the way shown by the dotted lines.

The secondary circuit is completed in the same way by metallic contact between the engine and the outer metal of the spark plug as shown.

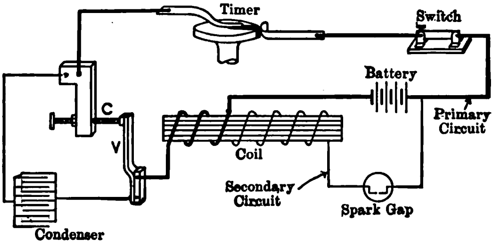


Fig. 58.

The condenser in this case, as in most real cases, is built into the box with the coil, and the connections to the trembler and contact screw are made within the box.

The diagrams which have been given should, if properly studied and understood, enable the reader to understand the diagrams of connections given by the various builders of ignition apparatus. In every case the essentials are the same as here given though they often differ greatly in type, arrangement and connections.

COMPARISON OF HIGH- AND LOW-TENSION SYSTEMS.

The low-tension systems are electrically very simple and therefore easily understood. Mechanically they are, however, somewhat complicated as the moving electrode must be maintained gas-tight in the igniter block and must be properly

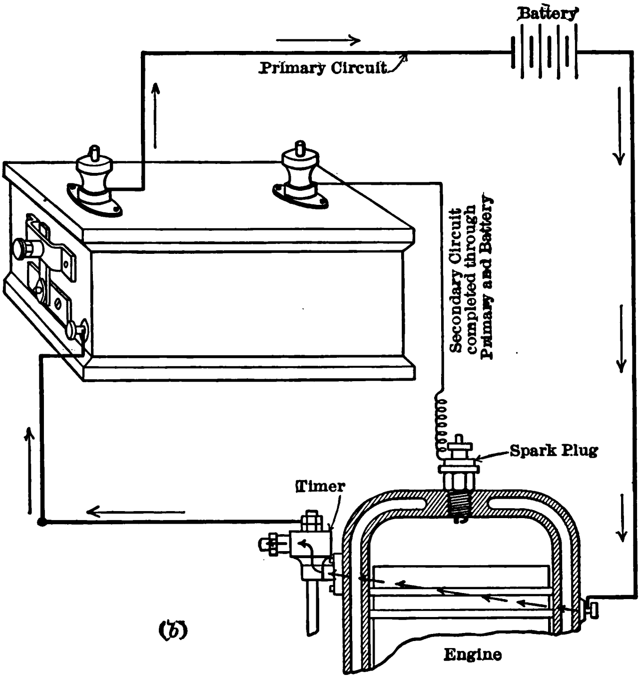


FIG. 59 (*a*).

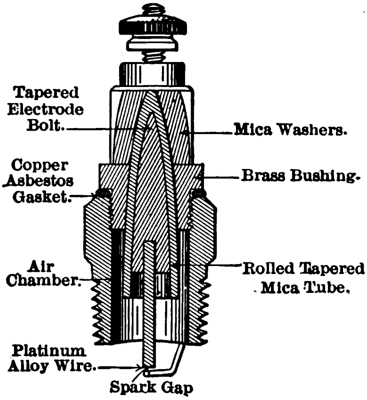


FIG. 59 (*b*).

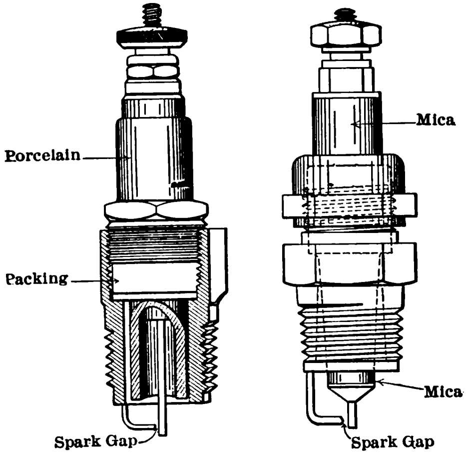


Fig. 59 (*c*).

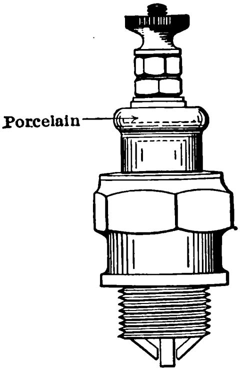


Fig. 59 (*d*).

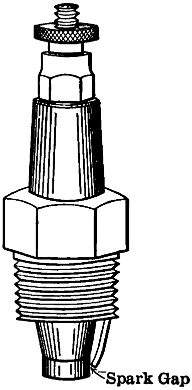


Fig. 59 (*e*).

moved by the engine. It is also often difficult to maintain the insulation of the stationary electrode in such condition as to prevent leakage of current direct to the engine. Such leakage would allow the current to flow through the engine instead of across the gap created between the igniter points and would therefore prevent the passage of a spark and cause rapid deterioration of batteries if they are used.

The high-tension system is, in contrast, mechanically simple but very complicated electrically. At first sight this would seem to be a serious fault but, practically, one does not need a complete knowledge of the electrical phenomena involved since the makers of this apparatus have perfected it to such a point that the user has merely to connect certain wires or cables as directed.

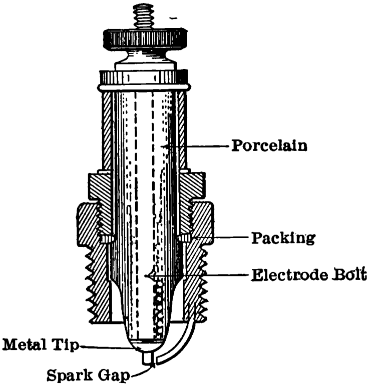


Fig. 59 (*f*).

The high-tension systems were developed principally for use with automobile engines, the high speed of which made the action of low-tension mechanisms very uncertain. In their modern forms these high-tension systems are so reliable and so simple, from the practical operating standpoint, that they are being more and more widely used on all forms of engines.

TIMING IGNITION.

The time at which the spark is made to pass within the cylinder must be accurately under control. The mixture should be almost completely burned before the piston has moved an appreciable distance on the expansion stroke and the spark must be made to pass at such a time as will bring about this result. Experience has shown that the charges used in internal-combustion engines do not burn instantaneously but that it takes a very definite length of time for the flame to spread throughout the mixture from the point at which the spark starts it.

For this reason the spark is practically always made to pass slightly *before the end of the compression stroke* so that by the time the piston reverses its direction of rotation the mixture will be well inflamed and a large part of it will be entirely burned. As it will always take practically the same length of time to burn a given mixture in a given clearance with a given compression pressure it is easy to see that ignition must be made to occur earlier in the compression stroke the higher the speed of the engine because the time during which the piston is at the end of its stroke is proportionally reduced.

For best operation the time of ignition should also be varied as the quality of the mixture changes, as the condition of the atmosphere varies, as the load on the engine is altered and so forth.

The effects of proper and improper timing of ignition are easily studied by means of indicator diagrams. For the sake of simplicity the lower loops may be omitted from these diagrams as they have little, if any, effect upon the phenomena under discussion.

The upper loop of a diagram which would represent very good performance is shown in Fig. 60. It will be observed that the line representing rise of pressure due to combustion is not quite vertical as originally drawn in Fig. 11, but tips slightly to the right as it rises. More than this, there is not a sharp point at the top of it as was indicated in the ideal diagrams, the combustion line rounding off into the expansion line.

When an engine is operating in such a way as to give a diagram of this type it generally runs very smoothly and gives its full power if properly designed and in good condition. The ignition does not, however, occur when the piston is on head-end dead center as was assumed in the ideal cases treated in previous chapters. The spark passes while the piston is still compressing the charge and the flame begins to spread and the temperature to rise before the end of the compression stroke. The first part of the combustion takes place so slowly that it has little effect on the diagram and is merely shown by the rounded corner where the compression line runs into the combustion line. In the case for which the diagram is drawn, the spark would have passed when the piston was in a position corresponding to some such point as that marked x on the compression line.

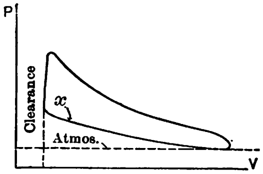


FIG. 60. — Normal Cord.

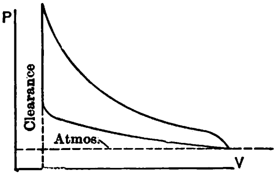


FIG. 61. — Early Ignition.

The rounded top of the combustion line indicates that the mixture was not entirely burned until after the piston had moved out quite a distance on the expansion stroke.

If ignition is made to occur too early the diagram looks more like that shown in Fig. 61. The combustion line becomes vertical and the maximum pressure attained is higher than in the case just considered. An engine operated in this way will give a very distinct "knock" or "pound" when combustion occurs and the connecting rod and shaft bearings will generally require frequent taking up to compensate for wear. Still earlier ignition would give a diagram like Fig. 62 and the effects would be still worse.

If ignition is made to occur too late, the diagram looks more like Fig. 63. An engine operated in this way does not use fuel economically and often gives trouble from heating. This is due to the fact that the gases continue burning during a large part of the expansion stroke and give to the cylinder walls and piston much of the heat which they should convert into mechanical energy.

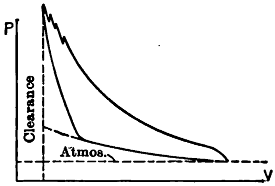


Fig. 62. — Very Early Ignition.

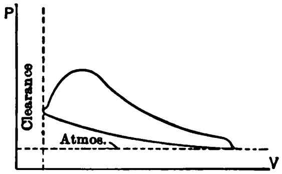


Fig. 63. — Late Ignition.

In actual operation it is rather difficult to tell whether ignition is just right or not and the best that can be done is to set the ignition so early that a knock is just noticeable and then to retard it a small amount. Most manufacturers indicate on the engine the position of the flywheel or crank at which the ignition apparatus should make or break contact but in many cases this position changes as parts wear so that one must eventually depend on one's judgment.

Very rich and very lean mixtures, that is, mixtures in which there are very large and very small quantities of fuel, burn more slowly than a mixture of the proper proportions. Hence such mixtures require an early spark in comparison with normal mixtures.

It follows that if an engine is supplied with an over-rich mixture, as is often done, it will give every evidence of late ignition when the spark is set in the correct position for normal operation. The proper remedy does not lie in making ignition earlier, "advancing the spark," but in making the mixture leaner.

With low-tension systems the timing is effected by varying the time at which the igniter points are separated. There are a great many ways of doing this but all of them depend upon simple mechanical principles which are easily understood from an inspection of the apparatus.

One typical arrangement is shown in Fig. 64 in which all but the essential parts of the ignition apparatus are omitted. Timing is effected by lengthening or shortening the igniter arm so that it releases the movable electrode at different positions of the cam shaft and therefore at different positions of the crank shaft and piston.

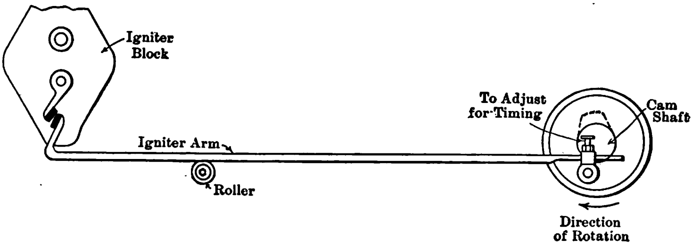


Fig. 64.

A somewhat similar mechanism is timed by means of an eccentrically mounted roller in place of the concentric roller in the figure. Changing the position of the center of the eccentric mounting produces the same result as changing the length of the igniter arm in the device shown.

In all high-tension systems some sort of timer is used. This may be a separate piece of apparatus or it may be built into a magneto in ways which will be described later.

The timer practically always consists of a stationary part which carries metallic contacts and of a rotating part which is driven by the engine and closes the primary circuit when a certain part of it touches a metallic contact on the stationary member. An elementary example is shown in Fig. 65, the central finger being rotated by the engine in the direction shown by the arrow on the spindle. The ring of insulating material carries a metallic piece shown in black and to this a wire forming part of the primary circuit is fastened. This circuit is connected in such a way through the engine that when the rotating finger touches the metallic piece in the ring the circuit will be completed or closed and the primary current will flow. With the ring in the position shown, this circuit will be made when the engine is in some definite position, that is, when the crank and piston occupy certain definite positions. If the ring is rotated in the direction indicated by the upper arrow, the engine will have to rotate further before the primary circuit is closed and hence ignition will occur later. If the ring is moved in the opposite direction, contact, and therefore ignition, will occur earlier.

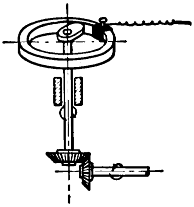


FIG. 65. — Timer.

HIGH-TENSION MAGNETO IGNITION.

There are a number of ignition systems in which the various elements of a high-tension system (electric pump, timer, transformer coil, condenser, etc.) are all incorporated in the structure of a single magneto. Such systems are generally designed for use with multicylinder engines, in which it is necessary to operate as many spark plugs as there are cylinders. The magnetos may be so arranged that it is only necessary to run a cable from the magneto to each spark plug in order to connect up the system.

These complicated magnetos are used principally for automobile ignition but as they are the last step in a long development from the simple types described in the early part of this chapter it is thought advisable to describe them. A thorough understanding of the simplest and the most complicated should enable the reader to understand the intermediate types which are at present more common on agricultural machinery.

A high-tension magneto system in which all parts are incorporated in the magneto structure is shown diagrammatically in Fig. 66. The parts have been moved apart and materially modified in order that they may be more easily comprehended. The armature (rotating part) of the magneto has two windings upon it; one consists of a small number of turns of coarse wire, and the other of a large number of turns of fine wire. In the real case they are not separated as shown; the coarse wire is first wound in place and then the fine wire is wound on top of it. The turns of coarse wire act as an electric pump when rotated in the magnetic field but, since they are wound on the same core as the turns of fine wire, they also act as the primary winding of a coil. The armature serves as the soft iron core of this coil and the turns of fine wire are the secondary windings.

One end of the primary winding is connected to the metal of the armature and from that through the metal of the magneto to "ground," that is, to the metallic parts of the engine as shown by the line *ab*. The other end is connected to one end of the secondary as was done in Fig. 59, and this common terminal is brought to the slip ring *c* which rotates with, but is insulated from, the shaft of the magneto. The other end of the secondary is connected with the slip ring *d* near the opposite end of the armature shaft.

Near the left-hand end of the shaft is carried a double cam which breaks the primary circuit twice in each revolution of the armature by raising the spring *s* and breaking contact at the points *P*. This is known as an *interrupter* and corresponds to the trembler in previous figures.

The primary circuit flows through the coarse wire on the armature, the slip ring *c*, the points *P*, the spring *s* and "ground" back to the end of the primary winding on the armature. When it is suddenly broken by the action of the double cam, an electrical pressure high enough to cause sparking at a plug is set up in the secondary winding. The action is similar to that already considered in other transformer coils. The secondary circuit flows through the fine wire on the armature, the slip ring *d*, the rotating finger *R* of the "distributor," any terminal *T* with which it makes contact, the gap in the plug to which that terminal is connected, through "ground" back to the grounded terminal of the primary and through the primary coil to the point where it joins the secondary.

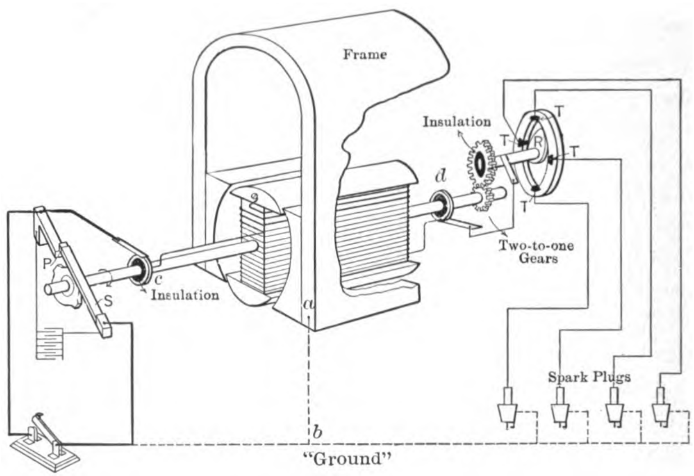


FIG. 66. — Diagrammatic Representation of High-tension Magneto System.

Two sparks occur during each revolution of the armature, since the primary circuit is broken twice during each revolution. It is therefore necessary that the rotor of the distributor rotate at such a speed that it comes in contact with two terminals *T* during one revolution of the armature. It must therefore be rotated at half the speed of the armature, which would result from the use of two to one gearing as shown in the illustration.

In the early part of this chapter it was pointed out that the current made to flow by rotating coils in a magnetic field is pulsating in character, increasing from zero to a maximum and then decreasing to zero again. Since the maximum intensity of spark will result if the primary circuit is broken when the current flowing in it is approximately at a maximum it follows that the cam should separate the points *P* when the armature is in the position giving maximum current.

Remembering that the spark must pass when the engine parts are in a certain definite position it is obvious that the magneto armature should be positively driven from the engine and that the drive must be so arranged that the magneto is "timed," that is, attains the sparking position when the engine parts are in the position calling for the passage of a spark. This is accomplished by driving through gears or a chain.

The switch shown in the illustration is used to prevent sparking when desired. When closed it short circuits the primary circuit so that the breaking of contact at the points *P* does not then break the primary circuit and hence produces no spark at the plugs.

THE WICO IGNITER.

This igniter has recently become very prominent. It combines many of the advantages of high-tension magneto ignition with the further advantage of great simplicity.

Its operation depends upon the same principle as is made use of in magnetos but the principle is applied in a different way. In the early paragraphs of this chapter it was shown that current may be made to flow by moving a coil of wire in the field of a magnet. It was also shown that the current increased in magnitude as the wire of the coil passed from a weak part of the magnetic field to a position in which magnetic action was more intense.

It is not necessary to move the coil to get such action. It is only necessary to have relative motion of the coil and the field so that the same result could be achieved by moving the magnets about the coil or by keeping both the magnets and the coil stationary and changing the intensity of the magnetic field in which the coil is located.

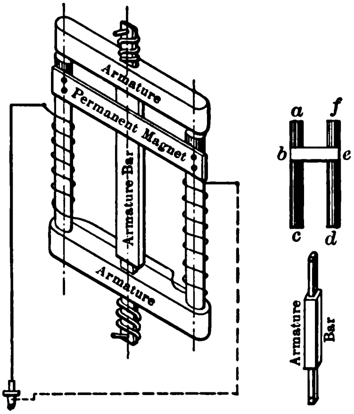


Fig. 67.—Essential Parts of Wico Igniter.

The latter method is used in the Wico igniter, the essential parts of which are shown semi-diagrammatically in Fig. 67. A permanent magnet is connected to two soft iron bars to form two ⊔ shaped magnets, *abef* and *cbed,* as shown in the smaller sketch. The presence of the permanent magnet will make the bars, to which it is fastened, magnetic, but they would lose practically all magnetic properties if the permanent magnet were removed.

If an iron bar were put across the ends *a* and *f* of such a structure, the magnet *abef* would become very strong, while the magnet *cbed* would become very weak. Thus the magnetic strength of the system could be almost entirely concentrated in either the upper or lower magnet at will.

In the igniter there are two bars designated as *armatures* which can be made to bridge across the ends of the magnets in this way. They are mounted on the *armature bar* in such a manner that they can slide a short distance on it, but the distance between the shoulders on this bar is such that both armatures cannot be in contact with the magnets at the same time.

In operation, the armature bar is moved upward just before a spark is desired. This results, first, in bringing the lower armature into contact with its magnet and, second, in compressing the spring below that armature. With the armature in this position the lower magnet is very strong.

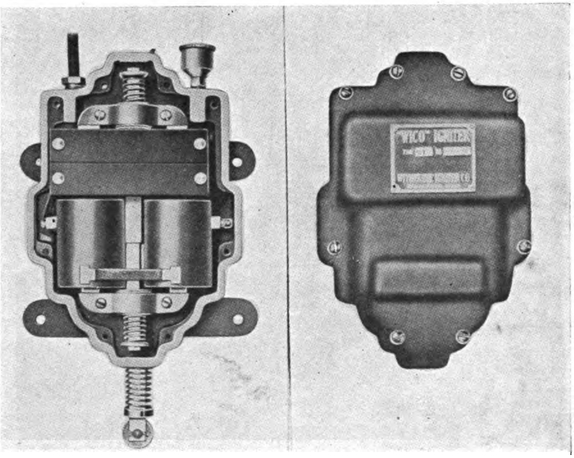


FIG. 68. — Wico Igniter.

When the spark is desired the armature bar is released and the compressed spring at its lower end draws it down very quickly. This results in pulling the upper armature into contact with the upper magnet and in driving the lower armature out of contact. The vertical legs of the lower magnet are thus suddenly changed from a strongly magnetic to a weakly magnetic condition; but they form the cores of two coils and the sudden change of magnetic strength causes a current to flow through the coils under a high electrical pressure. If the coils are connected to a spark plug as shown in the sketch a spark will result.

The armature bar is pushed up by motion derived from any convenient part of the engine. The motion is transmitted to the bar through a latch which is thrown out of action by a wedge at the proper time. By changing the position of this wedge the time at which the latch is tripped can be changed and hence ignition can be timed.

The real igniter is shown in Fig. 68 in which the principal parts shown in the last illustration should be easily recognized. It is inclosed in a waterproof case, so that it can be exposed to the weather without damage.

CHAPTER XIII.

THE GOVERNING SYSTEM.

All engines are required to deliver different quantities of power at different times. An engine running without load is delivering no useful power; an engine carrying the maximum possible load is delivering the maximum quantity of useful power.

Since all engines of the type here considered must develop power within their cylinders proportioned to the useful power to be taken from the shaft, it follows that these engines must be provided with some means of varying the power made available within the cylinder. When the engine is carrying no load but is running at full speed sufficient power must be developed within the cylinder to overcome the friction of the engine itself; when the engine is carrying maximum load the power developed in the cylinder must be the equivalent of the sum of that load and the power required to overcome the engine friction.

Controlling the power made available within the cylinder to suit the instantaneous demand for power at the shaft is called governing or regulating.

Governing may be done entirely by hand, as in the case of automobile engines, small marine engines and such; or it may be performed mechanically, as in the case of most stationary and portable engines.

In the case of stationary and similar engines it is generally desirable to have the engine run at approximately the same speed for all loads within its capacity. In such cases the governing device must do two things: it must suit the power made available in the cylinder to the power demand, and it must maintain approximately constant engine speed.

To appreciate the mechanical operation of such devices it is necessary to realize what would happen in an engine of this type if the power made available did not fit the demand. Common experience shows that when an engine is overloaded it slows down until it stops. On the other hand, if an engine makes available more power than is being taken from its shaft it must speed up, the work done in speeding up the engine absorbing the excess made available. An engine then slows down when the power made available is insufficient for the demand, and it speeds up when the power made available is greater than necessary.

Advantage is taken of these facts by fitting to the engine a mechanical device (commonly called the governor) which will change its position as the speed changes. By connecting this device with some other which will control the amount of power being made available a governing system is obtained. The connection must obviously be so made that with increasing speed the power-making ability is decreased and that with decreasing speed the ability to generate power is increased.

Before taking up real governors it will be necessary to consider how the power made available by an engine can be increased and decreased at will. It has already been shown that all the power is first generated within the cylinder and that this amount, less friction losses, finally arrives at the shaft and belt wheel. It has also been shown that the power generated within the cylinder depends upon the energy liberated by the burning gases per cycle and the number of cycles completed in a given time.

If it is desired to change the power generated there are obviously two possible methods available. They are (1) change the number of cycles in a given time or (2) change the power made available per cycle. Both of the methods are actually used.

If the number of cycles per unit of time is varied to suit the load while the engine continues to rotate at a practically constant speed the system of control is called *"Hit-and-Miss" Governing.* It derives its name from the fact that when the speed is normal or below normal some moving part of the engine hits another part as necessary to produce the next cycle, but when the speed is above normal the moving part fails to hit (misses) the other and the next cycle is not produced, *i.e.*, is "missed."

Most modern engines which are governed on this principle cut out cycles when necessary by holding the exhaust valve open and the inlet valve closed. The piston then simply pumps burned gases back and forth through the exhaust valve and no new charge can be drawn in.

Examples of regulating systems of this kind as applied on real engines are given in Chapter XVIII.

The other method of governing previously mentioned depends upon the production of as many cycles as possible, and the variation of the power made available per cycle. Since the power generated within the cylinder per cycle depends directly upon the quantity of fuel burned per cycle it is obvious that the work value of a cycle can be varied by changing the quantity of fuel supplied. This can be carried out in real engines in two ways. They are

(1) The fuel supply can be varied while the air supply is maintained constant, and

(2) The relative proportions of the mixture can be maintained constant but different quantities of mixture supplied to suit the demand.

The first method is called *quality* governing because the quality (proportion) of the mixture is changed. The second method is called *quantity* governing because the quantity of a constant-quality mixture is varied to suit the load.

Most agricultural engines which do not use the hit-and-miss method are supposed to be governed by the quantity method. In reality it is practically impossible to keep the quality of the mixture constant, so that these engines are really governed by varying the quantity of a variable mixture.

This variation of quantity is produced by partly closing some passage through which the mixture must pass on its way to the cylinder. The effect upon the charge is called *throttling.* Examples will be given later.

There has always been considerable discussion over the relative merits of hit-and-miss and the other forms of governing which, for present purposes, will be called throttling methods.

So far as efficiency is concerned, that is, the power obtained per unit of fuel used, the hit-and-miss method is theoretically the better. Practically, there is very little difference observable in small liquid-fuel engines, such as are used for agricultural purposes, with the exception of engines using kerosene and distillates, so that the matter of efficiency need, in general, be given little weight. Hit-and-miss governing possesses the advantage that the requisite parts are very simple in design and can be cheaply made, but even in this respect it is not much superior to the throttling methods in the hands of a good designer.

The hit-and-miss method labors under a great disadvantage. An engine governed in this way does not deliver its power in regularly distributed impulses with each impulse graduated to suit the instantaneous demand but gives a series of full power impulses erratically broken up by periods during which no power is developed. It follows that the fitting of the supply to the demand is much more approximate than with the throttling method and that the speed will therefore fluctuate much more. As a result, engines which are governed on the hit-and-miss principle require heavier flywheels than do those which are governed by throttling if the same degree of uniformity of speed is to be attained.

Practically, either method can be used for agricultural purposes with satisfactory results, but, with other things equal, the throttling method is to be preferred because of the more even distribution of impulses, the lighter flywheels, longer life of bearings resulting therefrom and longer life of engine which is not subjected to the wracking operation that results from hit-and-miss governing.

CHAPTER XIV.

LUBRICATION.

All metal parts which move over other metal parts must be lubricated or "oiled" to reduce the frictional resistance. If not lubricated this resistance will be high and the wear will be rapid. The oil used for lubrication forms a thin film between the surfaces and keeps them from touching, so that they may be pictured as riding over one another on an oil cushion with minimum frictional resistance.

The principal rubbing surfaces of internal-combustion engines are generally continuously lubricated; that is, provision is made to supply lubricant to them as long as the engine is in operation. The minor rubbing surfaces, those which travel slowly and those on which pressure is low, are generally arranged for hand lubrication at intervals. The better the design of an engine the more nearly will the lubrication of all parts be continuous and automatic and the less hand lubrication will be required.

The principal surfaces requiring lubrication in the ordinary, single-acting, internal-combustion engine are the external surfaces of the piston, the wrist pin, the crank pin and the main journals. These are often lubricated by what is called the splash method, illustrated in Fig. 69, in which are also shown separate oil cups for insuring more perfect lubrication of piston and main bearings.

In order to apply this method a closed crank-case construction must be used and as this is most common with vertical engines the splash system is most often applied to engines of this type. Splash lubrication has the great advantage of simplicity, but it is at best a haphazard method. There is no assurance that all parts will get as much oil as they need, and, unless special provision is made to prevent it, the cylinder walls are apt to get too much oil, resulting in carbon deposits, gummed rings, and smoke. The large quantity of oil in the crank case gradually becomes fouled with carbon and small particles of metal, so that it must be drawn out and replaced at intervals.

In small gasoline engines operating on the two-stroke principle with crank-case compression the lubricating oil is sometimes mixed with the gasoline and fed into the engine through the carbureter. Part of it is left suspended in the air as a fine oil fog after the gasoline vaporizes and this fog is carried by the mixture through the crank case and into the cylinder. During its passage it strikes, more or less perfectly, all of the principal surfaces requiring lubrication and hence may be expected to lubricate those surfaces to a certain extent.

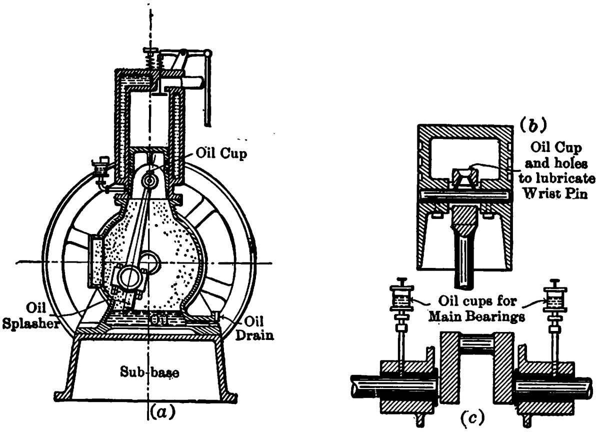


FIG. 69.—Splash System of Lubrication.

In engines of this type it has been found undesirable to use splash lubrication, because of certain interactions between gasoline and oil, and this fog method has formed a satisfactory substitute for small engines.

In general, it may be said that the most satisfactory lubrication will result when provision is made for feeding the lubricant when and where needed and in the exact quantity required. Such methods are slightly more expensive than the others but are to be preferred because they insure more satisfactory operation.

CYLINDER LUBRICATION.

An oil specially prepared for that purpose should always be used for lubricating the cylinder and piston. It must have a good body, that is, appear heavy, and yet it must be of such character that it will completely burn within the cylinder and not leave solid residues. Steam-engine cylinder oil does not possess this latter property and therefore should not be used.

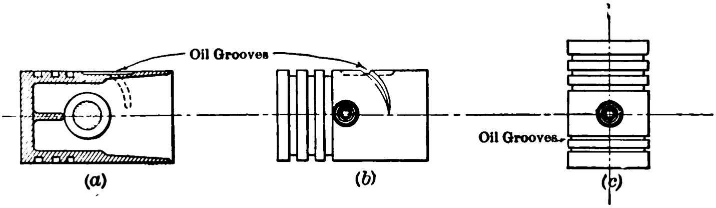


FIG. 70. — Piston Lubrication.

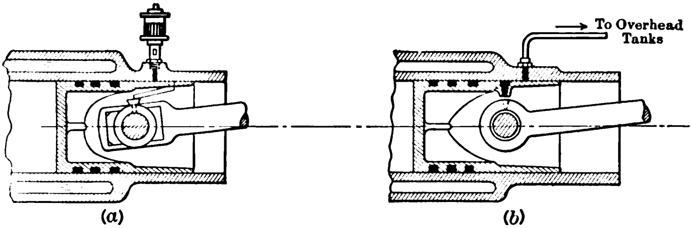


FIG. 71. — Wrist-pin Lubrication.

Provision should always be made for spreading the oil over the surface of the piston so that the latter can "wipe" it over the cylinder wall. This is generally provided for in horizontal engines by feeding the oil onto the top of the piston and by cutting grooves in the latter as shown in Fig. 70 (*a*) and (*b*). In vertical engines grooves like those shown in Fig. 70 (*c*) or a ring near the open end of the piston may be used.

Two methods of introducing the oil are shown in Fig. 71.

WRIST-PIN LUBRICATION.

The wrist pin is located within the piston and close to the hot piston face, so that there is a natural tendency for the bearing to heat up and for the oil to become thinner and less viscous and more easily squeezed out from between the two surfaces. The pin is, moreover, located in a position in which it cannot readily be inspected while the engine is in operation.

Particular attention should therefore be given the lubrication of this member. If splash lubrication is depended on, means must be employed for guiding the oil to the pin. Several typical methods are shown in Figs. 69 (*b*) and 71 (*a*) and (*b*).

CRANK-PIN LUBRICATION.

In the case of splash lubrication the crank is almost always sure of an excess of oil, so that perfect lubrication is assured unless gross carelessness prevents. It may be prevented by allowing the oil level to get too low in the case, or by clamping the end of the rod too tightly around the pin.

In open crank-case types the condition of the pin is easily determined by feel during operation. Imperfect lubrication will always cause the pin and the end of the connecting rod to heat up and this can easily be felt by allowing the rod to rub over the fingers of one hand as it revolves.

One of the oldest and simplest methods of lubricating this pin is shown in Fig. 72. It is at best very wasteful because a great deal of the oil is thrown off and never reaches the pin. One of the newest and most perfect methods is shown in Fig. 73. It is a little more expensive but it is absolutely certain. The oil once fed into the ring is retained in that ring by the centrifugal tendency and flows out through the hole shown and into the hole in the crank pin. There is but one way for it to go and that is in the direction of the surfaces to be lubricated.

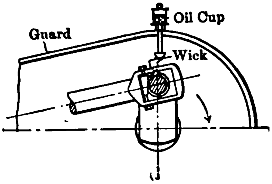


Fig. 72. — Old Method of Lubricating Crank Pin.

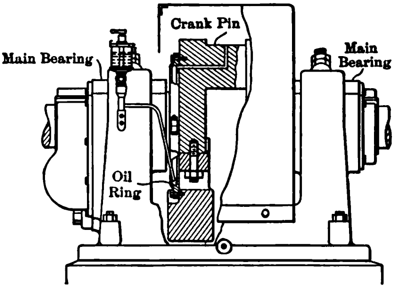


Fig. 73. — Oil Ring Method of Lubricating Crank Pin.

Lubrication of Main Bearings.

The main bearings in agricultural engines are generally lubricated by a simple oil cup as shown in Fig. 69 (*c*). These cups should always be of the "sight-feed" variety, one type of which is shown in Fig. 74, so that the number of drops per minute can be regulated to what experience has shown to give satisfactory operation.

The more expensive engines are quite commonly fitted with ring-oiling or chain-oiling bearings similar to those shown in Figs. 75 and 76. The ring or chain is moved by the shaft in the direction of rotation and spills over that shaft some of the oil which it brings up from the oil well. This either flows out along the shaft to waste or returns by gravity to the well.

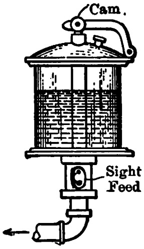


FIG. 74. — Oil Cup with Sight Feed.

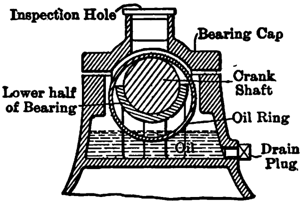


FIG. 75. — Lubrication of Main Bearing by Means of Ring.

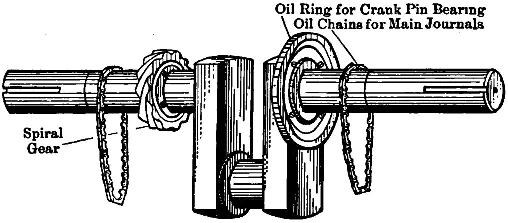


FIG. 76. — Lubrication of Main Bearings by Means of Chains.

CENTRALIZED LUBRICATION.

There is at present a tendency to centralize the oil supply and feed it at predetermined rates to the various surfaces requiring lubrication. An arrangement for doing this is shown in Fig. 77, the sight feeds connecting to small brass or copper piping which carries the oil to the various rubbing surfaces.

Such arrangements not only save time, as it is easier to fill one large reservoir than a number of small ones, but they also produce a beneficial effect upon the attendance. The operator is much more apt to closely watch the lubrication of his engine if he can do it by inspecting one piece of apparatus than if he has to inspect as many cups as there are bearing surfaces to be lubricated.

This central reservoir also possesses another advantage. By placing it high on the engine, it becomes possible to maintain a head of oil upon such bearings as are hardest worked and thus to improve their lubrication.

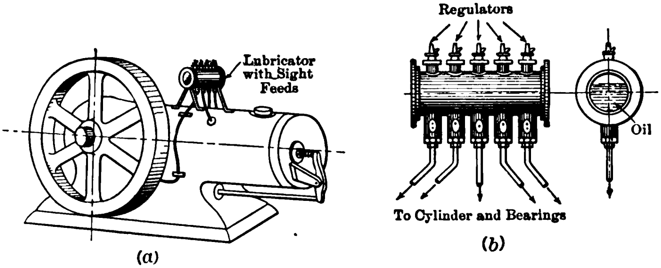


Fig. 77. — Centralized Lubrication with Multiple Feed Lubricator.

In some two-stroke engines using crank-case compression the natural head due to location has been further increased by connecting the upper part of the oil reservoir to the crank case in such a way that the compression pressure in the crank case is applied to the surface of the oil in the reservoir.

FORCED-FEED LUBRICATION.

There is at present also a growing tendency toward the use of lubricating pumps to force oil to the various bearings. In the most perfect development of this form an excessively large quantity of oil is forced to all the principal bearing surfaces excepting those of the piston where it would do more harm than good. The excess is caught as it flows from the bearings, is drained to a sump and again circulated by the pump. Systems of this kind are in use on many automobile engines and give excellent service.

In some cases a small centrifugal or a small gear pump is used to circulate the oil, the discharge of the pump being proportioned between the several bearings by sight feeds with adjustable needle valves. In other cases the oil is contained in a reservoir which also contains the suction ends of a number of small plunger pumps. The discharge of each pump can be separately regulated and is led to a single bearing surface, or to a group of bearing surfaces.

For stationary purposes in small sizes such pump circulation has generally been considered prohibitively expensive or complicated and is therefore seldom used. Many tractor engines are, however, equipped with such systems and, as their advantages become appreciated, their use will undoubtedly be extended to the stationary type. A pump of this variety is shown in position on an engine in Fig. 78.

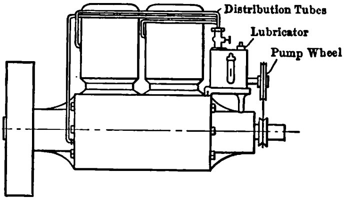


Fig. 78.—Pump Arranged for Forced-feed Circulation.

Provisions for Catching Oil.

In all engines there is more or less leakage of oil from the various bearing surfaces. Unless provision is made to prevent it, some of this oil gradually flows over the external surfaces of the engine frame toward the lowest possible point. The best engines are therefore arranged to catch this oil before it spreads over the external surfaces or they are provided with a groove running around the outside of the frame at the bottom as shown in Fig. 4. This groove is arranged to drain toward one end so that the oil caught by it can be run off into a convenient receptacle. Occasionally engines are constructed with the equivalent of such a groove below the main bearings only.

The best engines also have a drain arranged to tap the lowest point of the crank case so that the oil which collects therein can readily be removed. Such an arrangement is shown in Fig. 4.

Many builders of agricultural engines are now making engines with entirely inclosed crank cases. These serve two very useful purposes; they protect the moving parts from the dust and dirt which is often present in large quantities in the surrounding atmosphere and they serve as inclosed oil reservoirs to which all oil can be drained and in which it is protected from contamination with dust and dirt until drawn off.

CHAPTER XV.

DESIRABLE AND UNDESIRABLE FEATURES OF CONSTRUCTION.

When about to purchase an engine it is well to have in mind some idea of what constitutes a good engine from which long service can be expected and what points of weakness, which are apt to give trouble during operation, may exist.

As a general average, it is true that the most expensive engine is the best engine from a mechanical standpoint, but this does not mean that it is the best engine to purchase for agricultural purposes. *For such use an engine which is good enough to do the work satisfactorily is the best;* any further refinements or trimmings merely add to the first cost without yielding a commensurate return.

It will be shown in another chapter that the cost of engines varies very widely, some costing twice as much as others of the same power. Attention has already been called to the fact that a small engine run at a high speed can give the same power as a large engine run at a low speed. The small engine can, however, often be sold cheaper than the large one of the same power, because of the smaller weight of metal, the shorter time required for machining and fitting, the smaller tools which can be used in manufacture, etc. In comparing the prices of engines it is therefore necessary to compare the speeds also. More will be said about desirable speeds in a later chapter.

Assuming now that engines rated the same and intended to operate at similar speeds are found to have different selling prices one must, in general, look to the mechanical features in order to determine the engine which best justifies its price. The following paragraphs are devoted to a consideration of some of the more prominent features of construction which may serve as guides to the quality of engines.

THE FRAME.

The frame serves to hold the other parts of the engine in the proper relative positions and to tie them to whatever foundation is used.

The most important things which it does are to *preserve the proper alignment* of the cylinder and crank and to *preserve the proper distance* between the cylinder and crank shaft. These functions will be considered in greater detail.

In Fig. 79 are shown two partial views of an engine, the first looking down upon the top of it, that is, a plan; the second looking at the side, that is, a side elevation.

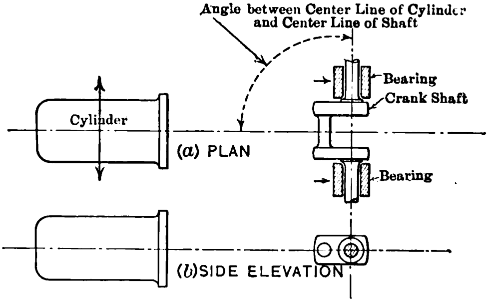


FIG. 79. — Alignment of Cylinder and Shaft.

The "center line" drawn through the center of the cylinder is seen to pass through the center of the crank pin and shaft. Most engines are so designed that the center line is supposed to have this position and a little reflection will show that if they are so designed any movement of the cylinder in the direction shown by the arrows will cause binding between piston and cylinder wall, and between connecting-rod ends and wrist and crank pins. The frame must, therefore, be so constructed as to *prevent relative shift-*

ing of the cylinder and shaft, so that the center line of the former no longer passes through the center of the crank.

Similarly, it is evident that the center line of the cylinder must be accurately at right angles to the center line of the shaft. The frame must therefore also insure such alignment.

The necessity of maintaining proper distance between cylinder and shaft is illustrated in Fig. 80. The gases at high pressure *P* in the combustion space tend to drive the cylinder off the piston, *i.e.*, toward the left, just as much as they tend to drive the piston out of the cylinder, that is, toward the right. Unless, therefore, the cylinder is rigidly tied to the bearings by means of the frame the cylinder will move off in one direction while the piston, connecting rod and shaft travel in the opposite direction.

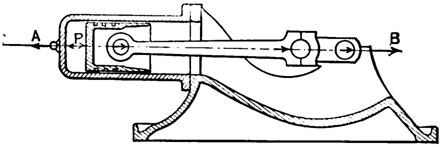


FIG. 80. — Action of Gas Pressure on Frame.

To some it is easier to picture this action by noting that it is just what would result if one could take hold of the head end of the cylinder and of the bearing end of the frame and pull them apart in the directions indicated by the arrows *A* and *B* in Fig. 80.

We may now investigate real frames to see how well they are adapted to meet these requirements. The great majority of frames can be divided into three classes, which for convenience will be called the *flange type*, the *bench type* and the *straight-line type*. These names are merely intended to be semidescriptive and are not commonly used. The three types are shown in Figs. 81, 82, 83, 84 and 85.

Consider first the *flange type* of frame. The cylinder may simply be bolted up to the face of this frame as shown in

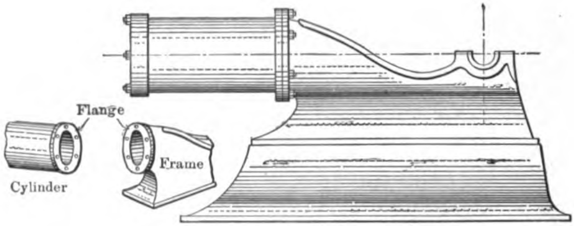


Fig. 81.—Flange Type, Cylinder Bolted onto Frame.

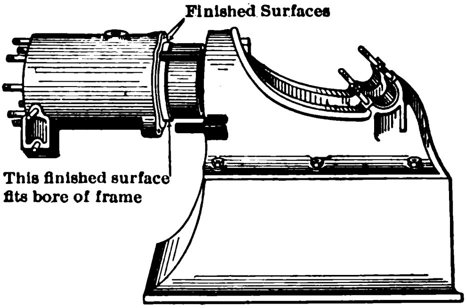


Fig. 82.—Flange Type, Cylinder Bolted into Frame.

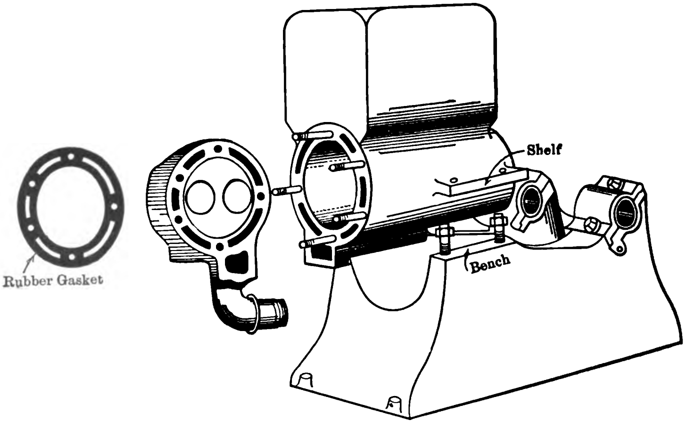


Fig. 83.—Bench Type Frame.

Fig. 81, or it may be set into the frame and held in this position by bolts or studs as shown in Fig. 82. It is obvious that in the first method, unless the bolts or studs are very carefully fitted into very carefully placed and finished holes, there is nothing but the friction between flanges to prevent the cylinder from shifting across the frame and causing binding of one sort or another. The construction in which the cylinder is set into the frame is therefore preferable.

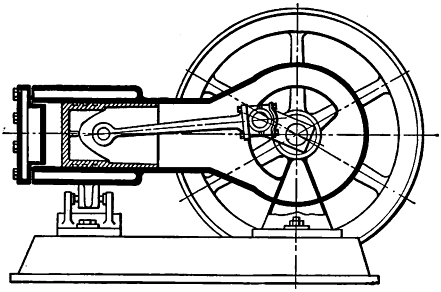


Fig. 84. — Small Straight-line Type of Frame.

Such counterbored designs are naturally more expensive to build and it should be noted that a casual inspection of the finished and painted engine may not indicate whether the cylinder is fitted into or simply bolted onto the frame.

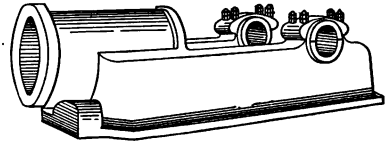


Fig. 85. — Large Straight-line Type of Frame.

For large engines the flange design is generally modified so that the flange on the cylinder is not located at the extreme end but nearer the center of length, the cylinder projecting into the frame so that less of it overhangs beyond the frame. For the sizes used in agricultural work this is hardly necessary, though it is advantageous if it can be obtained without increased cost.

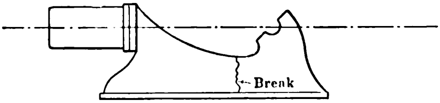


Fig. 86. — Line of Rupture in Frame.

Many frames, and particularly those of the flange type, are weak in resisting the tendency of cylinder and bearings to separate. The weakness lies in the location of the *upper curves of the frame* which join the cylinder flange to the bearings. The lower these curves the greater is the tendency to rupture along some such line as that shown in Fig. 86. These cracks start at the top and work down. The higher the curve is kept the stronger is the frame in this respect. Thus the frame shown by full lines in Fig. 87 is a great deal stronger than that shown by dotted lines.

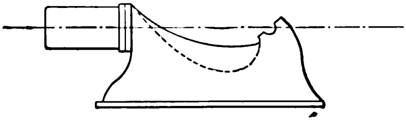


Fig. 87.

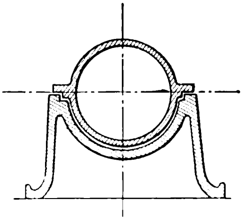


Fig. 88. — Section of Bench Type Frame.

Consider next the *bench type* of frame. This construction prevents up-and-down motion of the cylinder with respect to the frame if the bolts or studs are properly set up. Unless the holes in the shelf on the cylinder and the holes in the bench on the frame are accurately aligned, however, there is again nothing but friction to prevent cross motion unless the shelves on the cylinders fit into the frame, as shown in

Fig. 88, or some corresponding construction is used. In engines of the size commonly used for agricultural purposes friction offers sufficient resistance to prevent lateral motion and the more expensive form need not be used.

It should also be noted that with this type the cylinder cannot overhang the frame its entire length as it can in the flange type. It is therefore intrinsically a better arrangement.

There is also a tendency in engines with frames of this kind to keep the upper line of the frame up. It is often done merely as a matter of looks — the frame looking very weak and the engine very unsymmetrical if the upper line is dropped down. Most frames of this type are therefore apt to be stronger than those of the flange type.

The *straight-line type* is undoubtedly the ideal arrangement, so far as alignment, strength and rigidity are concerned. In most engines of agricultural size which are built in this way the cylinder and frame are cast in one. This is advantageous so far as strength and cost are concerned, but it should be noted that injury to cylinder barrel or jacket, as, for instance, by freezing, might necessitate practically an entirely new engine. On the other hand, the other types are arranged with separate cylinders which can easily be replaced.

There are two ways of overcoming this objection to the straight-line type. One is to use a separate cylinder, in conjunction with a frame of the type shown in Fig. 84, and the other is to use a frostproof type of jacket, — say, a hopper arrangement with generously proportioned opening, or a thin, easily broken plate bolted over an opening in the wall of a closed jacket.

While discussing frames it will be well to speak of the metal of the frame which backs up the main bearings. There are, in general, three different types of bearings in use. These are illustrated in Fig. 89 (*a*), (*b*) and (*c*), and may be called the *inwardly inclined* bearing, the *horizontally split* bearing and the *outwardly inclined* bearing respectively.

The *inwardly inclined bearing* is the one most commonly found on agricultural engines. It possesses the advantage that a great deal of metal is easily massed in such a way as to take the thrust of the piston during ignition and the early part of the stroke. It possesses a further advantage in the fact that there is an unbroken bearing surface from the point *e* downward. It is upon this part of the bearing that most of the load will be borne and hence any break which will allow lubricating oil to ooze out under pressure is undesirable.

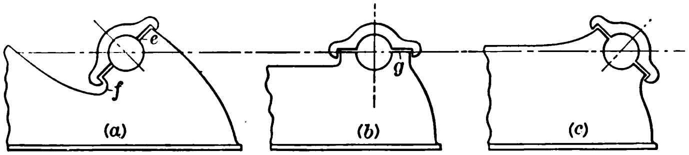


FIG. 89. — Three Different Types of Bearings.

On the other hand, inclining the bearing in this way necessitates a low part of the frame at *f* and thus weakens the frame to a certain extent.

Many engines now on the market have bearings of this type so constructed that the bearing itself is several times stronger than the frame. It is, therefore, wise to examine engines with inwardly inclined bearings with this point in mind. If there is a very low point in the upper curve of the frame and a great mass of metal to the right of *e* the construction is probably faulty and it would be a justifiable inference that other things about the engine are equally faulty.

The *horizontally split bearing* is almost standard for large engines and a necessity for practically all vertical engines. For small horizontal engines, it is not greatly in favor because of the assumed difficulty of getting a good bearing surface at *g*, it being commonly thought that there must either be a crack at this point through which the oil will ooze out or that a very expensive form of construction must be used. This is not necessarily so, as is evidenced by the successful operation of many engines with bearings of this type.

The horizontally split bearing comes the nearest to the ideal as it permits the use of high lines on the frame in combination with any desired amount of backing for the bearing.

The *outwardly inclined bearing should never be used.* It is inherently weak in practically every respect. The bearing cap has to take the thrust of the piston at the instant of ignition and during the early part of the expansion while the pressures in the cylinder are high, and it is not well adapted to resist such loading. It, in turn, is held to the frame by studs which cannot be made very large and which are too weak to safely carry the loads imposed.

Engines with bearings of this type should be viewed with suspicion on general principles.

More will be said about the details of bearings in later paragraphs.

When purchasing an engine it is always advisable to observe what provision has been made to guard against the splashing and waste of oil. The general character of the engine is often indicated by the degree of detail with which such things have been worked out.

The best horizontal engines will always have a "crank-case floor," as it is called. This is shown in section in Fig. 90. The floor should be so arranged that it slopes from the cylinder end of the frame downward to a low point beneath the crank shaft. In this way any lubricating oil which drains out of the cylinder, and any which is thrown onto the crank-case floor from the revolving crank, is made to drain automatically to this low point from which it can easily be

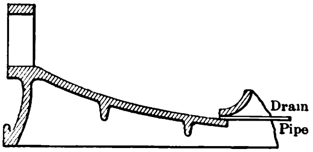


Fig. 90.—Shape of Crank-case Floor.

removed by means of a small pipe tapped into the metal of the floor as shown. If this small pipe or equivalent is not provided, the oil will simply collect in a puddle until it gets deep enough to be struck by the revolving crank and connecting-rod end, after which there will be a continuous shower of oil as long as the engine is in operation.

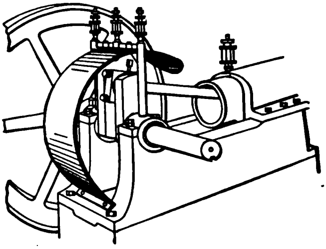


FIG. 91.—Oil Shield.

Horizontal engines which do not have an inclosed crank case should be fitted with an oil guard over the crank case as shown in Fig. 91. This serves the double purpose of receiving any oil splashed upward, so that it is drained back into the crank case, and of covering the moving crank and connecting rod. This latter function is worth considering in connection with farm engines as it prevents injury to people who might otherwise be struck by these parts and it also prevents injury to the engine which might result from the accidental dropping of tools and such into the crank case.

THE CYLINDER.

As a general principle *the simpler and the more symmetrical the cylinder casting the better*, as this not only simplifies the manufacture and therefore cheapens the engine but it also generally insures longer life and is a mark of careful designing.

Water-cooled cylinders are roughly divisible into two classes; those which have a *separate head* and those which have the *head and cylinder cast integral.* The former construction is shown in Fig. 83, the latter in Fig. 93. There is no particular disadvantage in having the head cast integral in small engines as the piston can easily be removed from the open end of the cylinder for inspection of the interior of the cylinder walls. There is, however, a great advantage in having this integral head, as it eliminates the cylinder-head joint which is often very troublesome.

When the separate head is used in engines of the agricultural type it is common practice to employ the construction shown in Fig. 83. The jacket of cylinder and head are made continuous by means of the cored holes shown and leakage of gases and water are prevented by means of a gasket such as that shown in the figure. It frequently happens that such joints cannot be kept tight, the water often leaking into the cylinder and causing ignition troubles. Very good metal and good workmanship will prevent such leakage but this can only be expected in the higher-priced engines. One very ingenious method of combining the good points of integral and separate heads without obtaining the disadvantages of either is shown in Fig. 52 (*a*). There is no cylinder-head joint and yet the interior of the combustion space is readily accessible through the ignition-block hole.

Igniter blocks of this type should never be so made that they require a gasket to prevent leakage of gas. They should make up against a shoulder in the cylinder casting as shown in Fig. 53, the contact being made gas-tight by grinding the block into position just as valves are ground in place. The shoulder against which the igniter block fits should always be as near the interior of the cylinder as possible; it should never be located as shown in Fig. 92 as this allows the hot gases to circulate about the block and the high temperature will soon cause binding of the movable electrode, if nothing more.

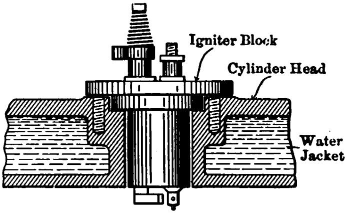


Fig. 92. — Incorrectly Designed Igniter Block.

The *jacket spaces* of all engines should be very liberally proportioned and openings into them should be provided of such size and in such position that all parts of the interior are accessible. When this is done, the mud and scale deposited by the jacket water can be cleaned out at intervals. When it is not done, this material can only be imperfectly washed out or else allowed to accumulate until it prevents proper circulation and causes local heating with consequent rupture of the metal or preignition of the charges. The jacket space should always be provided with a drain at its lowest point to facilitate washing out of solids and to make it possible to drain out all water when the engine stands idle in freezing weather.

The water jacket should cover the head of the cylinder and at least a little more of the barrel than is exposed to hot gases by the motion of the piston. Jackets which extend far enough to cover the piston rings when the piston is at the outer end of its stroke give perfectly satisfactory operation.

The pipe leading the water from a closed jacket should always be connected at the highest point of the jacket. If this is not done the air and other gases which are given up by the water as it is heated may collect at the highest point and cause local overheating. This is shown in very exaggerated form in Fig. 93.

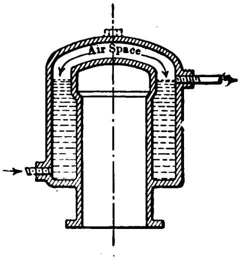


FIG. 93. — Improper Location of Offtake Pipe.

When hopper-cooled engines are to be mounted on skids or trucks, provision should be made to prevent water splashing out of the jacket because of surging when the outfit is being moved. This is generally provided for either by so shaping the top of the hopper that any wave started within the water will cause the latter to turn back into the hopper instead of spilling out, or by using a perforated "splash plate" within the top of the hopper and so located as to be struck by any waves formed.

The necessity of some such provision should be borne in mind when purchasing engines of this type.

The *internal surface* of the cylinder may be machined in several different ways. It is self-evident that the cylinder which is so machined that its interior surface is most nearly a true cylinder will be the best as it will allow the smallest amount of leakage.

Such surfaces are best finished by grinding, which has the further advantage of giving the metal a very hard, glasslike surface which is very resistant to wear.

Many manufacturers now finish their smaller cylinders in this way and it is a point which should be investigated when purchasing an engine.

VALVES.

The imperfect operation of horizontal valves was considered in Chapter IX. Notwithstanding the fact that this is well known to the builders of engines, the greater number of horizontal agricultural engines are fitted with horizontal valves. This is probably due to the fact that the mechanism required to operate horizontal valves is much easier to design and can be more cheaply built than that required with the more perfect vertical types. With hopper-cooled, horizontal engines it is particularly difficult to arrange the design so that vertical valves can be used, but it has been done in several instances so that it is not at all impossible.

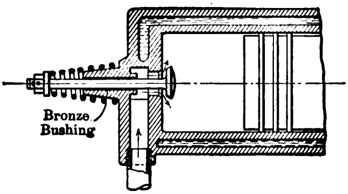


Fig. 94. — Horizontal Valve with Bronze Bushing in Stem Guides.

If it seems to be desirable to purchase an engine with horizontal valves the stem guides should either be bushed with bronze as shown in Fig. 94, or else the metal of the guides should be thick enough to permit of reboring and the insertion of a bushing when wear becomes excessive.

In this connection it is worth noting that many manufacturers provide absolutely no means of lubricating the stems of the valves. A horizontal valve, operating in an unlubricated cast-iron guide may be reasonably expected to wear to a prohibitive extent in part of a season so that the question of lubrication should always be investigated.

For small engines, an oil hole which can be filled occasionally from a squirt can is all that is necessary; for larger engines, compression grease cups, or small oil cups, should be used.

All valves should be carried in *removable cages* as described in Chapter IX, or should be so located that they can be removed through holes properly located and normally closed by plugs or equivalents. Valves should never be arranged as shown in Fig. 94, because of the difficulty of inspecting, caring for, and removing when so located. When cages are used they should seat, metal to metal, at their inner end as described in the case of the igniter block.

The so-called *automatic-inlet valve* is very commonly used on agricultural engines. It possesses the advantage of requiring no driving mechanism and therefore simplifies and cheapens the engine, but it operates imperfectly at best. When installed in a horizontal position it is particularly bad both because the friction on the stem retards its opening and because the weak spring which must be used cannot properly seat the valve after the guide has been worn out of true.

THE PISTON.

The piston should always have at least three rings at the head end in order to effectually prevent excessive leakage of gas. Even with three rings there will generally be appreciable leakage unless they are very well fitted.

Rings made by a grinding process are the best as they are most nearly true to shape. They operate particularly well in ground cylinders.

The individual rings should always be pinned in place to prevent their rotating in their grooves and thus bringing all the openings in line and facilitating leakage. In horizontal engines the joints should all be on the lower part of the piston, so that they do not serve as oil reservoirs, and they should be staggered so as to make the distance between successive joints as great as possible. In vertical cylinders distance between joints is the only controlling factor.

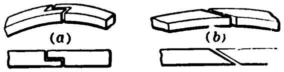


FIG. 95. — Method of Cutting Piston Rings.

The joints or "splits" should preferably be made as shown in Fig. 95 (*a*) as this form is better able to prevent leakage than is that shown in Fig. 95 (*b*).

The piston should be provided with grooves or rings such as those described in Chapter XIV, to facilitate spreading of the oil and to thus insure good lubrication.

THE CONNECTING ROD.

The *material* used in the connecting rod of the engine is of the greatest importance. Steel is the standard for this purpose and cannot be improved upon when price is taken into consideration. Steel connecting rods can now be secured practically ready made for the smaller sizes of engines, being forged out by heavy machine tools.

In the earlier days of the industry such rods were not available and many manufacturers made their rods of cast iron and then put them through a process known as malleableizing. This converted the brittle cast iron into a less brittle form of iron but did not make it a satisfactory substitute for steel. Such rods frequently broke in operation and in many cases completely wrecked the engine. There is only one type of cast rod which is safe and this is a rod cast of phosphor bronze. This is fully the equal of steel when properly made but is generally more costly excepting where a small number of engines of one size are being made. As there are still builders who use malleable iron rods it is well to determine the metal of which the rod is made before purchasing.

The *wrist-pin end* of steel rods should always contain a *bronze bushing* to inclose the steel wrist pin, as steel does not run well on steel. In all but the smallest engines this bushing should be split and some arrangement should be provided for taking up wear. The bushing should also be prevented from rotating within the end of the rod. A very common and simple form is shown in Fig. 96.

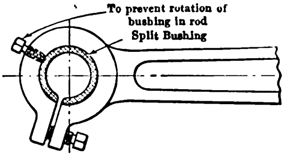


Fig. 96.—Wrist-pin End of Connecting Rod.

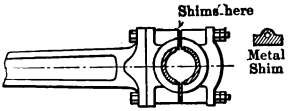


Fig. 97.—Crank-pin End of Connecting Rod.

The *crank-pin end* of the rod should be lined with a good quality of *white or antifriction metal* and should be so arranged that it can be adjusted to compensate for wear. One of the most common forms is shown in Fig. 97. This type should be provided with "shims" such as those shown in the figure so that the cap can be clamped tight against the solid part of the rod and thus form a rigid bearing with proper clearance for the crank pin.

Crank Shafts.

The crank shafts are always made of steel, as this is the only metal which will stand the very severe usage to which they are put. They are made in three distinct ways; these are,

(1) Drop forged in large presses which shape hot metal by pressing it between dies. Such shafts are very satisfactory

and are generally machined on main bearings and crank-pin surfaces only. They are not generally made in very large sizes so that some other kind must be used on the larger engines.

(2) Forged out into approximate shape by hand or steam hammer. Such shafts are excellent when well made but a great deal depends upon the skill of the blacksmith and they are generally costly if properly forged. They are machined on main bearings and crank-pin surfaces only.

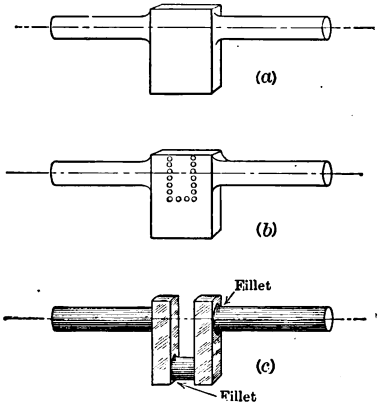


Fig. 98. — Forged Crank Shaft.

(3) Forged out to the shape shown in Fig. 98 (*a*) and then finished by machinery to the shape shown in Fig. 98 (*c*). Such shafts are generally regarded as the best that can be produced at a reasonable price. They are machined all over.

It is very important that there should be *no sudden changes of size* along the length of crank shafts. That is, a shaft should be finished with fillets in all corners as shown in Fig. 98 (*c*), not with square corners. Experience has shown that shafts with square corners will invariably crack through if used long enough, the crack starting in one of the corners.

MAIN BEARINGS.

The general shape of the main bearings has already been considered under frames. They should always be so arranged that the cap can be clamped solid against the frame (by use of shims or similar devices) without pinching the shaft but so as to fit tight enough to give the shaft the necessary support. The bearings should always be lined with white antifriction metal.

It is self-evident that provision must be made for *taking up the wear in the main bearings.* This wear occurs almost entirely upon the lower part of the bearing because the pressures are exerted almost entirely upon that part. In most engines of the agricultural type this wear is compensated for by following it up with the bearing cap.

Ultimately the wear will become so great that rebabbitting will be necessary. As relining a bearing with babbitt and subsequently scraping this babbitt to form a good fit on the shaft calls for more skill than the average operator may be expected to possess, some manufacturers are now putting out bearings of a different type. In these bearings a removable shell of appropriate metal takes the place of the cast-in babbitt of the older form. When wear becomes excessive the shell is removed and replaced by another which has been accurately fitted by the manufacturer at his works. The operator therefore need not possess any particular skill.

For small engines oil cups placed on the caps will give satisfactory lubrication. The bearing should always have oil grooves cut into the bearing metal to assist in distributing the oil.

Larger engine should be fitted with ring-oiling or chain-oiling bearings, such as those shown in Figs. 75 and 76, or with pressure-feeding devices such as those previously described. In all cases provision should be made for carrying away all excess of lubricant.

FLYWHEELS.

Small flywheels can be *cast solid,* but the larger wheels should have a *split hub.* These two constructions are shown in Figs. 2 (*b*) and 3 (*b*). The split hub is used to neutralize certain strains which would otherwise be set up as the metal cooled and solidified in the mold after casting.

Split hub wheels should be bored so as to form a good fit on the shaft and should then be clamped on that shaft with bolts as well as being held against rotation by means of a key. In all cases the keys of flywheels should be well fitted over their entire length as the usage to which they are subjected is very severe. It is well to test the fit of keys in such cases by slacking the nuts on the hub bolts and then trying to rock the flywheel back and forth while holding the shaft so that it cannot rotate.

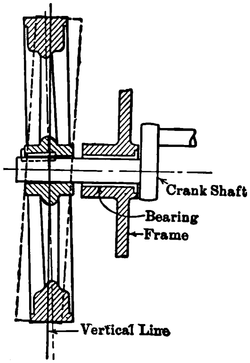


FIG. 99. — Flywheel Hub not Bored accurately.

It is also well to test all engines for "squareness" of flywheels before purchasing. If a flywheel hub is not bored true the wheel will not fit "square" on the shaft but will take a position such as that shown in very much exaggerated fashion by the full lines in Fig. 99. When such a wheel is rotated it has a distinct "wobble," and this not only seriously strains the wheel but overloads the shaft and bearings as well.

BALANCING.

It is customary to "balance" all the better engines to a certain extent. The necessity for such balancing comes from two sources; they are

(*a*) The unbalanced rotating masses, and

(*b*) The unbalanced reciprocating masses.

The unbalanced rotating masses are composed of the crank pin, part of the crank webs and part of the connecting rod, all of which rotate about the center line of the shaft, see Fig. 2 (*a*), and are not balanced by similar masses on the other side. They constantly tend to pull the shaft in their direction and, since the shaft is held to the frame by the bearings, they tend to pull the frame in the same way. They can be balanced by placing masses opposite them (on the other side of the center line of the shaft) so proportioned as to give an equal and opposite centrifugal effect. The common construction for the more expensive engines is shown in Fig. 100. For cheaper engines it is customary to cast these weights into the flywheels, giving a construction similar to those shown in Fig. 101. The flywheels are then put on the shaft in such positions that the balance weights

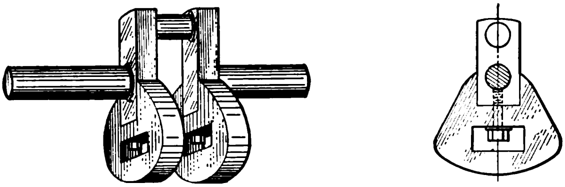


FIG. 100. — Balance Weights on Crank Webs.

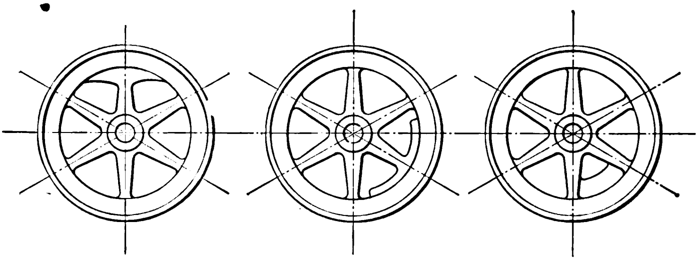


FIG. 101. — Balance Weights in Flywheel.

are opposite the crank pin. For small engines this is permissible, but for larger sizes it puts very severe local loads on the shaft and on the rim of the flywheel and is not to be commended.

The reciprocating parts, consisting of the piston, wrist pin, and piston end of the connecting rod, cause certain unbalanced forces which it is impossible to explain in a book of this character. Their occurrences can, however, be appreciated by comparing the engine to a gun as was done in an earlier chapter. It is common experience that a gun "kicks" or "recoils"; that is, it moves in the opposite direction to that taken by the bullet. The cylinder and frame of an engine tend to behave in exactly the same way, moving in the direction opposite to that taken by the piston and other reciprocating parts.

The effect cannot be perfectly balanced by rotating counterbalances, but it can be partly overcome in this way. The better engines have their counterbalances so proportioned as to balance part of the effect of the reciprocating masses.

Reciprocating masses can be most nearly balanced by other reciprocating masses located so as to be opposite in every sense to those which are to be balanced. One example of such practice is shown in Fig. 150 which represents what is called an opposed engine. It will be observed that this construction is equivalent to two separate engines, connected end to end n such a way that they tend to move in opposite directions.

Such engines are extensively used in two-cylinder and four-cylinder constructions for driving tractors and for mounting on trucks. The high degree of natural balance is particularly desirable in such cases.

Two-, three- and four-cylinder vertical engines, so arranged that the pistons of the different cylinders move in the proper relation, also give a similar form of imperfect balance.

GASOLINE PUMPS.

Many gasoline engines are fitted with a fuel pump which raises gasoline from the reservoir to the overflow or constant-head vessel of the carbureter. These pumps are generally driven from the half-time shaft of the engine and are so proportioned that they circulate more gasoline than can be used in the cylinder, as described in Chapter XI.

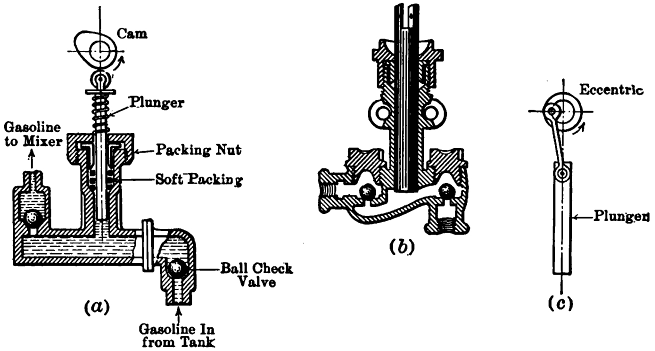


FIG. 102. — Types of Gasoline Plunger Pumps.

Gasoline pumps are operated in two distinctly different ways which are shown diagrammatically in Fig. 102 (*a*) and (*b*). In both cases a solid brass or bronze bar moves up and down within a cylinder which is fitted with suction and discharge valves. The combination forms an ordinary plunger pump; the cylinder fills with fuel when the plunger moves up and this fuel is forced through the discharge valve when the plunger again descends. The plunger cannot be made to fit so tightly within the cylinder that no gasoline can leak past it on the downstroke and *packing* is therefore used, in the way shown, to prevent leakage.

As the plunger moves up and down it gradually wears the packing so that the latter must be "taken up" at intervals to prevent leakage. This is accomplished by screwing down the cap forming the top of the stuffing box. It often happens that this results in setting the packing up so tight that it grips the plunger and, when the arrangement shown in Fig. 102 (*a*) is used, the spring may not be strong enough to return the plunger against this added resistance.

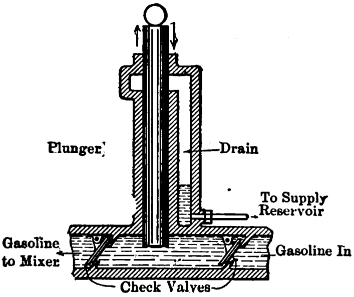


Fig. 103. — Plunger Pump with Drain.

It is obvious that the positively driven arrangement shown in Fig. 102 (*b*) and (*c*) obviates this difficulty and is therefore the better of the two when this type of pump is used.

The pump can, however, be so constructed that tight packing around the plunger is not really necessary. A design of this type is shown in Fig. 103. Any leakage by the plunger will automatically drain back to the suction side of the pump and the packing of the other types is theoretically unnecessary. Packing should, however, be used to prevent the efflux of gasoline vapor and the splashing out of liquid.

CHAPTER XVI.

MUFFLING AND MUFFLERS.

It was shown in earlier chapters that the exhaust of a gas engine (opening of exhaust valve or uncovering of ports) must occur before the end of the expansion stroke. When the exhaust valve or ports open, the pressure within the cylinder is very high and the burned gases rush out very suddenly and with a very high velocity. Velocities of between one and two miles a minute are quite common.

This sudden rush of gas, striking the air opposite the end of the exhaust pipe, would literally strike that air a blow just as a hammer strikes an anvil. The result would be very similar, in that a distinct sound would follow. In the case of the gases striking air the sound is not at all pleasant; it is the familiar "explosion" of an unmuffled engine. Such explosions do the engine no harm because they are merely vibrations of the air near the engine. They are, however, very annoying to human beings and animals and most engines are fitted with a device called a *muffler* to decrease their violence.

The action of a muffler can be appreciated only when the way in which a gas engine exhausts is understood. Between the time at which the exhaust valve opens and the time at which the piston arrives at the end of the exhaust stroke from one half to two thirds of all the burned gas rushes out of the cylinder. The remainder is discharged comparatively slowly during all of the return (exhaust) stroke. It is the sudden rush at the beginning which causes the unpleasant sounds.

The *muffler* must, therefore, be constructed in such a way that it *prevents the sudden outflow of a solid column of gas at* *high velocity.* It must not, however, prevent a free exhaust because this would decrease the power of the engine by decreasing the amount of burned gases exhausted and therefore decreasing the quantity of fresh charge drawn in for the succeeding cycle. The function of the muffler can best be described by saying that it must convert spasmodic discharges at high velocity into slightly less spasmodic discharges at lower velocity.

Mufflers practically always accomplish this result by cooling the gases to a certain extent, so as to reduce their volume; by offering a large volume which the gases must fill before striking the external atmosphere; and by imperfectly obstructing their sudden flow.

A form which is comparatively simple and very effective is shown in Fig. 104. The gases rushing into the smaller pipe at end *C* pass out through the holes in the walls of that pipe and into the larger outside pipe. From here they again enter the central pipe on the other side of the obstruction *B* and flow to the atmosphere through the outlet *A*. When such a muffler is used the discharge from *A* is very smooth as compared with the inrush at *C* and it is also comparatively noiseless.

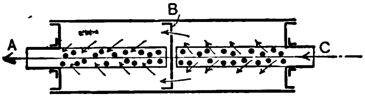


FIG. 104.—Simple Muffler.

This is due to the facts that the gases are partly cooled by radiation from the large metallic surfaces and that the gases rushing in at *C* have to completely fill the large pipe before any flow into the discharge end of the small pipe and leave at *A*. The expansion into this large pipe, combined with the lowering of pressure due to cooling, decreases the pressure which causes the flow through *A*, and hence decreases the violence of impact and the resulting sound.

Other types which operate in very similar ways are shown in Fig. 105 (*a*), (*b*) and (*c*).

Small engines are often fitted with what is called an exhaust pot in place of a muffler. This is really a muffler but gets its name from the fact that it consists of a cast-iron pot with a cast-iron cover. Many varieties are in use; some are good silencers and many are not. A very good form is shown in Fig. 106. The exhaust enters at *A* in such a direction that it whirls around the inside of the pot and then gradually works its way through a perforated plate (not shown) and out of the pipe *B*. The action is similar to that of the mufflers already shown, but the whirling action also assists in preventing sudden discharge by causing the gases to hang to the walls for a short period of time.

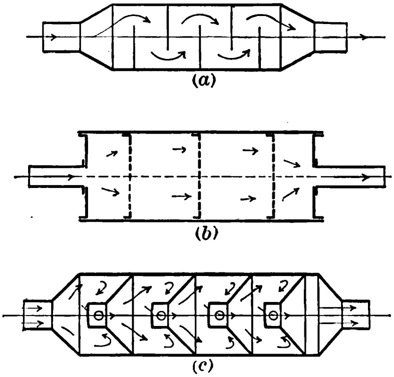


Fig. 105.—Types of Exhaust Mufflers.

In Fig. 107 is shown a type of muffler used on very small engines. When well proportioned it can be made to give a very quiet exhaust, but if improperly designed it may cause very disagreeable ringing and whistling sounds. Its silencing properties depend almost entirely upon offering so large a discharge area in comparison with the area of the exhaust pipe that the exhaust gases strike the atmosphere with a very low velocity.

The *combustion* which occurs within the cylinder of an internal-combustion engine always *results in the formation of water*. This water is formed by the combination of hydrogen, contained in the fuel, with oxygen taken from the air in the charge.

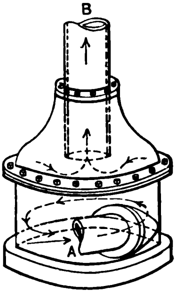


FIG. 106. — Exhaust Pot Muffler.

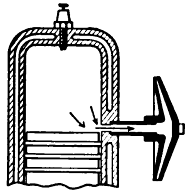


FIG. 107. — Muffler Used on Very Small Engines.

The water exists as steam in the burned gases but part of it can be liquefied by cooling these gases. This often occurs within the exhaust pipe and muffler of an engine, and it is therefore best to so arrange the exhaust that such water cannot back into the engine cylinder when the exhaust valve is opened. It is also advisable to install a drip pipe or its equivalent on the muffler when this is located at a low point in the system so that the water would normally drain toward it.

CHAPTER XVII.

POWER, PRICE AND SPEED.

In previous chapters attention has been called to the facts that *power* of engine, *cost*, *weight* and *speed* are intimately connected and that the best combination may be expected to give the best results.

Engines of the agricultural type are still in the process of development and no one type has yet proved its superiority. Most of these engines are merely single-cylinder, horizontal, four-stroke engines which have been developed from the similar stationary engines previously built by the manufacturers. There are, however, a few engines which have been designed along new lines particularly for agricultural purposes. These engines all indicate a *tendency toward the use of much higher speeds* than are common in the other type and are therefore much lighter than the others. This property is very desirable as it makes the engines more readily portable.

There is also a marked *tendency toward the use of vertical constructions* instead of the more common horizontal type. Vertical construction possesses several advantages in the ease with which valves and valve-operating mechanisms can be arranged, the simple and symmetrical castings which can be used, the higher speeds which can be attained and the smaller weight of metal which can be made to suffice.

Despite the increased speed and reduced weight of these newer designs, the engines are not sold at prices appreciably lower than those of the more common type. This is probably partly due to economic considerations, the prevailing price being set by the cost of production of the more common type, but it is also due, in a large measure, to the facts that the high-speed engines in many cases are of recent development and are therefore burdened with the cost of designs, patents and patterns, that they are in some cases constructed of better materials, and that they are often very carefully machined and finished.

In order to obtain information with regard to the prices of engines and their variation with different designs, the products of nearly all American manufacturers of agricultural engines were carefully studied and compared. The results of comparison are shown in Fig. 108 in which are indicated the selling prices per horse power of engines of different capacities.

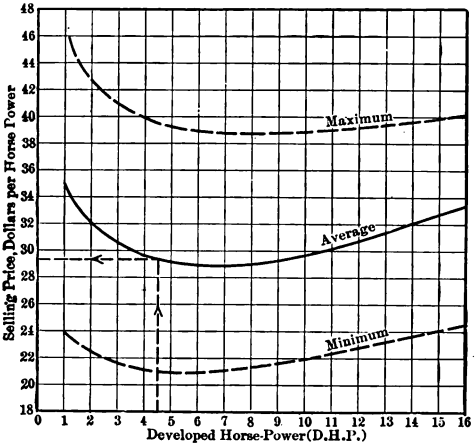


Fig. 108.

The curve in the center of the figure gives rough average values. From it the average selling price per horse power of any size of engine can be determined by finding on the lower horizontal line the horse-power rating of the engine in question, running vertically upward to the curve and then running horizontally to the left until the left-hand vertical line is reached. The figure indicated is the average cost per horse power of the engine in question. This process is illustrated for the case of a 4½-horse-power engine by the dotted lines in the figure. The average price per horse power appears to be about $29.40 so that the average selling price of such an engine would be about $132.

The *extraordinary variations in prices* are indicated by the upper and lower curves which represent approximately the maximum and minimum prices quoted by manufacturers. From these lines it is apparent that the price of a 4½-horse-power engine, for instance, may vary between about $21 and $40 per horse power. This is equivalent to prices of about $95 and $180 for an engine which is sold at an average price of about $132.

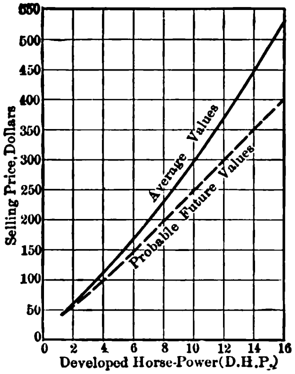


Fig. 109.

This great variation is due to a number of causes, some natural and some artificial. The cost of production of exactly similar engines would naturally vary in different factories because of different location, different size, different arrangement and so on. The cost of advertising and selling would also vary in a similar way. Added to such variations are the facts that the manufacturers are offering many radically different types, some good but salable at a low price, some good but very expensive, some made to sell at a low figure regardless of lasting worth and some very costly but not worth the money charged for them.

The upper curve in Fig. 109 gives average selling prices of engines corresponding to the values given by the average curve in Fig. 108. The lower curve will be referred to later.

In an effort to determine the best prices that might be expected, a more elaborate analysis was made. It was confined to the single-cylinder, horizontal, water-cooled, four-stroke type as there were the largest number of figures available for this variety.

This analysis very conclusively showed that, as the operating speed chosen by the designer for engines of any horse-power rating increased, the *selling price* decreased until a certain *minimum value* was attained. Further increase of speed caused a rise of price.

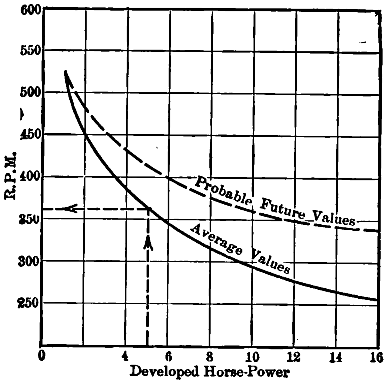


FIG. 110.

This can be explained by the fact that, within limits, and for any given horse-power rating, the size and weight of engine decrease as the speed increases and that this results in decreased selling price up to the point where further increase of speed necessitates refinements of design and construction which overbalance the gain from increased speed. These conclusions would be modified at high speeds by the throttling effect of valves and carbureters which have already been discussed.

Other things being equal, the speeds which give minimum costs would be the *correct speeds* to use and might be expected to be those toward which manufacturers would gradually work. Checking of these best speeds with good design formulas and constants showed that they are not excessive and, hence, that they may legitimately be expected in future designs.

In Fig. 110 are given two curves showing the rated rotational speed of engines of the type under consideration. The lower curve gives the average speeds now used and the upper curve gives those which may be expected in the future as a result of an effort to decrease the selling price of agricultural engines of this type. The method of obtaining values from the curves is indicated by the dotted lines in the figure and is the same as that described in connection with curves previously given.

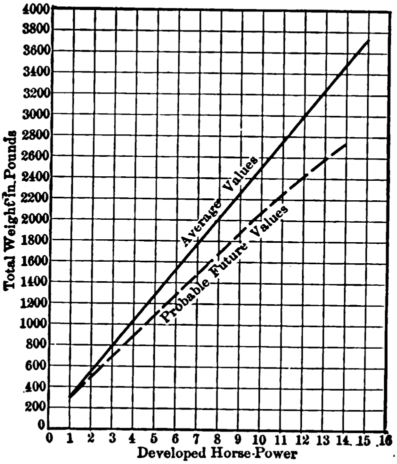


Fig. 111.

It will be observed that the changes are negligible in the smaller sizes but that they increase in relative magnitude as the size of engine increases. This is what would be expected from the fact that a large proportion of the manufacturers are making special farm engines in the smaller sizes but have not yet changed their larger models.

The lower curves of Figs. 109 and 111 are drawn for probable values; that is, the values of selling price and of weight which may be expected if the speeds are raised to the probable values shown in Fig. 110 and if nothing else develops to modify conditions.

The *probable prices* per horse power are shown by the lower curve of Fig. 112, the upper curve being a reproduction of the average curve originally given in Fig. 108.

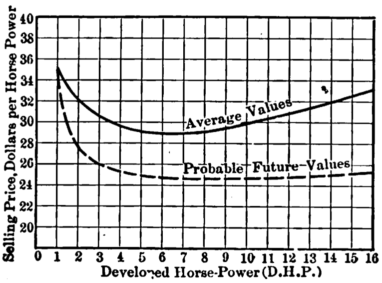


FIG. 112.

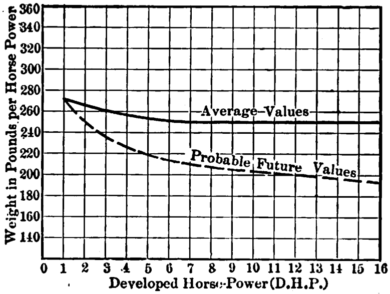


FIG. 113.

In Chapter VII it was shown that the *power* of an engine can be expressed with reasonable accuracy in terms of the diameter of the cylinder (d), the length of the stroke (l) and the revolutions per minute (n). In Fig. 114 are shown several straight lines which give means of obtaining the values of d^2ln for different horse-power ratings. The line marked "Average" gives the average values as obtained from engines as now built, while the lines marked "Maximum Displacement" and "Minimum Displacement" serve to indicate the great variations in present-day ratings.

The line marked "Probable Future Values" gives the values which correspond with the other data already given as probable in the future.

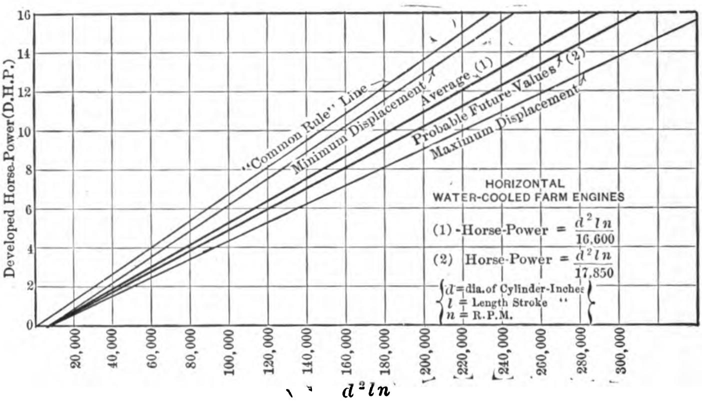


FIG. 114.

It is interesting to note that the values indicated as probable averages for the future call for greater piston displacement for a given horse power than do the present average values. This means simply that the increase of speed which has been suggested as the means of reducing selling price will progress to such a point that throttling losses will be appreciably greater than they are in the average engine of to-day, and that therefore the diameter and stroke cannot be decreased to as great an extent as the increase of speed would seem to make possible.

This throttling loss can be decreased by better valve and carbureter design and by other simple and inexpensive refinements, so that it is possible that the engines of the future may not have so large a piston displacement as here indicated.

The equations given in Fig. 114 are not absolutely correct as they have been slightly modified for the sake of simplicity. The greatest error that will result from their use is, however, so small as to be negligible in comparison with the rough averaging which is necessary in obtaining results of the character given here.

In connection with these lines it is worth noting that they show the *error of a very common rule* for the estimation of the capacity of water-cooled, gasoline farm engines. This rule is that one horse power can be obtained for every 10,500 cubic inches of piston displacement per minute counting only the part of the piston displacement which corresponds with the pumping part of the cycle. This is equivalent to the area of the piston multiplied by the stroke and by the revolutions per minute. In the figure the line marked "Common Rule" shows the results of this rule in the same terms as have been used before. It will be observed that for any given horse power, the common rule calls for a smaller value of the piston displacement than is shown by any one of the other lines. In other words, the common rule would give an engine too high a rating.

CHAPTER XVIII.

TYPES OF FARM ENGINES.

THE following pages are devoted to descriptions of a number of typical gas engines sold for agricultural purposes.

It should not be assumed that the particular engines chosen for description are believed by the authors to be the best that are available. The choices made were guided by the desire to present characteristic types so that the agriculturist could become familiar with those types and thus obtain a broad view of the kinds of engines which are built to meet his needs.

There is no one of these engines which possesses all the advantageous features which have been mentioned in preceding pages, nor has any one builder eliminated all the undesirable features to which attention has been called. Each engine represents a particular commercial solution of the problem presented to the designer and it is hoped that the impartial descriptions which follow may, when coupled with the material which has preceded, enable the reader to form a much better conception of the degree of success with which the problems have been solved than is generally possible from the reading of the glowing and rosy descriptions which appear in the average engine catalogue.

Having acquired such a viewpoint a prospective purchaser should be able to measure the good and bad points of the particular engines which happen to be most readily available in his locality and, being able to give these points their true weight, he should be able to purchase to the best advantage.

I. H. C. AIR-COOLED ENGINES.

The International Harvester Company markets several complete lines of gas engines of various kinds. They are roughly divisible into water-cooled and air-cooled types.

The air-cooled engines are built in both vertical and horizontal types, the former in 2 and 3 horse power sizes and the latter in units rated at 1, 2 and 3 horse power respectively. The engine chosen for description is the 1 horse power, horizontal engine marketed under the trade name of the Tom Thumb Famous Engine.

This engine is shown, mounted on a wooden base with all accessories, in Fig. 115. An idea of relative size can be obtained from the fact that the flywheel diameter is 15½ inches.

It will be observed that the cylinder is cast with radiating webs or fins and that a fan, shown behind the cylinder, forces air over these fins. The fan is driven by belt from the rim of the flywheel on the fan side of the engine.

The inlet valve, located in the cylinder head, is automatic. The air charge is drawn in through the right-hand branch of the forked pipe shown below the valve in the figure. The lower end of this branch is fitted with a throttling device for regulating the flow of air by hand.

The gasoline is contained in the circular galvanized-iron tank shown below the cylinder and is fed to the carbureter by suction. That is, the pressure around the fuel nozzle which is located in the left-hand branch of the inlet pipe is lowered during each suction stroke and atmospheric pressure on the surface of the fuel in the tank forces some of it up the fuel pipe and through the fuel nozzle. The quantity discharged through the nozzle is regulated by the needle valve located just above the fuel tank.

The exhaust valve is mechanically operated by a horizontal push rod running along the side of the cylinder as shown in the figure. This rod engages a horizontal lever running

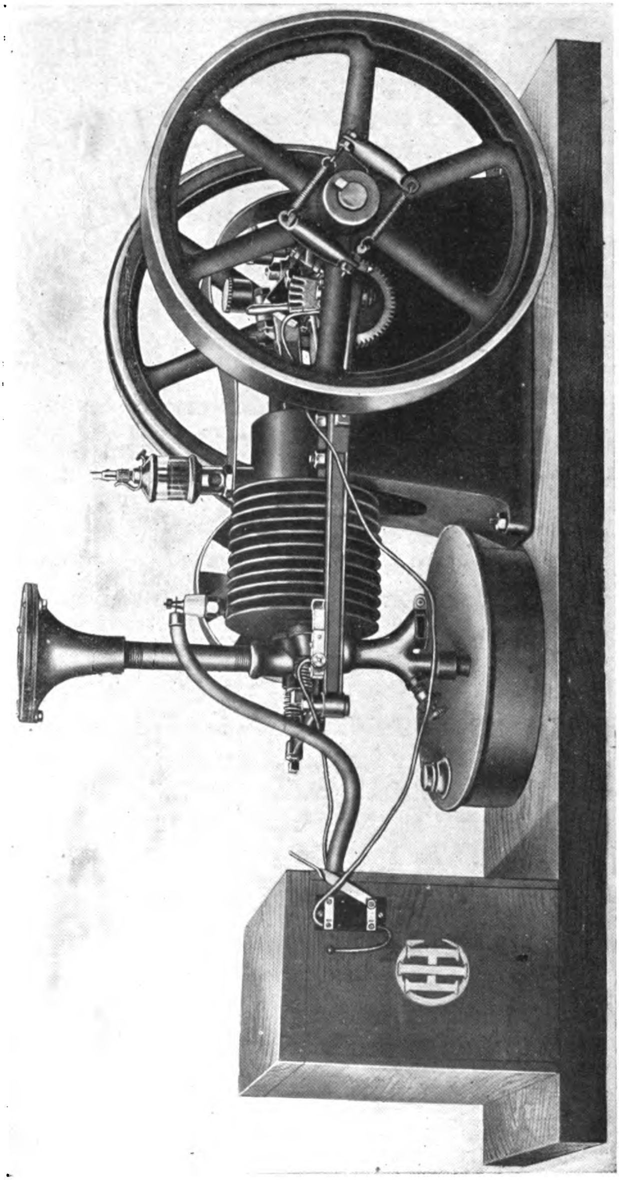


FIG. 115.

across the head of the cylinder, the lever being pivoted at its center to a stationary bracket. When the push rod moves its end of this lever to the left, as seen in the figure, the other end of the lever moves to the right and opens the exhaust valve against the pressure of its spring. The valve is closed by its spring when the returning lever and rod make this possible.

Governing is by hit and miss. The governor weights and springs are carried in the flywheel on the valve-gear side of the engine as shown in the figure. When these weights move out because of excessive speed, they operate a detent through bell cranks and a collar on the shaft. This detent fits into, or behind, a projection on the push rod which operates the exhaust valve, the projection being so located that the detent can engage it only when the exhaust valve is open. In this way the detent prevents the return of the push rod whenever the speed is above normal, thus holding the exhaust valve open and causing missed cycles until the speed decreases.

The burned gases are exhausted through the short vertical pipe shown above the exhaust valve. The muffler is located on top of this pipe and is of a type already described in a previous chapter.

Ignition is by high-tension jump spark, the spark plug being located on the top of the cylinder as shown in the figure. Batteries and coil are installed in the box shown at the left-hand end of the wooden base. The part of the primary circuit not within this box consists of the lightly insulated wires shown in the figure, the primary switch fastened to the side of the box, the metal of the push rod and engine and the timer or the contact maker shown on the upper side of the push rod near the cylinder head.

With the primary switch closed the timer makes and breaks the primary circuit by passing over the first fin on the cylinder as the push rod moves. This causes the passage of the necessary spark at the points of the spark plug which forms part of the secondary circuit.

The part of the secondary circuit outside of the battery box consists of the heavily insulated wire leading to the plug, the insulated terminal and the metal of the plug, the metal of the engine and one of the primary wires.

This engine is a typical representative of the small, light-weight, air-cooled type which has been developed during the past few years to meet the demand for a small, readily portable engine for doing general work and odd jobs about the farm. Crated for shipping it weighs about 280 pounds, so that the weight of the outfit itself is a little less than this. Mounted on a two- or four-wheeled truck it is therefore readily portable and can easily be carried to the work instead of having to bring the work to the engine.

THE "INGECO" ENGINE.

The "Ingeco" engines are manufactured by the International Gas Engine Co. of Cudahy, Wis., to operate on gas, gasoline, oil and producer gas. They are built in various sizes and types, viz.: horizontal and vertical water-cooled, particularly adapted to stationary use; horizontal and vertical hopper-cooled, intended primarily for farm use; and horizontal air-cooled.

Fig. 116 shows a typical horizontal, hopper-cooled "Ingeco" farm engine, this type being built in sizes rated at 1½, 2½, 4 and 6 horse power. The valves are located horizontally in the head of the cylinder as shown in Fig. 117, the inlet valve being automatic and the exhaust valve mechanically operated, through bar *L*, from spur gears *S* and *S′* as shown in Fig. 118.

Governing is by hit and miss, the governor weights being located in the half-time gear *S* shown in Fig. 118. When the speed is above normal the movement of the weights causes the engagement of a latch on the back of the push

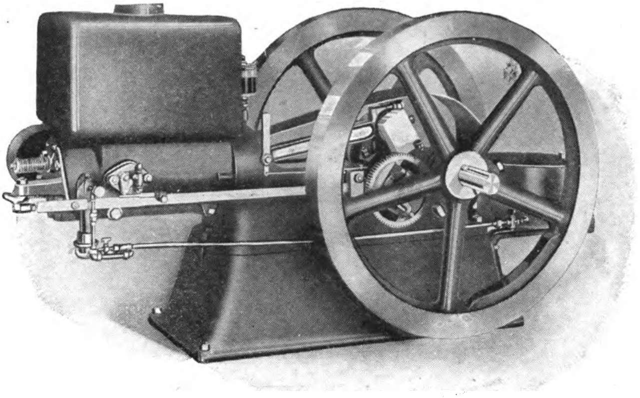


FIG. 116. — "Ingeco" Horizontal, Hopper-cooled Engine.

rod *L*, in such a way as to hold the exhaust valve open until the speed drops to normal. The mechanism by which this is accomplished is shown in Fig. 119.

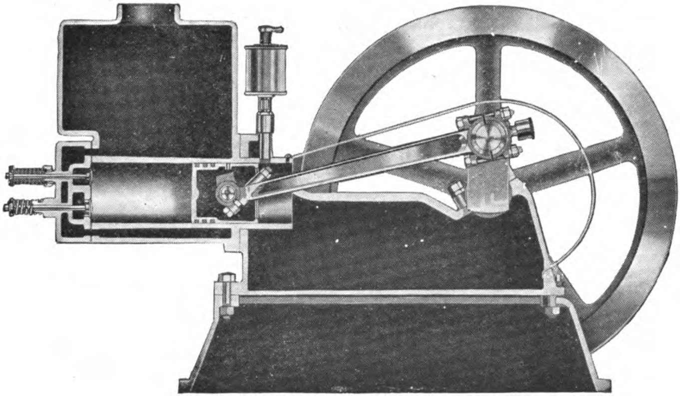


FIG. 117. — Sectional Elevation "Ingeco" Engine.

Ignition is effected by a make-and-break plug, shown at *P* in Fig. 118. The movable electrode *N* is operated by the igniter striker *I*, the left end of which is forced upward by

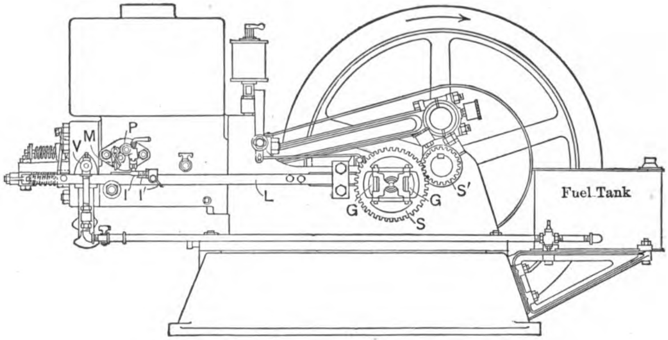


FIG. 118. — "Ingeco" Engine. Elevation.

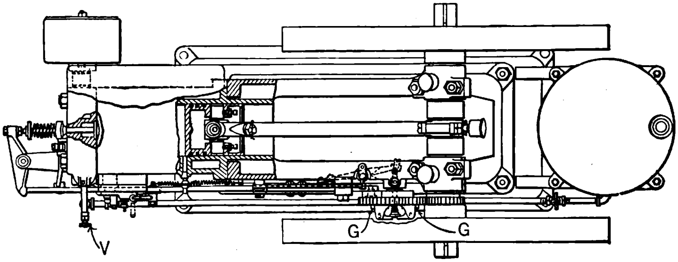


FIG. 119. — "Ingeco" Engine. Plan View.

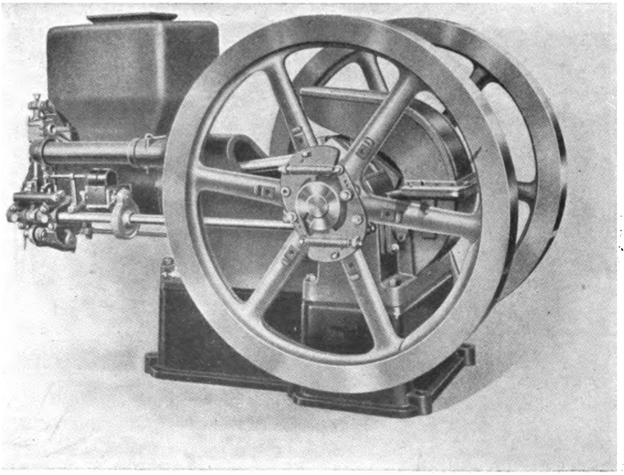


FIG. 120. — "Ingeco" Engine.

the igniter spring *I'*. As the push rod *L* moves to the left, the left end of the striker engages the movable electrode and causes it to make contact with the stationary electrode within the cylinder.

Contact is broken when the striker runs under the contact breaker *C*, and timing is effected by regulating the height of this breaker.

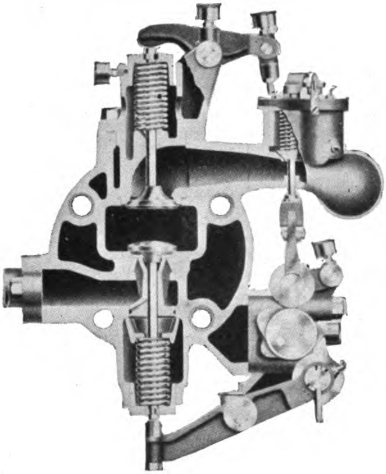


FIG. 121. — Section of "Ingeco" Engine.

The fuel is forced into the air entering the cylinder during the suction stroke by atmospheric pressure acting on the surface of the fuel in the tank; that is, a suction type of carbureter is used so that the piston pumps its own fuel supply and no fuel pump is required. The quantity of fuel in each charge is regulated by a needle valve, the hand wheel on which is indicated by *V* in Figs. 118 and 119.

Fig. 120 shows another type of horizontal hopper-cooled engine, with the valves located vertically, the inlet valve opening downward, and the exhaust upward — both being mechanically operated — as shown in Fig. 121. This type is built in sizes rated at 6, 8, 10, 12, and 15 horse power.

The valve shown to the right of the inlet valve in Fig. 121 is a fuel valve which may be used with gas or with gasoline. When it rises from its seat the fuel is admitted to the venturi tube below it and there mixes with the air on its way to the inlet valve. This fuel valve is operated by a finger shown in Figs. 120 and 121 which, in turn, is operated by a cam on the half-time shaft. When the speed rises above normal this finger is swung out of line by the

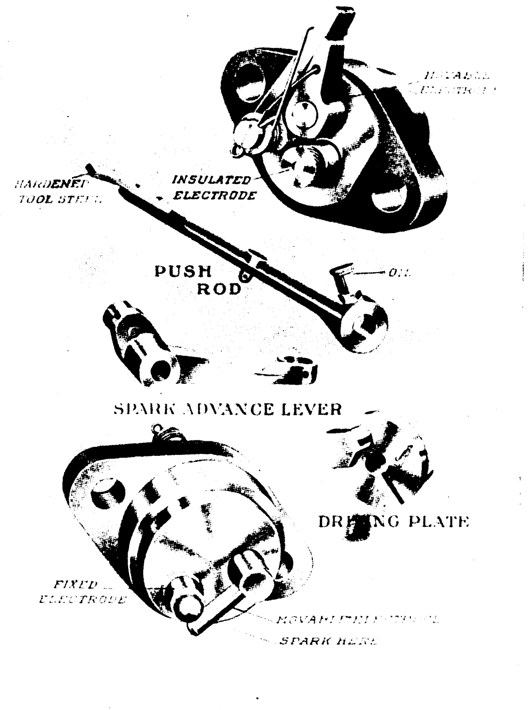


Fig. 122. — Details of Igniter, "Ingeco" Engine.

governor and the fuel valve does not open to admit a charge. The other valves, however, function as usual.

The make-and-break system of ignition is used, the igniter and levers being shown in Fig. 122, and a section of the igniter block in Fig. 123.

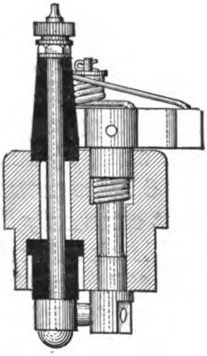


FIG. 123. — Vertical Section of Igniter Block.

Fig. 124 shows a small "Ingeco" vertical engine with open-jacket or hopper-cooling system. This type is built in units rated at 2, 4 and 6 horse power. The principle of operation and general details of construction are similar to those of the larger horizontal type. Both valves are vertical and are mechanically operated from cams on a half-time shaft which is driven by spiral gearing from the crank shaft.

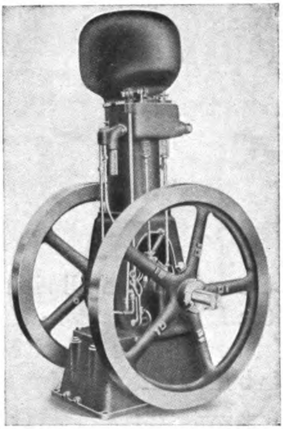


FIG. 124. — "Ingeco" Vertical Engine.

The "Ingeco" air-cooled engine, suitable for farm work where small power is required, is shown in Fig. 125. With the exception of the cylinder casting this type is built exactly like the smaller, hopper-cooled, horizontal engines already described. This type is furnished only in the $1\frac{1}{2}$ horse power size.

It will be observed that the "Ingeco" engines are built in practically all models commonly used for agricultural purposes. The development of a complete line of engines in this way is becoming customary on the part of the larger manufacturers while the smaller concerns generally concentrate on a small number of models or on one model only.

THE GRAY GASOLINE ENGINE.

This engine, constructed by the Gray Motor Company of Detroit, Michigan, is of the four-cycle, stationary, hopper-cooled type, especially designed for farm use. It is built in four sizes, 1½ horse power, 2½ horse power, 4 horse power, and 6 horse power, which the manufacturers claim are those most commonly demanded for agricultural purposes.

Side elevations of Gray motors are shown in Figs. 126 and 127. In the very latest model, the location of the oil cup for lubricating the piston has been changed and the auxiliary exhaust, formerly used, entirely omitted, so that the section of the engine, as now built, is as shown in Fig. 128.

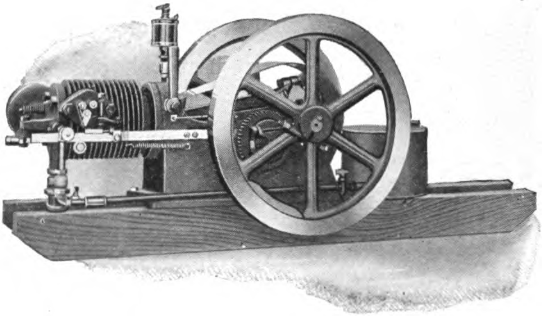


FIG. 125.

The hopper is cast integral with the cylinder in all sizes, and the cylinder cast integral with the frame except in the 6 horse power engine, which is of the bench type described in Chapter IX, where the cylinder is bolted onto the frame as shown in Fig. 21(*a*).

The working parts, placed in their relative positions, as when assembled on the engine frame, are shown in Fig. 129. The valves are horizontal and are located in the head. The exhaust valve *D* is operated through levers *A*,

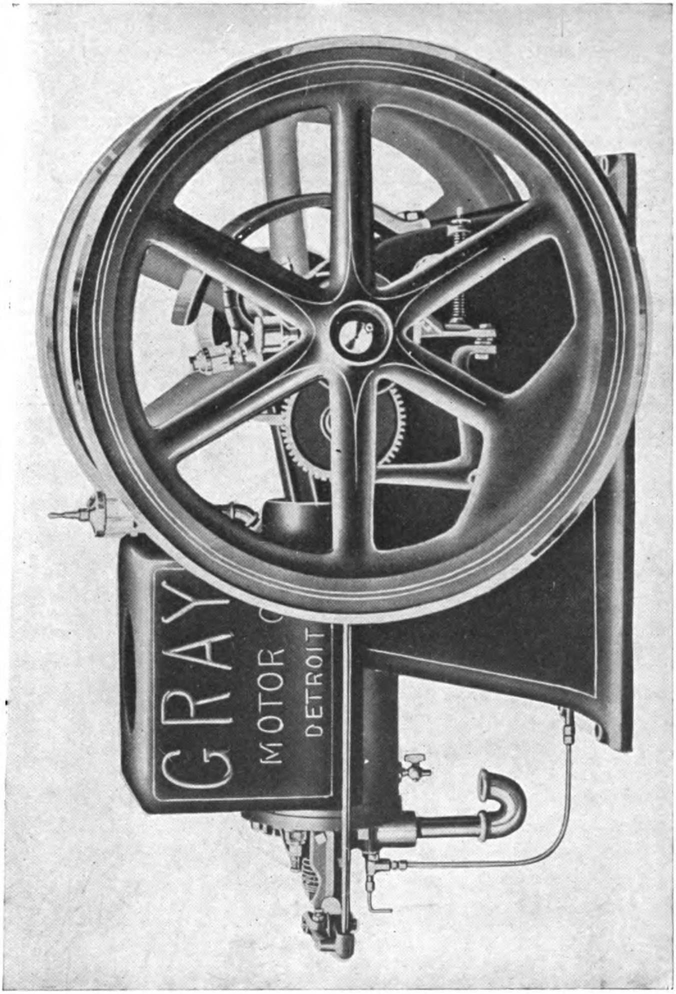


FIG. 126.

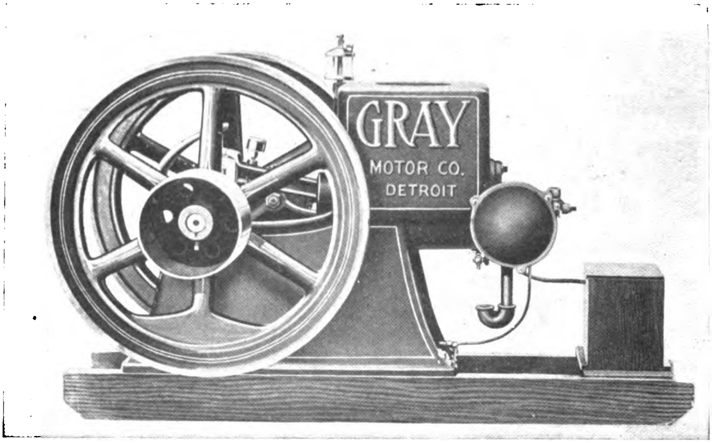


FIG. 127.

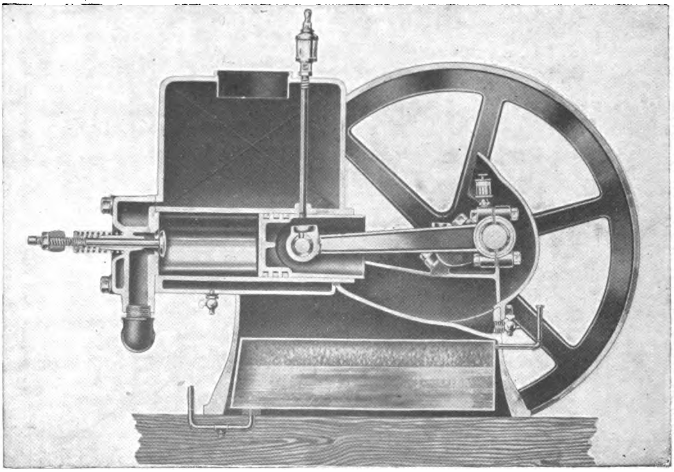


FIG. 128.—Section, Gray Engine.

F and *P*, by cam *I*, on the half-time spur gear *K*. The inlet valve *E* is automatic.

Suction-feed gasoline supply is used on all the Gray engines, the gasoline being lifted by suction from the tank *T* in the base, Fig. 130, to the mixing chamber *F*. When operating, the piston *A* moves outward, creating a partial vacuum in *B* and causing the inlet valve *E* to lift off its seat because of the unbalancing of the pressures on either side of it. Air then rushes up through pipe *I*, past nozzle *G* and into the cylinder *B*.

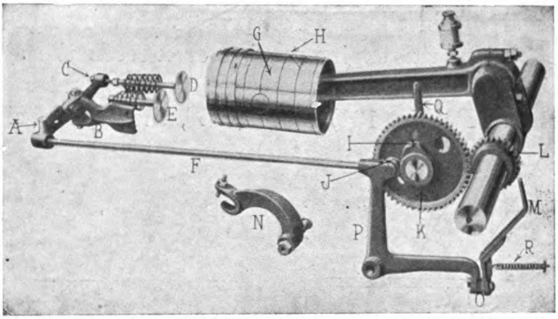


Fig. 129. — Working Parts, Gray Engine.

Because of the reduced pressure at the tip of the nozzle *G*, the air pressure acting on the surface of the liquid in the tank *T* forces that liquid up through the pipe *K*, and out through nozzle *G*, where it mixes with the air flowing into the engine cylinder.

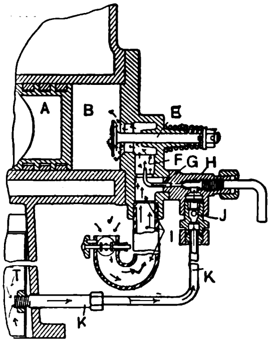


Fig. 130. — Section through Carbureter and Inlet Valve.

A ball check valve *J*, above the end of pipe *K*, prevents the gasoline from flowing back to the tank through pipe *K*, so that the engine piston during each suction stroke merely causes the flow of an amount equivalent to that drawn from the nozzle.

Governing is effected by holding the exhaust valve open during one or more revolutions when normal speed is exceeded. The governor weight *N* (Figs. 129 and 131) which is fastened within the flywheel presses outward against the blade *M* when the engine reaches or exceeds the speed at which it is set to run. Then when cam *I* operates on bell-crank lever *P* (Fig. 131) and rod *F*, thereby opening the exhaust valve, the horizontal arm *a′* of the bell-crank *P* is lifted at the point *O*, permitting the engagement and locking of the governor hooks or detents at *O*. This prevents the cam roller *J* from following cam *I* and thereby holds the exhaust valve open until the speed decreases enough to allow the governor weight to recede toward its stop pin. Such inward motion of the weight permits the spring *R* to pull the governor lever to the right, thus disengaging the hooks at *O* and allowing the exhaust valve to close. The piston then draws in a new charge of mixture through the automatic inlet valve and the cycle of operations is resumed.

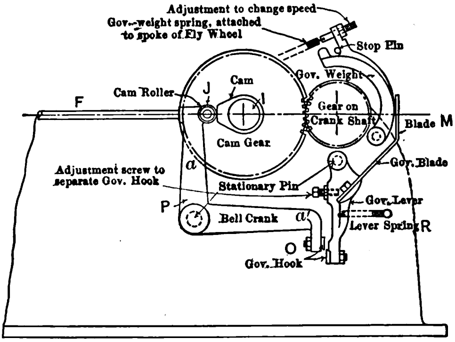


FIG. 131.

In addition to holding the exhaust valve open, the spark is cut out by breaking the electric circuit at *A* (Fig. 129) and no charge is drawn into the cylinder because of the approximately equal pressures existing outside and inside.

The jump-spark system of ignition is used on all Gray engines, the spark plug being shown in position in the cylinder head in Fig. 126.

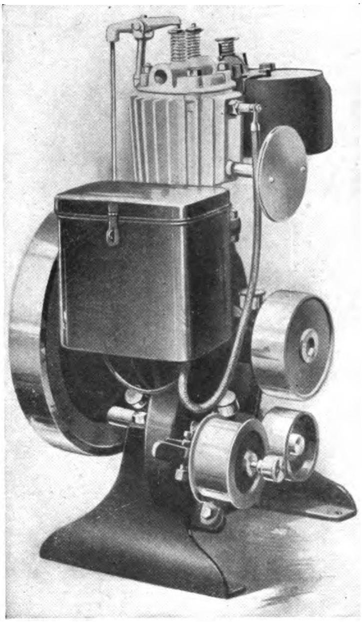


Fig. 132.—Fuller and Johnson Multimotor.

FULLER & JOHNSON GASOLINE ENGINES.

The engines sold under this name are made by the Fuller & Johnson Manufacturing Company of Madison, Wis. The company builds three distinctly different models known as The Fuller & Johnson Multimotor, The Fuller & Johnson Peoples Price Engine and The Fuller & Johnson Double Efficiency Engine.

The first is an air-cooled engine and is shown in Fig. 132.

The second is an open-jacket engine of very simple construction as shown in Fig. 133.

The third is a more elaborate and more expensive type. The smaller sizes of this type, 3, 5, 7 and 9 horse power, are built somewhat simpler than the larger which are made in single-cylinder units up to 18 horse power.

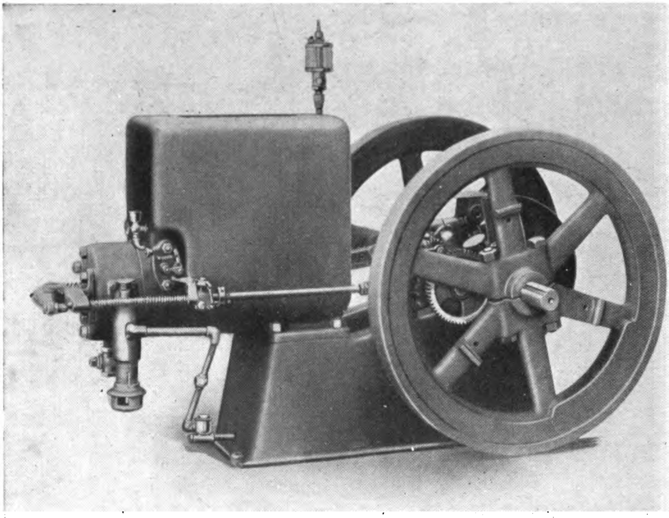


Fig. 133. — Fuller and Johnson Engine.

External views of the smaller models of the third type are shown in Figs. 134 and 135, the latter showing the engine with one flywheel removed in order to bring out the half-time mechanism and the governor to better advantage.

A vertical section of the engine is shown in Fig. 136 and a horizontal section in Fig. 137.

The cylinder barrel, the cylinder head, the jacket walls and the hopper are all cast in one piece as shown in Fig. 136. This construction eliminates many of the troublesome joints which are found in cases where these parts are cast separate and it also insures very efficient cooling of the cylinder head. The valves are, however, located in a water-cooled valve chest or box, bolted to the side of the cylinder casting as shown in Fig. 137, and this entails the use of a packed joint, which must be tight against gas and water, in order that the jackets on the cylinder and valve chests may open into one another.

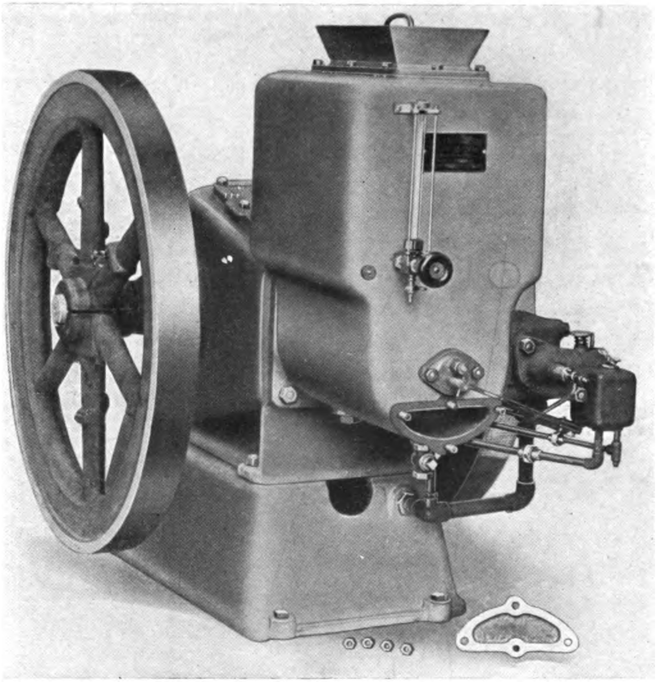


FIG. 134. — Fuller and Johnson Engine.

The jacket space is provided with a drain cock as shown at the bottom of the cylinder in Fig. 136 and with a large hand hole shown open in Fig. 134. This hand hole simplifies the removal of mud and similar sediment at intervals.

The crank case is inclosed, but is fitted with two large doors as shown in Fig. 136. The upper door gives ready access to the piston pin and associated parts, while the vertical door on the end gives access to the crank-pin end of the connecting rod. This door is arranged with a latch so that it can be quickly opened and closed without the use of a wrench and is used for setting up the grease cup shown in Fig. 136, which supplies lubricant to the crank pin. The piston is lubricated with oil fed by gravity from the cup shown on top of the cylinder in Fig. 136. As shown in the same illustration, the crank case is provided with an oil drain at its lowest point for the purpose of removing excess oil as it accumulates.

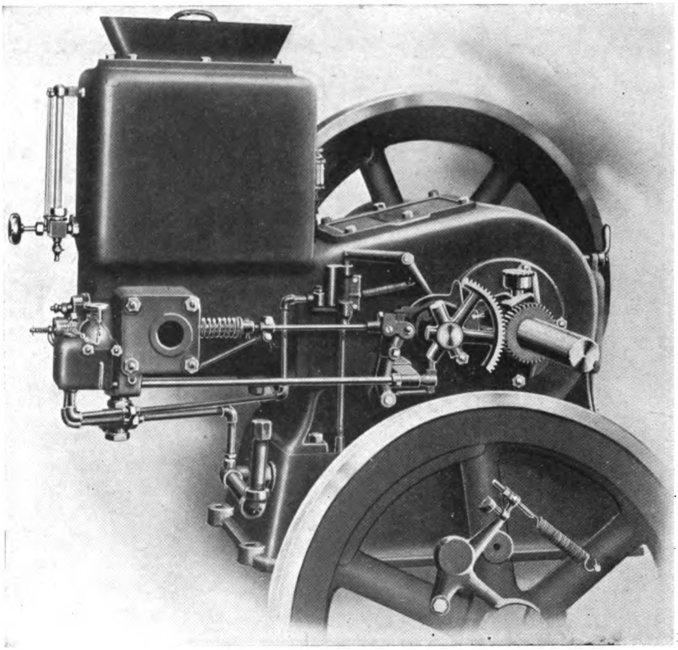


FIG. 135. — Fuller and Johnson Engine.

The valves and their method of operation are shown in Figs. 135 and 137. Both valves are horizontal and open into a pocket on the side of the cylinder as shown to best advantage in Fig. 137. The inlet valve, located to the left in this illustration, is automatic. It is carried in a removable cage as clearly shown in the figure. The removal of this cage gives ready access to the exhaust valve and its seat. The exhaust valve is opened by means of a horizontal push rod (Figs. 135 and 137) and closed by the usual spring. The push rod is moved by a cam on the shaft of the half-time gear as shown in Fig. 135.

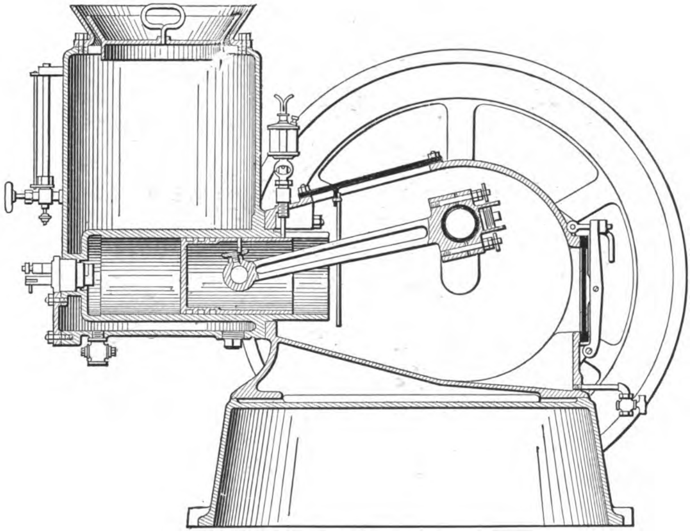


FIG. 136. — Section, Fuller and Johnson Engine.

To this push rod is fastened a bent rod, shown in Figs. 134 and 135, which passes under the valve pocket and then turns up so that a ring carried on its end encircles the stem of the inlet valve. The usual coiled spring is located on the stem between the ring on the bent rod and a nut on the

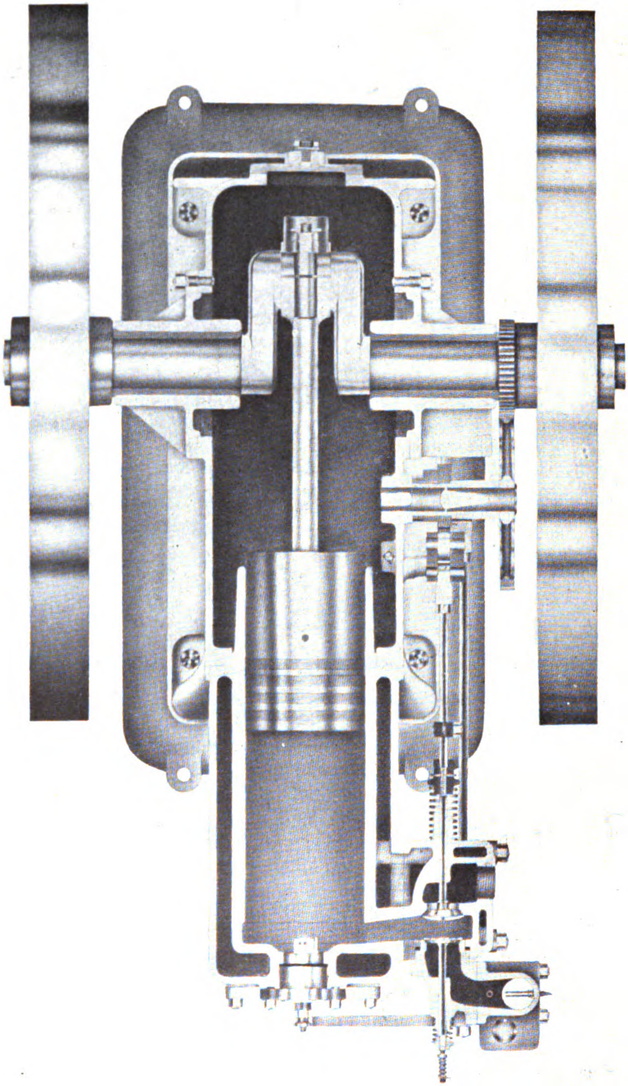


FIG. 137.—Section, Fuller and Johnson Engine.

end of the stem. When the exhaust valve is held open for governing purposes, as will be explained later, the bent rod compresses this auxiliary spring and holds the inlet valve closed.

Governing by the hit-and-miss method is effected by means of the single-weight governor shown in Fig. 135. This governor is located on the engine side of the flywheel, the latter having been turned about in Fig. 135 in order to show the mechanism. As the flywheel rotates the governor weight moves out (rotating about a pin in an arm of the wheel) until the centrifugal tendency is just balanced by the spring shown. When the engine is operating at normal speed the position assumed is such as not to affect the valve gear so that the latter operates normally. Whenever the speed exceeds the normal value the weight moves further out and thus moves the curved lip, shown in the figure, further away from the shaft. As the flywheel rotates this lip runs under a detent extension at the time when the exhaust valve is open and depresses the detent so that the exhaust valve is held open and the inlet valve is held closed. As long as the speed remains above normal the lip of the governor keeps this detent in position to prevent closure of the exhaust valve, but, as soon as the speed drops to normal or below, the governor again moves in, thus allowing the valves to operate normally.

Ignition is caused by a make-and-break igniter shown in position in the engine in Figs. 134 and 137 and separately in Fig. 138. Its method of operation should be clear from the illustrations taken in conjunction with previous descriptions. The operating mechanism is so arranged that it ceases to act when the exhaust valve is held open, thus preventing the passage of useless sparks, unnecessary wear of igniter points and excessive drain on batteries if these are used.

The carbureter is shown in position in Figs. 134 and 135 and in sectional detail in Fig. 139. It is similar to those shown diagrammatically in Fig. 34. Gasoline is raised from a reservoir in the base of the engine by means of the fuel pump shown in position in Fig. 135 and in sectional detail in Fig. 140. This pump discharges into a constant-head chamber forming part of the carbureter casting, the surplus draining back to the gasoline reservoir through the pipe shown in Fig. 135.

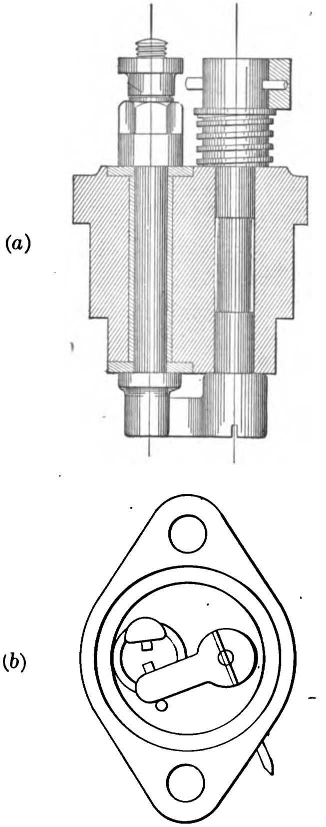


Fig. 138.—Igniter Block, Fuller and Johnson Engine.

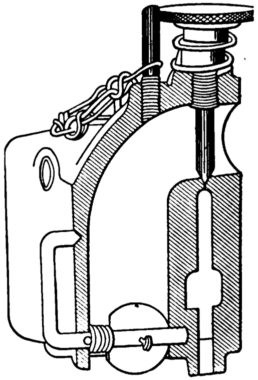


Fig. 139.

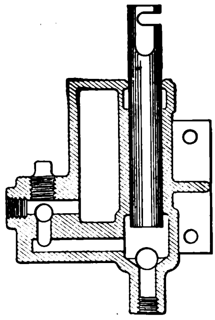


Fig. 140.—Section, Fuller and Johnson Fuel Pump.

THE RUMELY-OLDS ENGINE.

This engine is manufactured by the Seager Engine Works of Lansing, Mich., and is sold by the Rumely Products Company of LaPorte, Ind.

Types A and AK, which are described here, are built in sizes ranging from 1½ to 15 horse power. They are single-cylinder, single-acting, horizontal engines operating on the four-stroke principle and are generally arranged for hopper cooling, though tank-cooled models can be supplied.

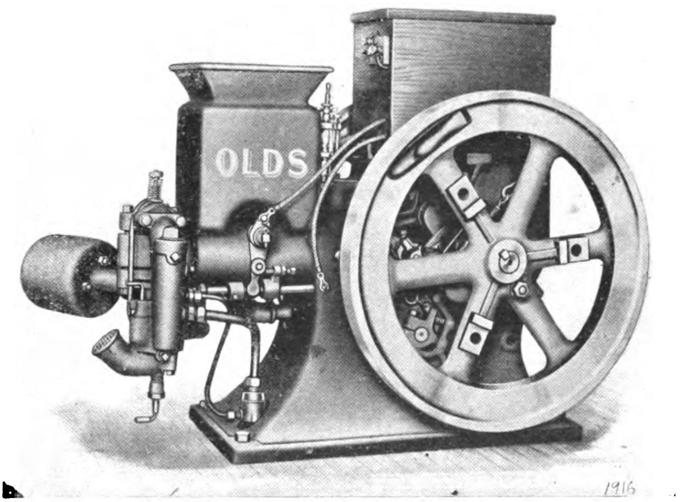


FIG. 141.—Rumely-Olds Type A, 1½ H.P.

The type A engine is intended to burn gasoline and type AK is fitted for use with kerosene. External views of 1½ and 4½ horse power type A engines are shown in Figs. 141 and 142 respectively, and an external view of a kerosene engine is given in Fig. 143.

The valves in all cases are located in an extended head and are arranged with their axes vertical, the inlet valve above and the exhaust valve below. This arrangement is shown in Fig. 144. The inlet valve is carried in a removable cage. The exhaust valve seats directly on the metal of the head and is removed through the hole which is left when the inlet valve and its cage are withdrawn.

The exhaust valve is operated by the mechanism shown in Fig. 145, the half-time spur gear carrying a cam which operates upon a system of two bell cranks connected by a rod. This arrangement opens the exhaust valve by pulling on the horizontal rod instead of by pushing on it as in the majority of engines, thus eliminating vibration and permitting the use of a light rod.

The inlet valve is automatic and is locked closed during missed cycles by a light bent rod which is pushed upward with the exhaust valve and increases the compression of the inlet-valve spring. The upper part of this locking device can be seen in Fig. 141, the end of it encircling the stem of the inlet valve below the spring.

The hit-and-miss governor is shown in Fig. 146. The governor weight *G* is pivoted to the flywheel at *P* and is very delicately adjusted by means of the two springs shown. When the governor weight is "in," that is, when the engine is below speed, the tail *T* of the governor weight is out. At each revolution this tail strikes the arm *A* and prevents the pick blade *B* from engaging the dog *D*. Under such conditions the exhaust valve is operated normally and the engine receives a charge. When the speed of the engine increases to a value above normal the governor weight *G* moves outward and the tail *T* moves inward. This prevents *T* from striking the arm *A* and allows the blade *B* to engage the dog *D* when the exhaust valve is open. This dog is mounted on the shaft *S*, which is the shaft on which the bell crank carrying the cam roller is mounted (see Fig. 145), and, through this shaft, it holds the bell crank in such a position as to lock the exhaust valve open.

Ignition is by jump spark, the plug being located near

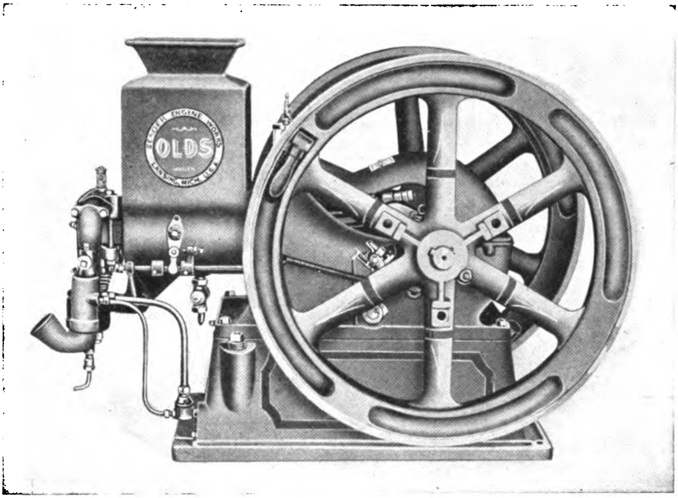


FIG. 142.—Rumely-Olds Type A, 3 and 4½ H.P.

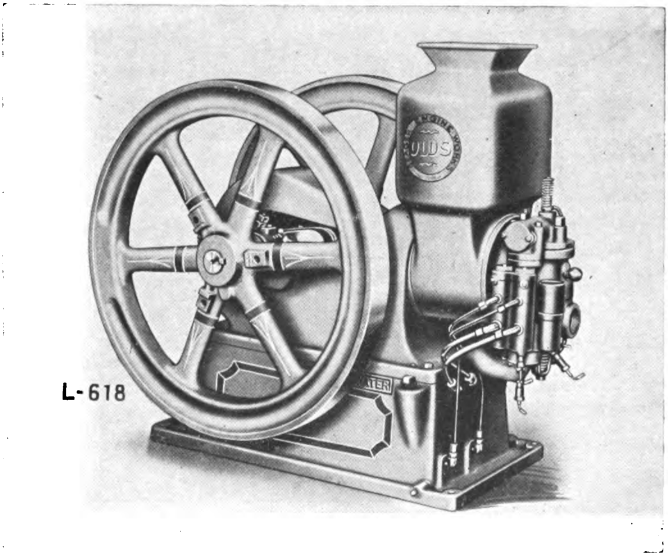


FIG. 143.—Rumely-Olds Type AK, 3, 4½, 6, 8 and 12 H.P.

the inlet valve in the cylinder head. The timer is located on the side of the cylinder and is operated by the rod which operates the exhaust valve. It is indicated by *T* in Fig. 145. Contact is made by the adjustable point *P* carried in the adjustable collar *C* and the provision of the second adjustable collar *C′* makes the adjustment of timing very accurate. The action of the governor is such as to prevent the rod from traveling toward the exhaust valve during missed cycles and this in turn prevents the operation of the timer. The spark is therefore cut out during missed cycles.

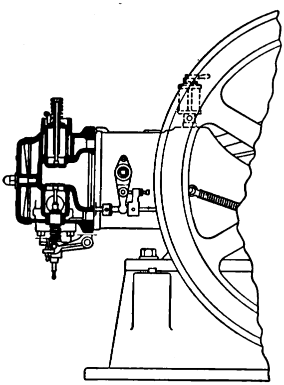


Fig. 144. — Valve Arrangement, Rumely-Olds Engine.

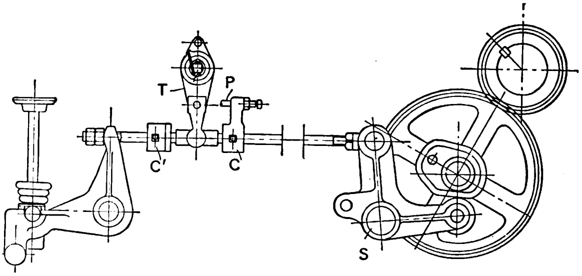


Fig. 145. — Valve Operating Mechanism, Rumely-Olds Engine.

The carbureter used on these engines is an elaborate development of the jet type with a long and carefully proportioned venturi tube. It is shown in Fig. 147. Air enters the carbureter through the intake *I*, passes up around the fuel nozzle *N* and leaves, on its way to the cylinder, at *C*. Fuel is supplied from a constant-head reservoir *R′* in which the level is maintained below the tip of the nozzle by the overflow pipe *P′*. The gasoline flows out of the nozzle because of the lowering of pressure opposite the tip as has been described in a previous chapter.

This carbureter draws its own fuel supply from a fuel reservoir located at *R* in the base of the engine. The low pressure existing during each suction stroke in the venturi tube opposite the point *O* allows air pressure on the surface of the fuel in the lower reservoir to force some of that fuel into the auxiliary reservoir *R′* through the pipe *P*. Any excess drains back through the pipe *P′*. Flooding of the reservoir by forcing of fuel upward through pipe *P′* is prevented by the small valve *V* which is automatically closed whenever there is any tendency toward upward flow in the pipe *P′*.

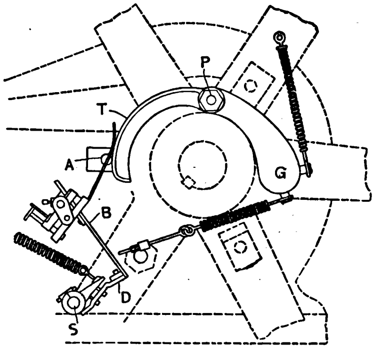


Fig. 146. — Rumely-Olds' Governor.

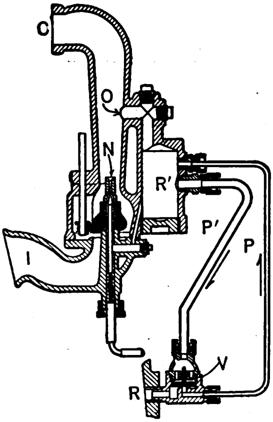


Fig. 147. — Rumely-Olds' Carbureter.

This arrangement insures a constant level of fuel at the nozzle and makes the operation of the carbureter independent of the level in the main reservoir at *R*.

The kerosene engine differs from the gasoline engine only in having two carbureter systems, one for kerosene and one for water. The kerosene and water are carried in separate reservoirs in the base of the engine.

Part of the air on its way to the engine passes through the fuel carbureter and the rest passes through the water carbureter. By properly proportioning the quantities taking each route and by adjusting the needle valves of the two carbureters the proportions of the mixture can be accurately controlled.

THE MANLEY GAS AND GASOLINE ENGINES.

The United Engine and Manufacturing Company of Hanover, Pa., are the builders of the Manley gas and gasoline engines here described. The type H–2 engines are horizontal, water-cooled, two-cylinder opposed, and type C engines are regularly built hopper cooled, tank cooled or screen cooled, with circulating pump or for cooling by city water.

Figure 148 is a side elevation of a Manley type H–2, two-cylinder opposed engine, built in sizes from 6 to 20 horse power and operating on gas, gasoline, distillate, kerosene or alcohol.

As may be noted in Figs. 149 and 150, this type has two pistons working opposite each other on a double-throw crank shaft. This arrangement produces almost perfect balance since the vibration strains due to the inertia forces are neutralized to such an extent that very smooth operation results. The flywheels can also be much lighter and can revolve at a higher speed than those of a single-cylinder engine of equal power.

Figure 150, which is a section through the double opposed engines, shows clearly the location of the valves, cams, etc., the details of cylinder and valve construction and the inclosed crank case.

The cylinder construction with integral head, valve cages and removable water jacket is brought out in Figs. 151 and 152. Reference to Fig. 150 shows how the water jacket *s* slips over the cylinder *c* and is fastened up against the cylinder flange *f* by the same bolts *b* which hold the cylinder to the

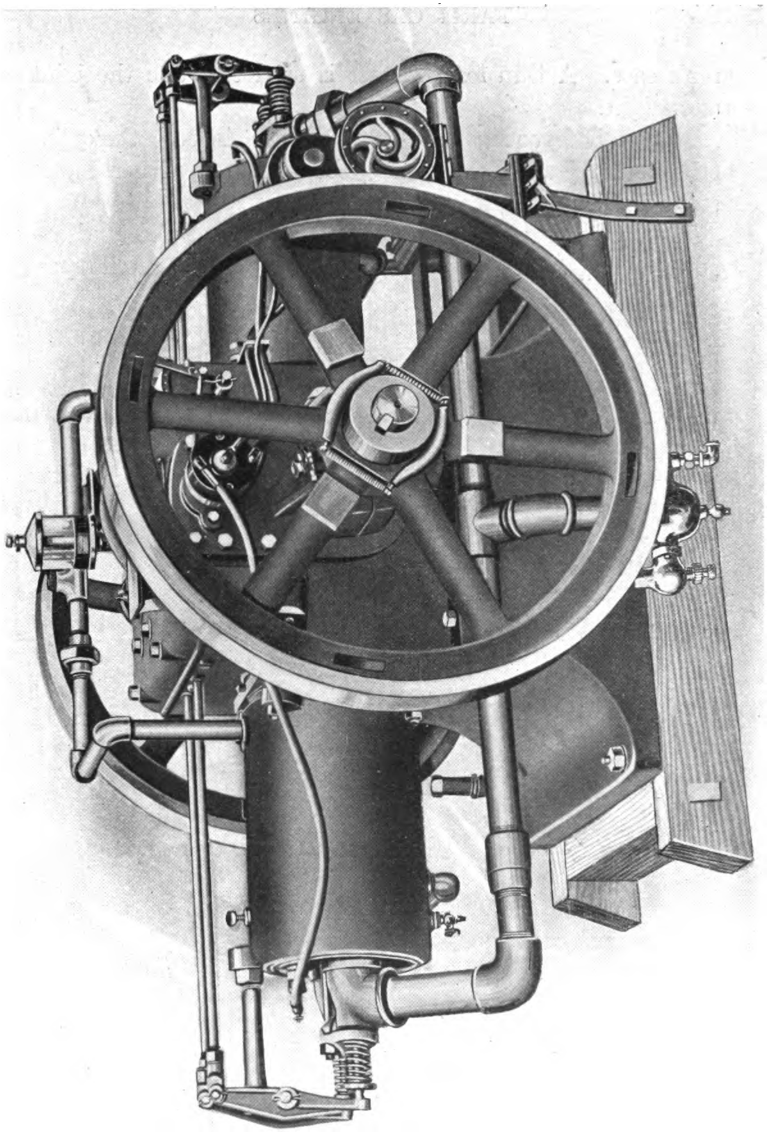


FIG. 148. — Manley Type H-2.

crank case. A thin lead washer is used to make the joint water-tight.

A dovetailed space, *m* in Fig. 150, is cast in both the cylinder and the jacket, and this space is calked with a metal composition making a water-tight joint.

The two types of cylinder jackets which may be used are shown in Figs. 150 and 152. Tubes are cast in the hopper, as shown at *l* in Fig. 150, which are drilled for the passage of the cam push rods *p* operating on the valve levers *k*. The valves are located horizontally in the head, and both are mechanically operated.

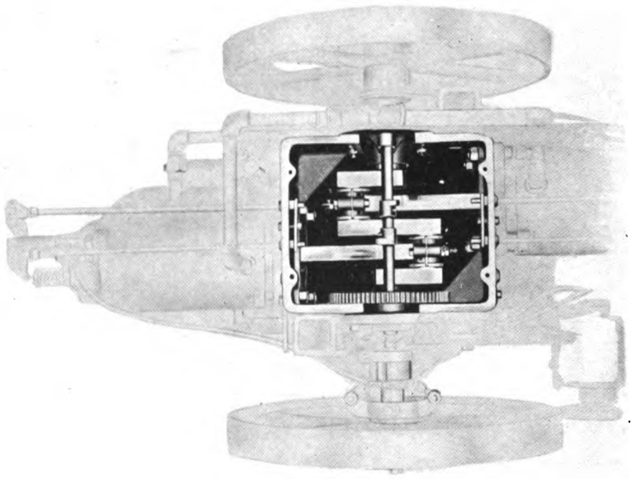


Fig. 149. — Type H-2 with Crank Case Cover removed.

Governing is accomplished by varying the amount of mixture entering the cylinder, so as to keep the speed constant with changing loads. The governor is located in the flywheel, as shown in Fig. 148, and operates, like an ordinary fly-ball governor, by moving a sliding collar on the shaft between the flywheel and the main bearing as is

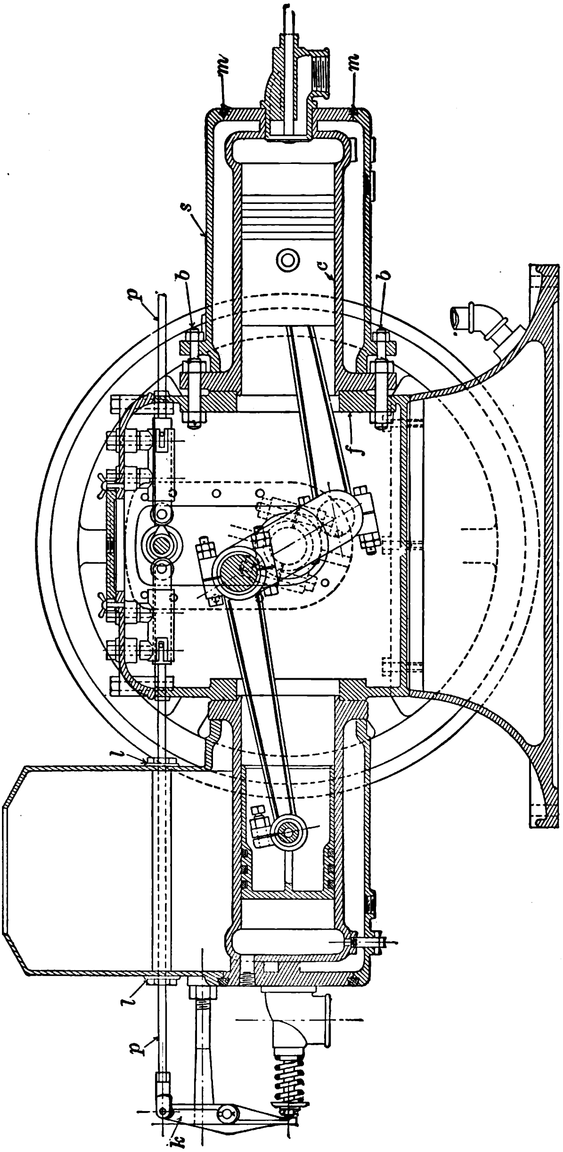


FIG. 150.—Section, Manley Type H-2 arranged for Hopper Cooling.

Fig. 151. — Cylinder, Valves and Cages, Manley Engine.

Fig. 152. — Jackets used on Manley Engines.

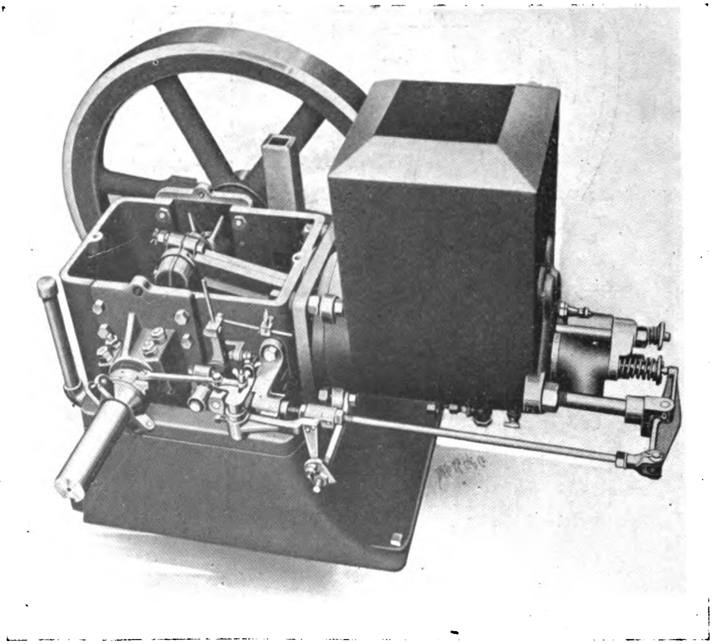


Fig. 153. — Manley Type C Showing Governor Mechanism.

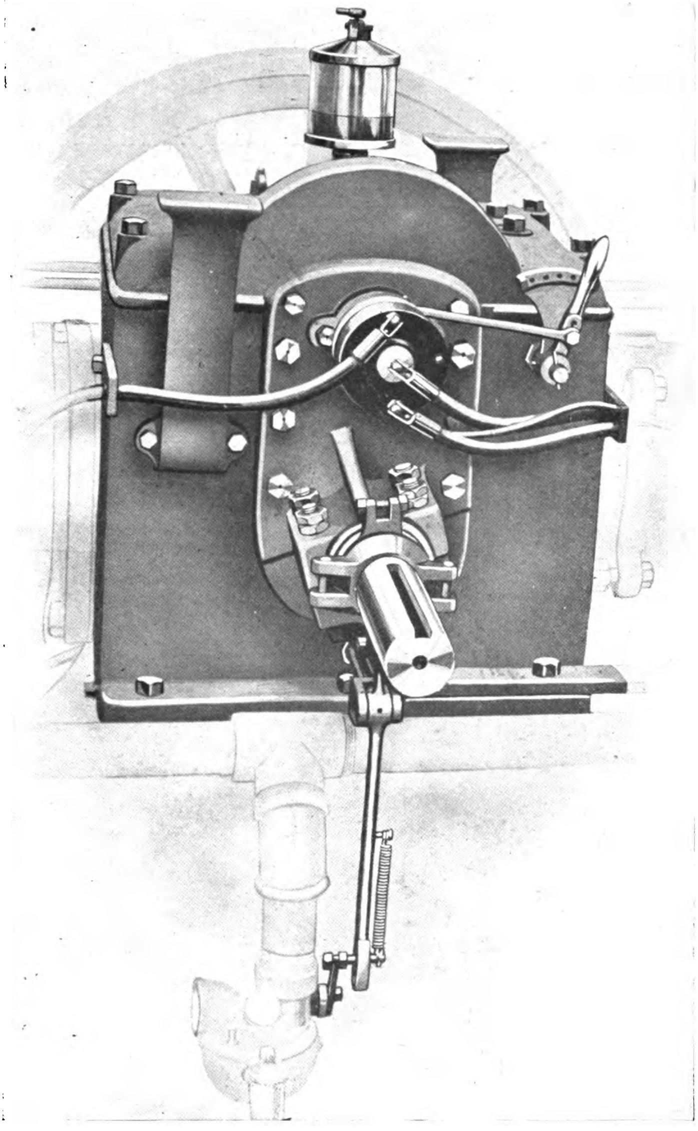


FIG. 154.—Timer and Throttle Mechanisms of Manley Engines.

clearly brought out in Fig. 153. This motion is transmitted by a single lever to the throttle valve on the carbureter as shown in Fig. 154.

The jump-spark system of ignition is used, with batteries for starting and magneto for continuous operation. The friction-driven magneto is located near the right-hand cylinder, as seen in Fig. 148, so that the friction wheel may engage with the rim of the flywheel.

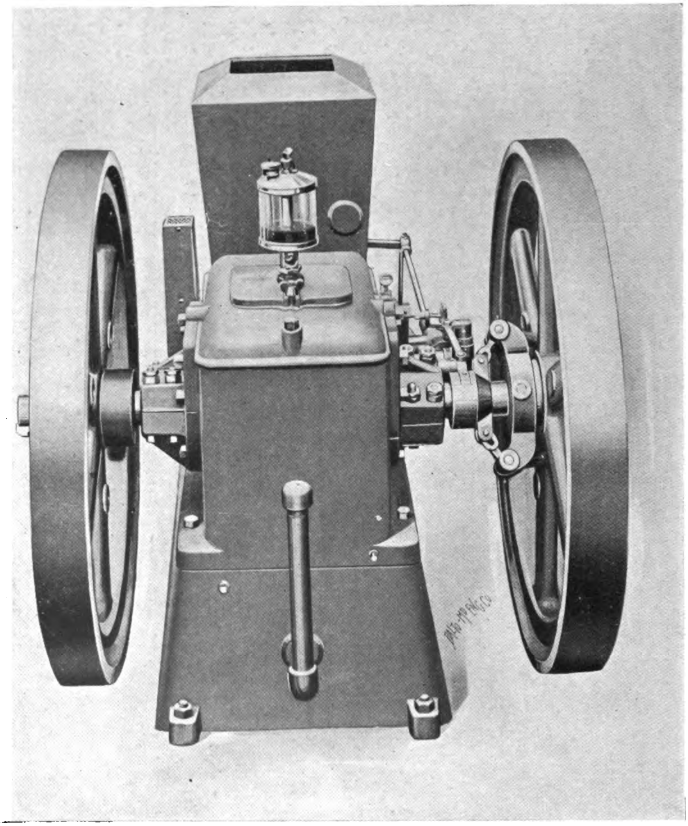


FIG. 155. — Manley Type C Engine.

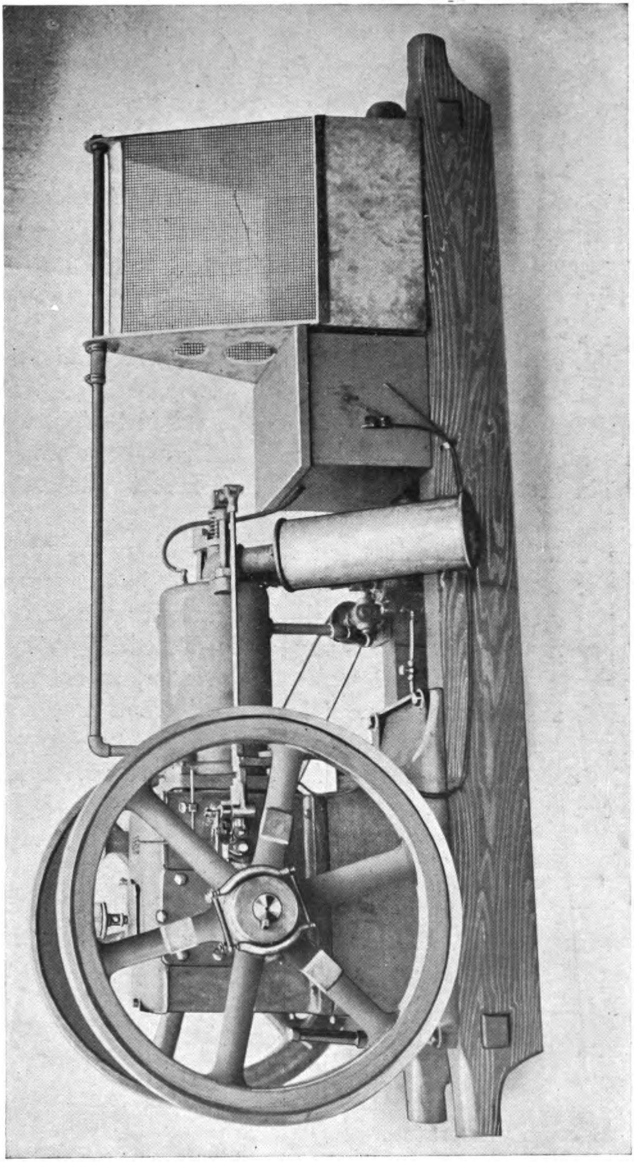


FIG. 156.—Manley Type C, with Integral Cooling and Circulating System.

An automatic float-feed carbureter of a type similar to those described in a previous chapter is used for operation on gasoline. For kerosene or alcohol, artificial or natural gas, a modified form of this mixing device is supplied.

The splash system of lubrication is employed for the crank pin and moving parts within the crank case, and a three-feed sight oiler is fitted for supplying lubricant to the bearings.

The type C Manley engines, shown in Figs. 153 and 155, are single-cylinder machines, built in sizes from 4 to 7 horse power. The hopper-cooled cylinder may be used as in Fig. 155, or a single closed-jacket system, with centrifugal circulating pump and screen cooling tower, as in Fig. 156. The muffler is shown attached to the exhaust pipe, close up to the engine cylinder. The batteries and coil are contained in the box standing on the skids next to the cooling tank.

The details of construction and operation are practically the same in both types, except that in the type C engines governing is accomplished by holding the exhaust valve open when the proper speed is exceeded. A latch arrangement is connected with the governor, as shown in Fig. 155, and when the speed increases beyond a set limit the latch engages a projection on the exhaust-valve push rod, holding the valve open for one or more revolutions, until the speed drops to normal.

THE NOVO ENGINE.

This engine is manufactured by the Novo Engine Company of Lansing, Mich., and is a typical four-stroke, vertical, hopper-cooled farm engine.

It is built in eight sizes from $1\frac{1}{2}$ to 10 horse power with the cylinder and combustion chamber cast integral with a large, open-top vessel, which serves as a "frost-proof jacket" or hopper. The inlet valve is automatic and the exhaust valve is mechanically operated.

Fig. 157 shows an elevation of the front of the engine and Fig. 158 is a side elevation with one flywheel removed. The half-time spur gear is partially cut away to show the governing mechanism. Fig. 159 shows all the parts labelled and Fig. 160 the engine side of the flywheel with governor weight attached. In Fig. 159, although the flywheel has been removed, the governor weight and its spring, which are fastened to that flywheel, are shown in their relative positions on the engine.

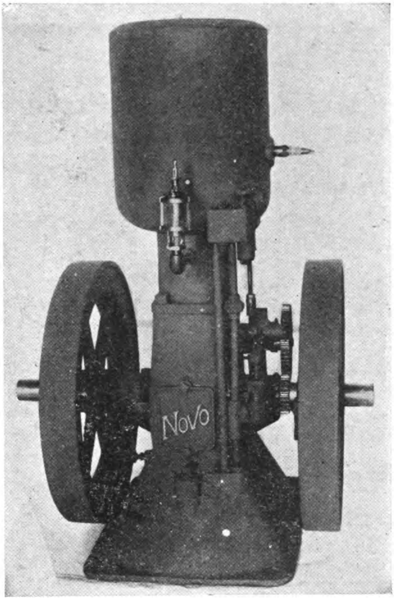


Fig. 157. — Novo Engine.

The hit-and-miss system of governing is used and the operation is effected as follows: When the speed of the engine exceeds that for which the governor is set, the governor weight, as shown in Figs. 159 and 160, acts on the governor shoe which brings a latch into contact with the block on

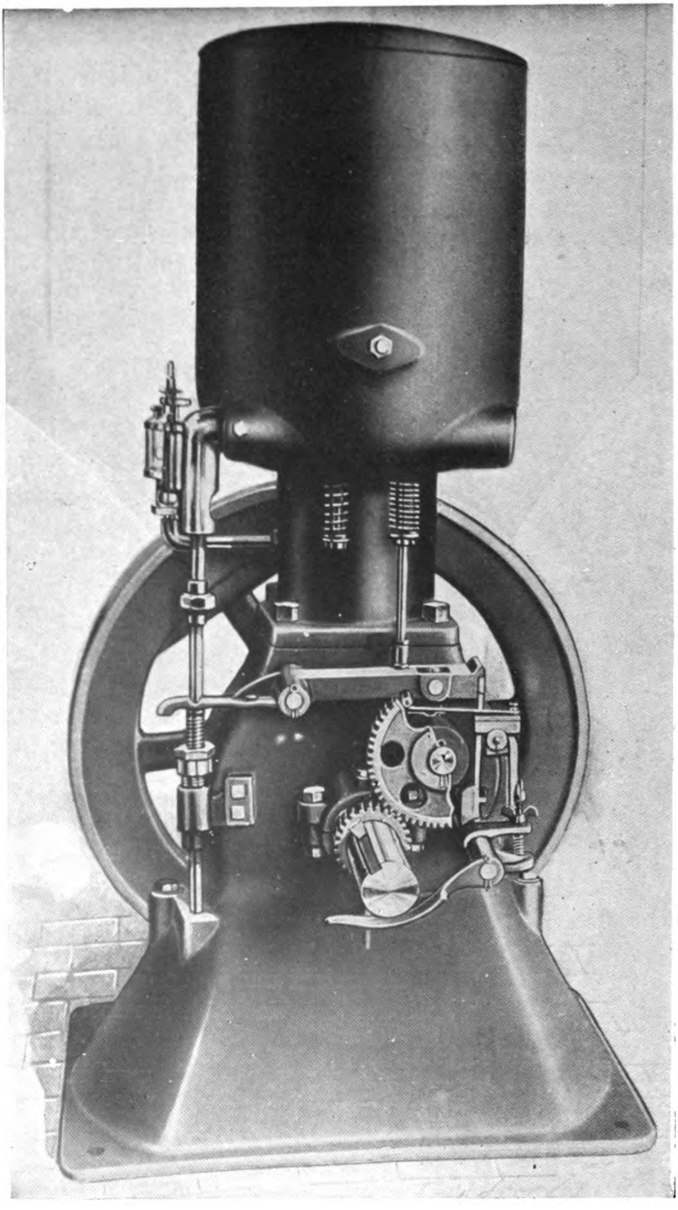


FIG. 158.—Novo Engine, Showing Valve Operating and Governing Mechanisms.

the right-hand end of the rocker arm. This occurs when the rocker arm is in its highest position, thus holding the exhaust valve open and preventing the drawing in of a new charge for one or more revolutions until the speed drops to normal.

The highest position of the rocker arm allows the governor latch to swing freely under the governor block so that the device can unlatch when the speed returns to normal. The operating speed can be regulated by raising or lowering the governor shoe by means of the "speeder screw," Fig. 159.

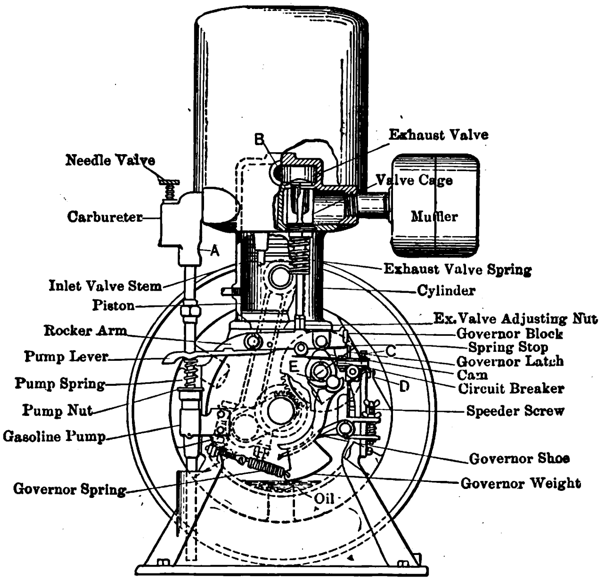


FIG. 159. — Novo Engine.

Fig. 161 shows a section through the hopper jacket, cylinder and exhaust valve. The spark plug is also shown in this view. In Fig. 162 are shown sections of the carbureter and gasoline pump. The operation of the carbureter is similar to that of those previously described, the amount of fuel entering the engine being controlled by the needle valve as shown.

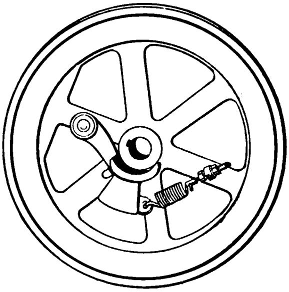


Fig. 160.—Flywheel and Governor Weight, Novo Engine.

The gasoline pump is very simple in construction and is operated by an extension on the end of the lever which actuates the exhaust-valve push rod, as shown in Fig. 159. As a result, the fuel pump is not moved during missed cycles when the lever is held up by the governor latch.

The check valves of the pump are simple steel balls as shown in Fig. 162.

All working parts of the Novo engine are thoroughly lubricated by a splash and sight-feed oiling system.

The jump-spark system of ignition is used in all sizes of these engines.

THE CUSHMAN FARM ENGINE.

This engine is manufactured by the Cushman Motor Works of Lincoln, Neb. It is made in two sizes, a single-cylinder unit rated at 4 horse power and a two-cylinder engine rated at from 6 to 8 horse power. The same company also builds a larger two-cylinder engine rated at 20 horse power.

These engines are all vertical, high-speed engines operating on the four-stroke principle. The manufacturers are exponents of high speeds and light weight, believing that such combinations most nearly meet the farmers' needs. Thus the 4 horse power engine weighs 190 pounds, the 6 to 8 horse power weighs 320 pounds and the 20 horse power 1200 pounds complete. The significance of these

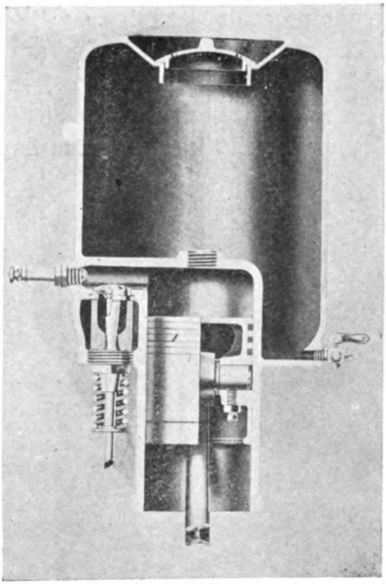


FIG. 161.—Section of Cylinder, Novo Engine.

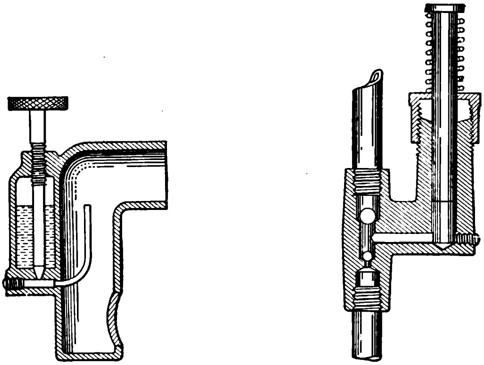


FIG. 162.—Carbureter and Fuel Pump, Novo Engine.

figures can be appreciated by comparison with the average values given in the preceding chapter.

The characteristics of the small engine are well shown in Figs. 163, 164, 165 and 166. The simple cylinder is fastened to the top of the inclosed crank case which contains practically all the moving parts including the half-time gearing and cam shaft.

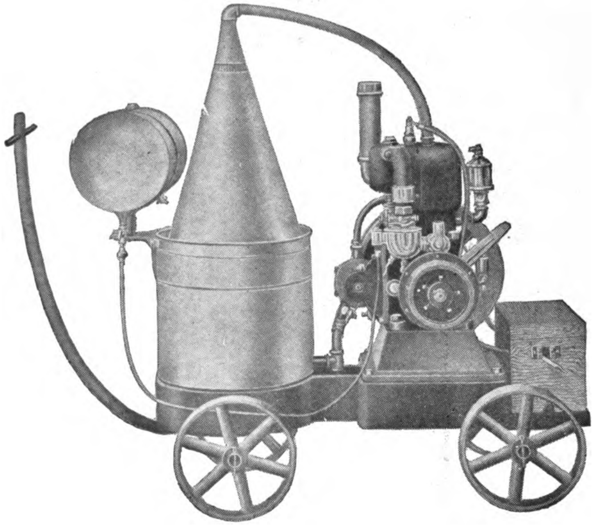


Fig. 163. — Cushman Farm Engine with Integral Cooling and Circulating System.

The valves are arranged vertically in a pocket at one side of the cylinder as shown by the section in Fig. 167. The inlet valve is placed above the other, is carried in a removable cage and operates automatically. The exhaust valve is opened by the straight-line motion of a push rod which rests directly on the operating cam as shown in Fig. 166. This valve is removed from the cylinder through the opening left after taking out the inlet-valve cage.

The mixture of gasoline and air used in the engine is formed by means of a Schebler float-feed jet carbureter

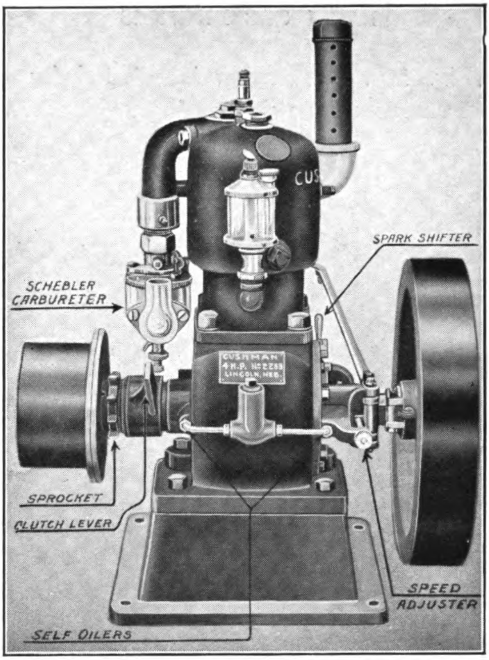


FIG. 164. — Cushman Farm Engine.

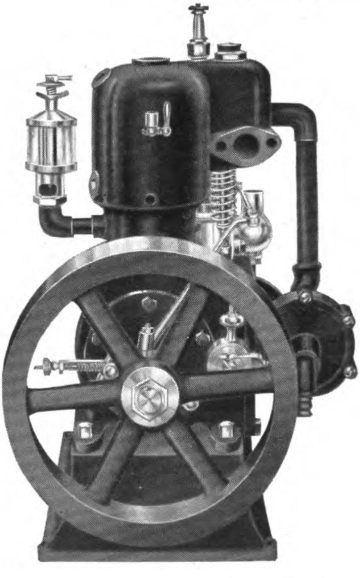


FIG. 165. — Cushman Farm Engine.

shown in Fig. 168. Governing is effected by throttling this mixture on the engine side of the carbureter by means

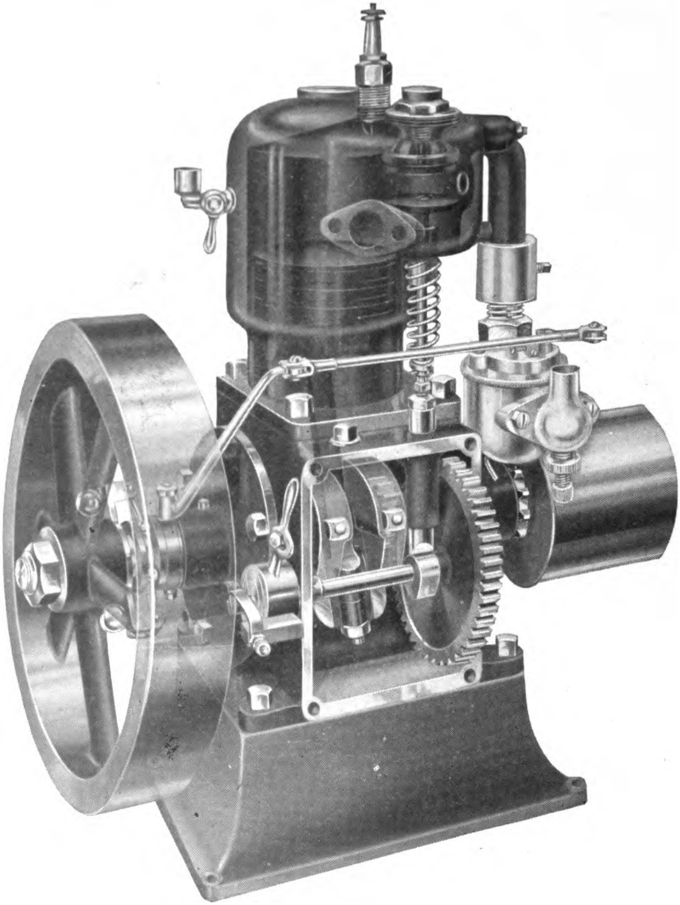


FIG. 166. — Cushman Farm Engine with Crank Case Cover Removed.

of a sheet-metal butterfly valve or damper. The method of operating the throttling device is shown in Fig. 169. The weights shown move out and in as the speed increases and decreases and thus move the fingers shown about the pivots *P*. These fingers move the collar, in which they bear, back and forth along the shaft and this collar operates the throttle through the governor arm and linkage shown.

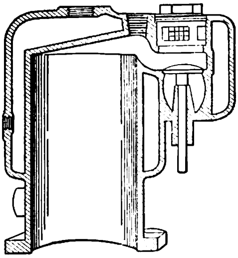


FIG. 167. — Section through Cylinder of Cushman Farm Engine.

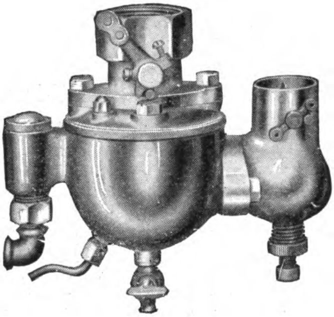


FIG. 168 — Schebler Carbureter.

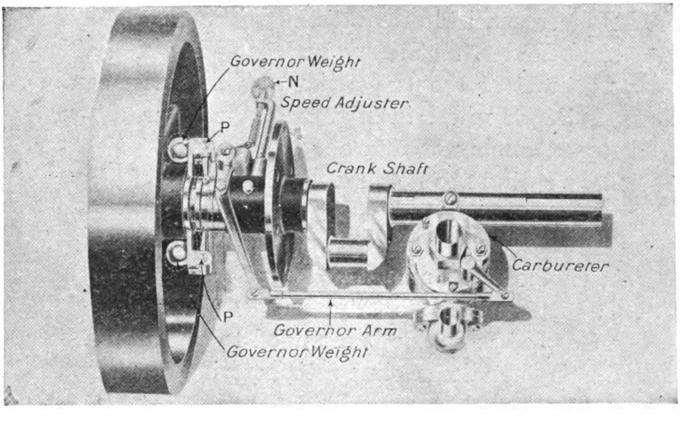


FIG. 169. — Governing Mechanism of Cushman Farm Engine.

The speed at which the engine rotates its shaft can be controlled while the engine is in operation by changing the tension of the spring in the speed adjuster. The location of this spring can be seen through the flywheel in Fig. 165. The spring is so connected to the governor linkage that it resists the tendency of the governor weights to move outward and increasing its tension makes it necessary for the engine to revolve at a higher speed before the weights move out and cause throttling. The tension of the spring is altered by turning the nut indicated by *N* in Fig. 169.

The normal speed of this engine is about 800 revolutions per minute and it is capable of developing its full rated power at this speed. The speed can be decreased to about 400 and increased to about 900 revolutions per minute.

Ignition is caused by a jump spark, the plug being located in the cylinder head as shown in Fig. 166. It will be observed that it is located close to the inlet valve and that its points project into the passage between the valve box and the cylinder. It is thus scoured by the incoming gas and kept clean, that is, free of oil and carbon.

The timer consists of a rotating piece on the end of the cam shaft and a stationary spring with which this piece makes contact at the proper time. This device can be seen through the flywheel in Fig. 165, the lever shown being used for advancing or retarding the spark by swinging the stationary spring about the cam shaft.

THE GASO-KERO ENGINE.

This engine is manufactured by the Bessemer Gas Engine Company of Grove City, Pa.

The Gaso-Kero engine is intended to operate on kerosene but will also handle gasoline satisfactorily. It is not a high-efficiency engine but represents a satisfactory commercial solution of the small kerosene engine problem. It is built in sizes ranging from 2 horse power to 10 horse power.

This engine is essentially a single-cylinder, single-acting, two-stroke machine using an inclosed crank case for compression. In these respects it resembles the small "two-cycle" marine and stationary gasoline engines as can be seen by inspection of Fig. 170, which gives a section of the

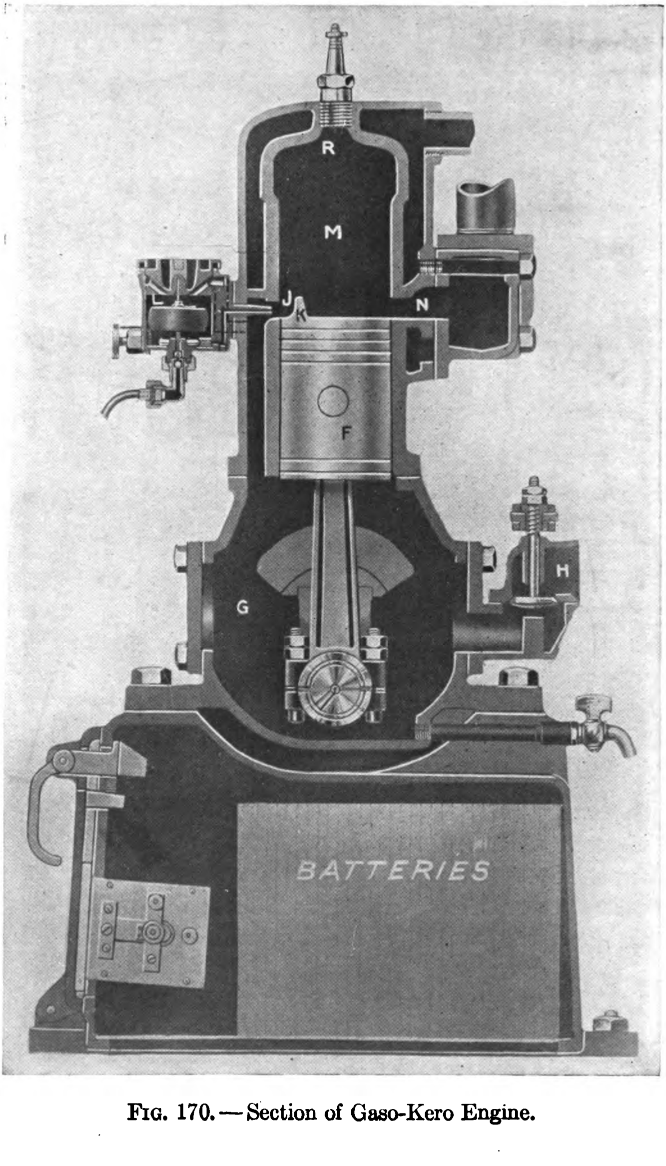


Fig. 170. — Section of Gaso-Kero Engine.

engine. The general arrangement with cooling tank in place and the whole outfit mounted on skids is shown in Fig. 171.

The engine differs from the ordinary small two-cycle gasoline engine however in that air only, and not a mixture of air and fuel, is compressed in the crank case. The fuel is added to the air just as it enters the cylinder by means of the fuel-feeding device shown fastened to the side of the cylinder in Figs. 170 and 171.

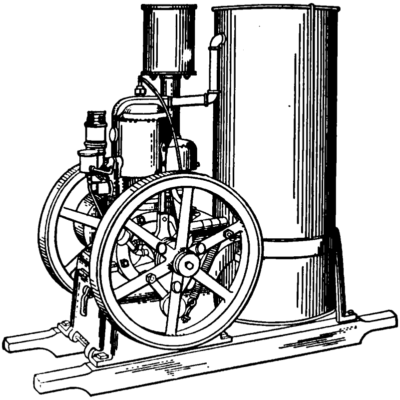


Fig. 171. — Gaso-Kero Engine with Integral Cooling System.

In detail, the engine draws a charge of air into the crank case through the automatic suction valve *H*, Fig. 170, as the piston ascends. During the next descending stroke this air is compressed in the crank case to a final pressure of five or more pounds, while the burned gases of the preceding cycle are expanding above the piston. Near the lower end of its stroke the piston uncovers the exhaust port *N* in Fig. 170, allowing the burned gases to rush out into the exhaust pipe. A slight further descent uncovers the inlet port *J*, allowing the air compressed in the crank case to rush into the cylinder through the bypass.

As the air enters the cylinder it picks up the requisite quantity of fuel in a way which will be described below and the mixture is formed within the cylinder itself.

The upward stroke of the piston compresses the fuel mixture into the clearance space and at the same time the next air charge is drawn into the crank case through the valve *H*.

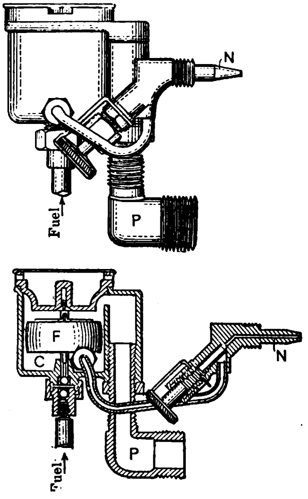


FIG. 172. — Fuel-feeding Mechanism, Gaso-Kero Engine.

The fuel-feeding mechanism is shown attached to the cylinder in Fig. 171 and separately in Fig. 172. In these figures it has been slightly modified from the real construction in order to better show its action.

It consists essentially of a cylindrical fuel bowl containing a float and connected with the bypass from the crank case by a passage *P*, which is shown dotted in Fig. 170. The lower end of the bowl is connected with the fuel reservoir by means of a pipe the upper part of which is shown in the figures. At a slightly higher level a connection is made to the fuel nozzle which screws into place opposite the inlet port of the cylinder.

The connection *P* insures the existence of the crank-case pressures on the fuel surface in the cylindrical bowl, so that when the crank-case pressure is low a low pressure exists above the fuel, whereas when the pressure in the crank case is high there is a high pressure on the liquid surface.

When the float in the cylindrical bowl rises to such a position that the ball on the end of its stem closes the fuel inlet it prevents further flow of fuel to the carbureter. When, however, the fuel level in the bowl sinks the float does the same and unseals the fuel pipe.

When air is entering the crank case through valve *H*, the pressure in the crank case is below that of the atmosphere and the same is therefore true of the space above the fuel level in the fuel bowl. If the float happens to be down at this time, atmospheric pressure on the surface of the fuel in the reservoir forces some of the fuel up into the fuel bowl through the ball check valve shown at the top of the fuel pipe. The device therefore pumps its own fuel supply into the fuel bowl as required.

During the downstroke of the piston the pressure in the crank case is raised and therefore the pressure on the fuel in the fuel bowl is also raised. This cannot, however, cause flow of fuel through the nozzle, because the end of the nozzle projects into the bypass in which the pressure must be the same as that in the bowl and in the crank case.

When the inlet port is later uncovered the air in the bypass rushes into the cylinder and the pressure opposite the end of the fuel nozzle suddenly drops to about that of the atmosphere. When this happens the compressed air above the fuel in the bowl forces some of the fuel out of the nozzle in the form of a fine spray. This spray enters the air current which is flowing into the cylinder, strikes the hot deflecting plate on the piston and is well mixed with the air during the compression stroke. The vaporization of the fuel is partly due to heat received from the hot piston, partly to heat from the cylinder walls and partly to the heat generated as the mixture is compressed.

It will be observed that this fuel-feeding device is essentially a jet carbureter and at first sight it would seem that it ought not to give better results with kerosene than are obtained with the ordinary forms of jet carbureters. There is, however, a very marked and important difference. In this device the pressure causing the flow of fuel out of the nozzle is high as compared with that obtained in the ordinary types. The spray is consequently much finer and this, combined with the vaporizing effect of the hot deflection plate and piston face and an imperfectly cooled cylinder head, makes possible the satisfactory vaporization of kerosene.

Governing is very ingeniously effected by limiting the opening of the valve *H*. The governor, which is located in the flywheel, is so connected with this valve that when the speed of the engine increases above normal the valve is not permitted to open to its full extent. This results in admitting less air to the crank case and when this air is compressed by the descending piston the pressure attained is lower than with normal filling. This lower pressure causes a smaller flow of fuel out of the fuel nozzle and therefore decreases the heat supply for the next cycle.

In a general way the quantity of fuel and quantity of air vary in the same way, so that the proportions of the mixture do not change greatly. The governing, therefore, corresponds approximately to quantity regulation described in Chapter XIII.

THE FAIRBANKS-MORSE TYPE T ENGINE.

Fairbanks, Morse and Company market engines of many types and sizes and the one here described is chosen simply because it differs most from the other engines described in this chapter.

The type T standard vertical engines are made in single-cylinder units in sizes of 2, 3, 4, 6, 9 and 12 horse power. These engines are normally equipped to operate with gasoline but when desired they are modified in such a way as to enable them to utilize kerosene or distillate as well.

The general construction of the engines as supplied for use with gasoline is best shown in Figs. 173 and 174 which give vertical sections on the center line of the cylinder. The sub-base, crank case, cylinder and cylinder head are separate castings bolted together as shown. The cylinder jacket

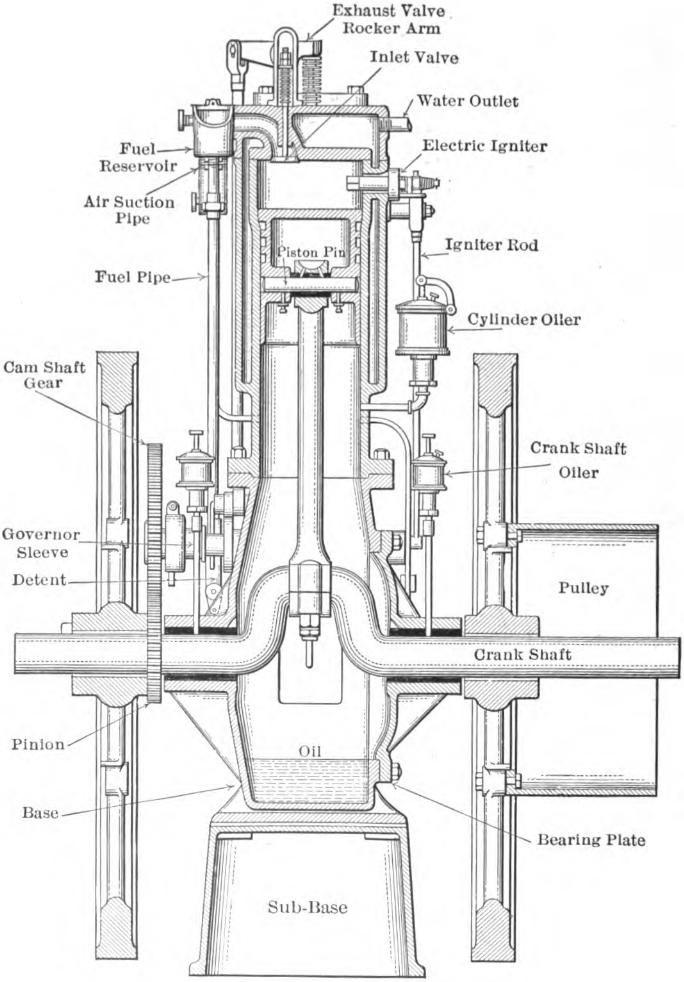


FIG. 173. — Section Fairbanks-Morse Type T Engine.

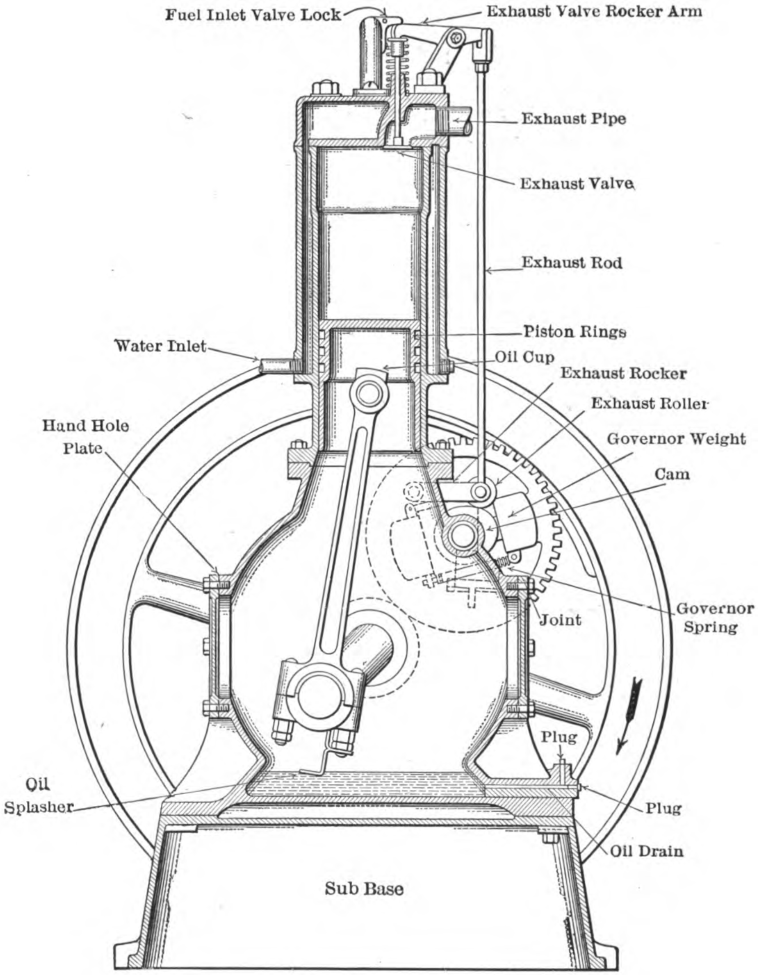


Fig. 174. — Section Fairbanks-Morse Type T Engine.

is of the ordinary closed type; but can be converted into the equivalent of an open or hopper type by the addition of an "evaporator tank," which is merely a large water reservoir connected to the upper part of the jacket space.

The valves are both located in the cylinder head. The inlet, which is automatic, is shown in Fig. 173. The exhaust valve and its operating mechanism are shown in Fig. 174.

Fig. 175. — Fairbanks-Morse Igniter Block.

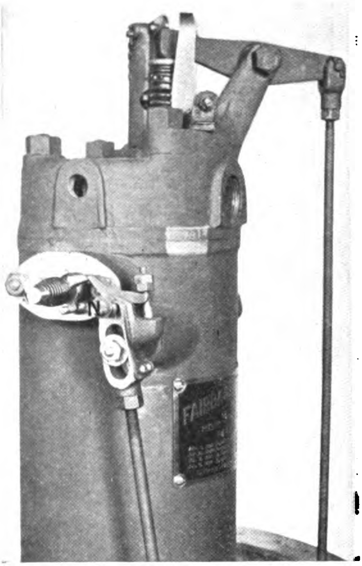


Fig. 176. — Fairbanks-Morse Igniter Operating Mechanism.

Lubrication of piston and main bearings is effected by means of the sight-feed oil cups shown in Fig. 173. The crank-pin and wrist-pin bearings are lubricated by splash from the oil in the crank case, the oil splasher shown in Fig. 174 insuring the proper distribution of the lubricant.

A make-and-break igniter is used on all engines of this type. It is shown in position in the right-hand side of the cylinder in Fig. 173 and in detail in Fig. 175. This igniter is operated by a push rod from the half-time shaft of the engine, the details of the upper end of the push rod being shown in Fig. 176. Setting for late and early spark during and after starting of the engine is effected by turning the wing nut *N*, while permanent change of timing to compensate for wear or for other reasons is made by altering the position of the two nuts on the stud to the right of *N* in the illustration.

The fuel mixture is made in a jet type of carbureter in which the gasoline level is maintained at a constant height just below the nozzle by means of a fuel pump and an overflow. The carbureter is shown in place on the left side of the cylinder in Fig. 173 and in detail in Fig. 177.

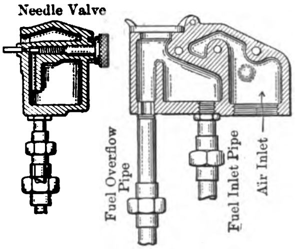


Fig. 177. — Carbureter, Fairbanks-Morse Type T Engine.

Governing of the gasoline engines is effected on the hit-and-miss principle, the exhaust valve being held open by a detent operated by the governor whenever the speed of the engine exceeds the normal value. The governor sleeve and the detent are shown in Fig. 173; the position and shape of the governor weights are indicated in Fig. 174.

Several modifications are made in this engine to fit it for the burning of kerosene and distillate. To prevent condensation of the heavier fuels within the cylinder during the suction or compression strokes, which would result in the formation of excessive quantities of carbon and smoke, the engine cylinder is operated with a higher average temperature than when utilizing gasoline. For this reason it is deemed advisable to leave openings in the hand-hole covers of the crank case in order that the resulting circulation of air may keep the various bearings at a moderate temperature. The use of a partly-open crank case, however, makes it impossible to use the splash system of lubrication and a centrifugal crank-pin oiler, such as that described on page 124, is therefore used.

In order to maintain more uniform cylinder temperatures, and thus give better operation on the heavier fuels, throttling governing is substituted for hit-and-miss regulation. With the throttling method there will be some fuel burned in the cylinder every second revolution, thus preventing the cooling of the walls incident to missed cycles with the other system.

During operation on the heavier fuels, the fuel is fed to a jet carbureter, similar to that used with gasoline, by means of a fuel pump like that used with the lighter fuels. The air supply to this carbureter is however differently arranged. This air is partly drawn direct from the atmosphere and partly drawn from around the exhaust pipe. A throttle valve in each supply pipe makes it possible to regulate the relative quantities of unheated and heated air until the best results are obtained. This arrangement is well shown in Fig. 178.

Oil-burning engines of this type cannot be started without preliminary heating of some kind. The engines described are arranged for two different methods of starting. The type shown in Fig. 178 is started by heating an auxiliary reservoir below the carbureter proper by means of a torch. This reservoir is merely the equivalent of an enlargement in the suction pipe just outside of the engine cylinder.

When this enlargement has been raised to a sufficiently high temperature, kerosene or similar fuel is dropped into it from the sight-feed cup shown at the top of the cylinder. This fuel is vaporized by the hot walls and the vapor is allowed to enter the cylinder by holding the inlet valve open. After the vapor has entered the cylinder in sufficient quantity to form an explosive mixture the engine is turned over

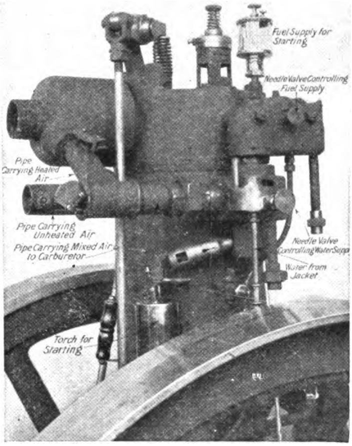


FIG. 178. — Fairbanks-Morse Type T Engine Fitted for Kerosene.

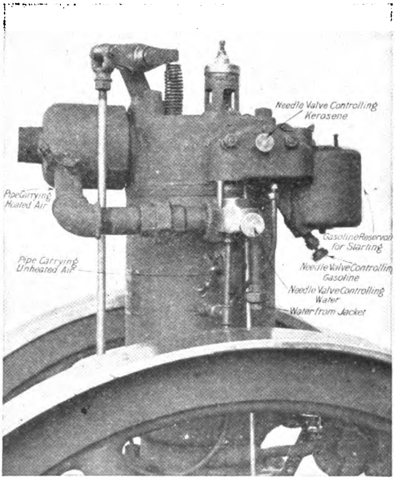


FIG. 179. — Fairbanks-Morse Quick-start Oil Engine.

by hand and started as though a gasoline mixture were being used. After starting, the engine is operated on vapor made in the heated enlargement of the suction pipe until the parts have become heated up to normal working temperature. When this temperature is attained the jet carbureter is brought into operation and the starting device cut out.

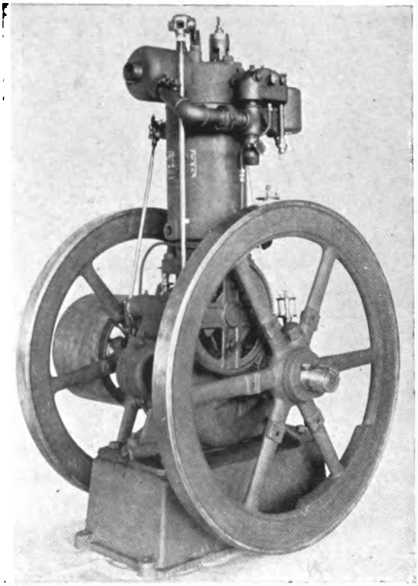


FIG. 180.—Fairbanks-Morse Quick-start Oil Engines.

A start of this kind requires from ten to thirty minutes, depending upon the temperature of the air and jacket, the character of the fuel and the skill of the operator. For quicker and simpler starting the company furnishes what is called a "quick-start" oil engine. This is merely the same engine with the torch heating attachment omitted and an auxiliary gasoline carbureter added as shown in Figs. 179 and 180. The engine is started on gasoline and is operated with this fuel until the temperatures of cylinder and parts have become high enough to enable the engine to operate satisfactorily on kerosene.

In both types of oil engine provision is made for injecting water with the charge in order to prevent preignition and to minimize the deposition of carbon. This water is taken from the jacket of the engine and the quantity flowing is controlled by hand by means of the small valve shown in Figs. 178 and 179.

The complete oil engine, equipped for starting with gasoline is shown in Fig. 180.

THE RUMELY OIL ENGINES.

The M. Rumely Company first developed a two-cylinder kerosene engine for use in the tractor which is sold under the name of "The Oil Pull." This engine is now marketed for stationary purposes, under the name of the "Oil Turn Motor," in 30, 45 and 60 horse-power sizes. More recently the company has developed a line of single-cylinder kerosene engines which are sold under the name of the "Falk Kerosene Engine" in sizes from 3 to 15 horse power.

The Oil Turn Motor is shown in Figs. 181 and 182, the Falk Kerosene Engine in Figs. 183 and 184.

All of these engines have the inlet and exhaust valves arranged vertically, the inlet valve above and the exhaust valve below. Both valves are mechanically operated. In the Oil Turn Motor the valves are operated through bell cranks by push rods which are moved by cams on a cam shaft inclosed within the upper part of the crank case as shown in Fig. 185. In the Falk engines the valves are operated through bell cranks by rods moved by cams on the half-time shaft which is driven by spiral gears.

Ignition in all cases is by make-and-break igniter. The plug is located in the cylinder head in the smaller engines and on one side of the combustion chamber in the larger models.

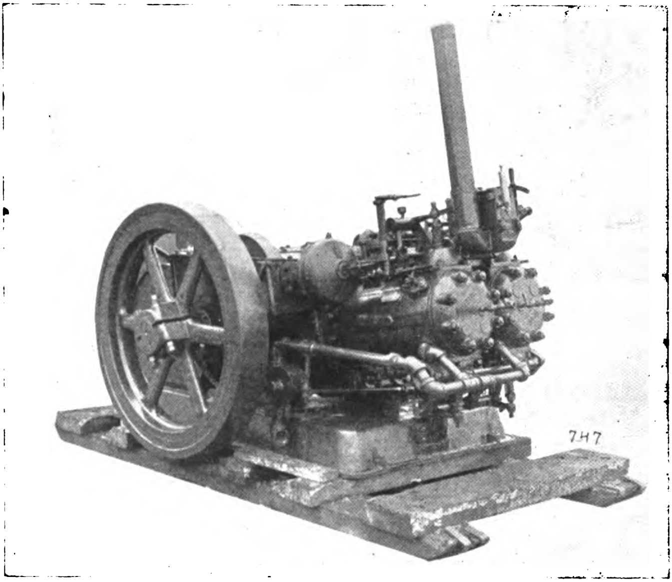


FIG. 181.—Rumely Oil Turn Motor.

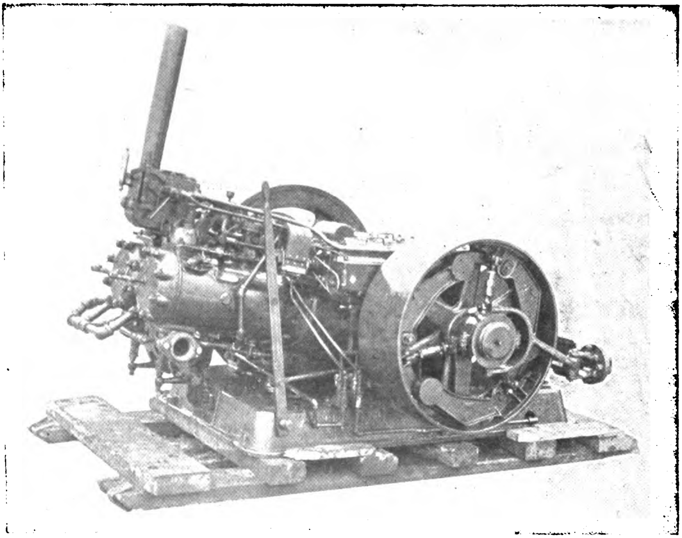


FIG. 182.—Rumely Oil Turn Motor.

The original Oil Pull engines embodied the Secor-Higgins patented system of oil combustion, and the same principles have been carried through the entire line of engines. The underlying principles of this system are:

(1) The use of a carbureting device for the formation of the combustible charge,

(2) The automatic control of the quantity of fuel in the mixture to suit the load on the engine,

(3) The automatic control of the quantity of mixture to suit the load being carried, and

(4) The automatic admixture of water with the charge in proportions best adapted to the load.

The way in which these principles are carried out in practice is best appreciated by studying the Secor-Higgins carbureter used with these engines. This carbureter or mixer is shown in Figs. 186, 187 and 188. It consists essentially of three boxes or chambers located over another box which has two holes in its lower wall. A sliding plate or valve moved by the governor controls the extent to which these holes are open.

During regular operation kerosene is supplied to one of the chambers in the upper part of the mixer and water to one of the others as indicated in Fig. 187. These liquids are pumped into their respective chambers in larger quantities than are required and the surplus flows over dams and back to the sources of supply through the overflows shown dotted in Fig. 187. Constant heads are thus maintained as in other cases previously described.

During each suction stroke the engine lowers the pressure within the lower chamber of the mixer, and if the pressure is lowered to a sufficient extent the atmospheric pressure then forces fuel and water through the screens surrounding the needle valves, up to the holes, indicated by *H* in Fig. 187, from which point they flow down into the air on its way to the engine.

The kerosene overflow is a little higher than that for the

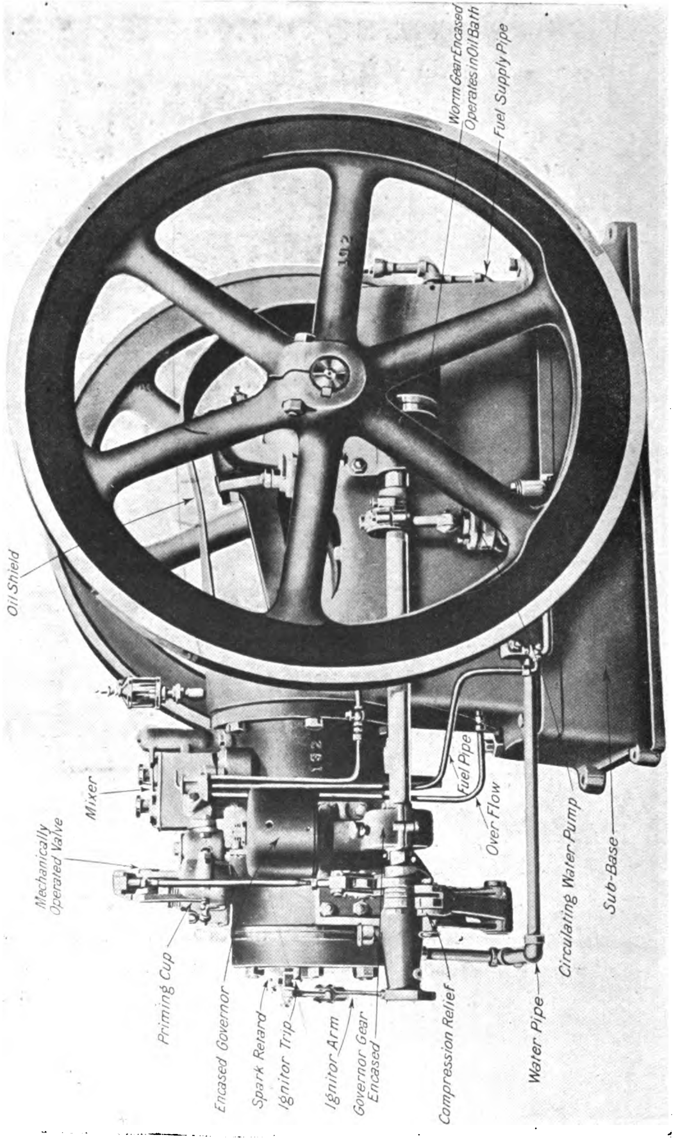


FIG. 183. — Falk Kerosene Engine.

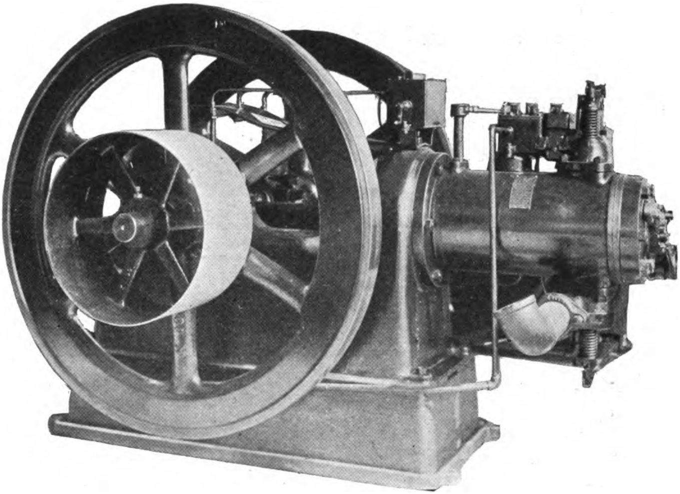


FIG. 184. — Falk Kerosene Engine.

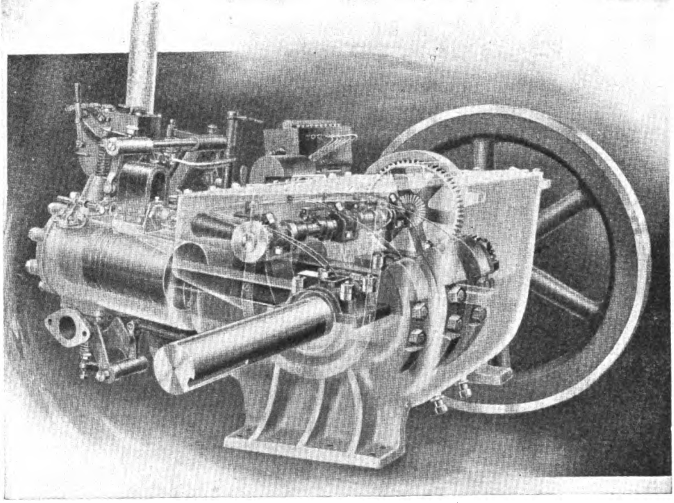


FIG. 185. — Valve Operating Mechanism of Oil Turn Motor.

water, so that the kerosene would normally stand at a slightly higher level. This, combined with the lighter weight of the kerosene, necessitates a greater lowering of pressure within the lower chamber to draw water into the mixture than is required to cause the flow of kerosene.

At light loads the mixture-control plate or valve is drawn toward the left by the governor into a position somewhat like that shown in Fig. 188. There are then two openings through which the external air can enter the lower chamber of the carbureter and only one comparatively small opening through which the mixture can enter the engine cylinder or cylinders. As a result the charge going to the cylinder is throttled, but the pressure within the lower chamber of the mixer is lowered to only a slight extent. This causes a small amount of kerosene to flow out of the kerosene chamber, but the lowering of pressure is not sufficient to cause the flow of any water.

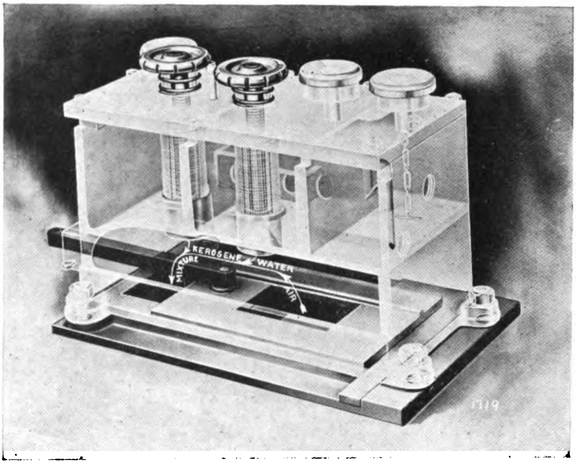


Fig. 186. — Secor-Higgins Carbureter.

With increasing load the governor shifts the plate or valve toward the right thus opening the port admitting charge to the cylinder and increasing its area with respect to the area of the other ports which admit external air to the mixing chamber. As a result of this shifting, the suction strokes cause a greater and greater lowering of pressure in the mixing chamber as the load increases and thus more and more fuel and ultimately more and more water are forced into the mixing chamber with increasing load. The carbureter is so adjusted that no water enters the charge until about half load is reached and from half load to full load the proportions change rapidly until the quantity of water becomes practically equal to the quantity of fuel at maximum load.

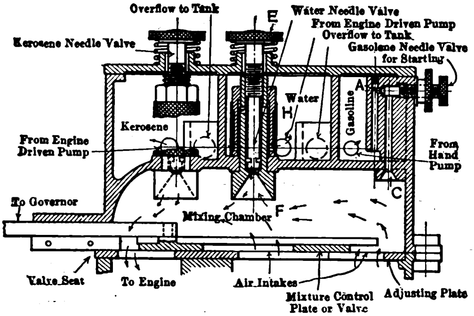


FIG. 187.—Section of Secor-Higgins Carbureter.

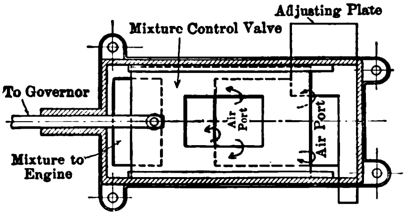


FIG. 188.—Arrangement of Governor Valve and Ports, Secor-Higgins Carbureter.

The operation of this carbureter is such that at light loads, when a small amount of charge is drawn in and when the compression pressure within the cylinder is therefore low, the relative relation of fuel to air is greater than at high loads when the absolute quantity of charge and of fuel is greater. In this way ignition and combustion are improved at light loads and a high compression and a good utilization of fuel are assured at full loads.

In some of the larger engines built under these patents the timing of the ignition has also been put under governor control in order to secure more perfect operation; but this feature is omitted in the smaller sizes for the purpose of securing simplicity of construction, adjustment and operation.

These engines are started on gasoline and operate on this material until the cylinders have been warmed sufficiently to insure proper vaporization of the less volatile fuels. For this purpose the third chamber in the top of the carbureter is used. This is filled with gasoline to the level of the overflow by means of a hand-operated pump. The amount of gasoline which the chamber will hold is sufficient for starting purposes under ordinary conditions.

The manufacturers claim that these engines not only operate perfectly when using kerosene and distillate as fuel; but have run satisfactorily for long periods of time on some of the crude oils.

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