VAN NOSTRAND'S
NAUTICAL MANUALS

MARINE GAS ENGINES

CLARK

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THEIR CONSTRUCTION AND MANAGEMENT

BY

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102 *ILLUSTRATIONS*

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PREFACE TO FIRST EDITION

In presenting the following material the author has not attempted to deal with the matter from a theoretical standpoint. The idea is rather to describe the construction and principles of operation of the standard types in a plain and simple and well-illustrated form. It is hoped that it will be found to be adapted to those desiring a systematic presentation of the principles of operation and construction of modern marine gas engines.

Boston, *November*, 1910.

PREFACE TO SECOND EDITION

In making the modifications for this edition no alteration in the governing principles would naturally be possible. Such changes have been made in the application of the principles as were necessary to bring the matter up to current practice. The material on oil and Diesel engines has been added in accordance with recent developments on these lines.

Boston, *July*, 1918.

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MARINE GAS ENGINES

CHAPTER I

Types of Engines

The rapid development of the gas engine during the past few years has made possible a great increase in the use of small units of power for various purposes. This is shown by the increasing use of the gas engine in automobiles, power-boats, and many other places where compact powers are necessary.

The gas engine, for small powers particularly, has many advantages over the steam engine. It is self-contained, with no cumbersome boiler, feed pumps, and piping. It is comparatively light and easily installed. As there is no fuel to be handled it is easily kept clean, and as the supply of fuel is nearly automatic, it may be run with the minimum amount of care, and little labor is required beyond the regulation of the lubrication and the fuel supply. Properly installed and in good hands, the gas engine may be nearly as reliable as the steam engine. The underlying principle of the operation of any engine, whether gas or steam, is the fact that a gas tends to expand when heat is applied to it, and if allowed to do so has the power of doing work. Any gas or vapor will absorb heat; during the process its tendency to expand is increased, or in other words, the pressure is increased. If the gas or vapor can then be confined, as in the cylinder of an engine, and allowed to expand, it can be made to do work upon the piston. In the steam engine the heat is applied to the boiler, vaporizing the water and raising the pressure of the vapor in the boiler. The vapor is then carried to the boiler under pressure, and allowed to expand in the cylinder, thus doing work on the piston. The action of the steam engine is thus complicated by the boiler, piping, and pumps, and the operation by the care necessary to feed the fuel, and maintain the proper quantity of water in the boiler.

The gas engine, whether operated on gasoline, alcohol, or kerosene, is of the type technically known as the internal combustion engine. The name originates from the fact that the combustion of the fuel and the consequent generation of heat take place directly in the cylinder of the engine, instead of in a separate chamber, or boiler, as in the steam engine.

Gas engines for marine use may be practically divided into two general classes, the two-cycle and the four-cycle. The cycle of events is the same in both cases, but the means of accomplishing it are quite different. In either type there are four operations to be accomplished during each cycle, viz.: (1) Drawing in a fresh charge of gas into the cylinder; (2) compressing and firing the charge; (3) expansion of the ignited charge and the absorption of its energy; (4) expulsion of the burned and exhausted gases. The completion of this series of events is termed a "cycle."

The "Two-cycle" Engine.—This type, being simpler of the two types, will be described first. The general outline of a two-cycle engine is shown in Fig. 1, where *C* represents the cylinder; the piston *P* moves freely up and down in the cylinder; the connecting rod *R* connects the piston with the crank shaft *S*. As the piston moves up and down it imparts a rotary motion to the crank shaft by means of the connecting rod. The crank case *B*, or chamber surrounding the crank, is made gas-tight. An opening into the crank case is provided with a check valve *V*, which allows gas to enter the crank case, but not to pass out. A transfer passage *T* leads from the base and opens into the cylinder at the inlet port *I*, which is above the piston when the latter is at the lowest point of its stroke, as in Fig. 3. At *E* another port, called the exhaust port, opens from the cylinder to the outside. The exhaust port is somewhat higher up than the inlet port. Both inlet and exhaust ports are covered by the piston except when it is near the bottom of its stroke. The flywheel *F* is provided in order to give a steady rotation.

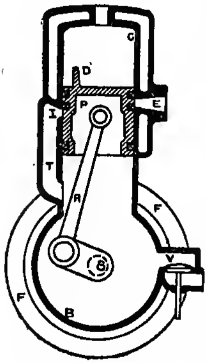


FIG. 1.—Outline of Two-cycle Engine.

For the operation, suppose the piston to be at the bottom of its stroke, and to ascend, as in Fig. 2; this action will create a partial vacuum or "suction" in the crank case and will draw in a charge of explosive mixture through the check valve. When the piston reaches the top of its stroke, the "suction" ceases, allowing the check valve *V* to seat, confining the charge in the crank case. As the piston again descends, the charge in the base, being confined, is compressed in the base and the transfer passage, the outlet of which is closed by the piston, as in Fig. 4.

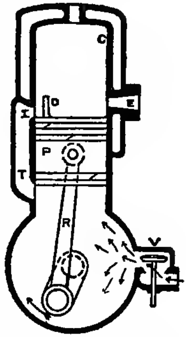


FIG. 2.— Two-cycle Engine on Compression Stroke.

When the piston reaches nearly the bottom of its stroke it uncovers the inlet port *I* and the charge from the crank case rushes in and fills the cylinder as in Fig. 3. Before, however, any of the new charge can escape through the exhaust port *E* which is also open, the piston has begun its next upward stroke and covers both ports, so that the cylinder is now filled with nearly fresh gas. As the up stroke continues, the charge in the cylinder is compressed into the space above the piston. When the piston has reached the top of its stroke, the compressed charge is ignited by some means, producing a powerful impulse from the heat generated by the combustion, which drives the piston downwards, giving the power stroke. As the piston nears the bottom of its stroke it uncovers the exhaust port *E*, allowing the pressure in the cylinder to drop and a part of the burned gas to escape. A moment later in the stroke the inlet port *I* is again uncovered and a fresh charge is admitted from the crank case, which drives out the most of the remaining burned gases and fills the cylinder as before. This new charge is then compressed on the next up stroke and a new supply drawn into the crank case and the operation continues.

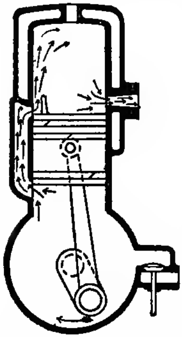


FIG. 3.— Two-cycle Engine at Admission of Gas.

Following through the sequence it will be seen that the cycle is completed during every revolution, or for every two strokes.

For this reason it is called the two-stroke cycle, or, as commonly stated, the "two-cycle." This cycle has a working or power stroke during each revolution. The momentum of the flywheel is depended upon to carry the piston up during the compressive stroke.

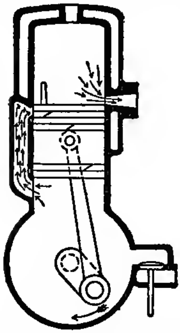


FIG. 4.—Two-cycle Engine at Exhaust.

The projection *D* on the top of the piston is a deflector, or shield, in front of the inlet port to deflect the incoming gas upwards, which not only produces a scouring action, but prevents the new charge from rushing directly across the cylinder and out through the exhaust port. The exhaust port is usually opposite and is somewhat higher up than the inlet port, in order that the pressure may be reduced and the burned gases partially escape before the fresh charge is admitted. If this were not done, the temperature in the cylinder would be so great that the incoming charge would be fired prematurely. The relative position and size of the inlet and exhaust ports is the key to the success of the two-cycle engine. The piston, in this type of engine, acts as its own valve, so that the engine, from its very principle, is valveless.

"Three-port" Engines.—A variation of the two-cycle engine, known as the "three-port" engine, is illustrated in Fig. 5. Aside from the means of admitting the vapor, the general characteristics and operation are the same as the usual two-cycle type. Instead of admitting the vapor to the crank case through the check valve, a third port *K* is provided, which is covered by the piston except when it is at the top of its stroke, as in Fig. 5, at which time this port is open into the space below the piston. The piston on its up stroke creates a partial vacuum in the crank case, and when the third port is uncovered at the top of the stroke, the vapor rushes in. The vapor is thus admitted in a sort of puff, instead of during the entire up stroke as in the two-port type. The action is therefore more energetic and positive at high speeds. As the piston covers the

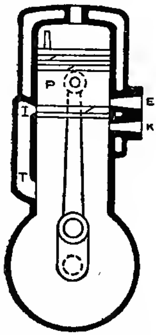


FIG. 5.—"Three-port" Engine.

admission port except during the admission, a check valve on the vapor inlet is unnecessary, and the admission of the vapor is less obstructed.

The action of the check valve on the two-port engine becomes somewhat uncertain at high speeds, as it does not have time to seat squarely between the strokes, so that some of the vapor is likely to be blown back around it instead of being confined in the base. For these reasons the three-port engine can probably be run at a higher rate of speed, and this type is usually adopted for light high-speed engines. There are one or two makes of engines which have both the check valve and the third port, which, it is claimed, have all the advantages of each type.

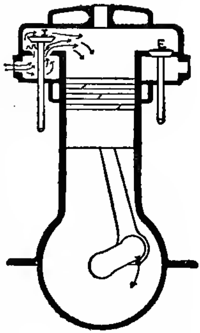


Fig. 6. — Four-cycle Engine on Admission Stroke.

The Four-cycle Engine. — In this type of engine the admission and exhaust of the gases are controlled by mechanical means. In Fig. 7, *I* is the inlet valve opening from the admission chamber into the cylinder, and *E* is the exhaust valve opening from the cylinder into the exhaust chamber. These valves are controlled by gears from the engine shaft. The other parts of the engine are substantially the same as the two-cycle engine, except that the crank case does not require to be gas-tight.

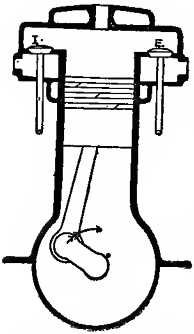


Fig. 7.—Four-cycle Engine on Compression Stroke.

For the operation, suppose the piston to be moving downwards, as in Fig. 6; the inlet valve *I* is open and the suction draws in a charge of fresh gas, filling the cylinder. On the piston reaching the bottom of its stroke, the inlet valve closes, confining the charge in the cylinder. On the next upward stroke, shown by Fig. 7, both inlet and exhaust valves remain closed, and the charge is compressed into the space above the piston. When the piston reaches the top of its stroke the compressed charge is ignited, expanding and driving the piston down, as in Fig. 8; both valves remaining closed. This gives the impulse or power stroke. During the next up stroke the exhaust valve *E* opens, and the burned gases are forced out by the piston through the exhaust port, as in Fig. 9. The cylinder is now clear and ready for the admission of a fresh charge through the inlet valve on the next downward stroke of the piston.

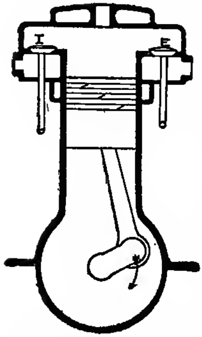


FIG. 8. — Four-cycle Engine on Power Stroke.

This cycle is completed in two revolutions, or four strokes, and is therefore called the four-stroke cycle, or "four-cycle." There are three idle strokes and one working or power stroke during each cycle, thus giving a power stroke for each alternate revolution. The flywheel must be heavy enough to carry the piston through the three idle strokes.

Advantages of Each Type. — The two-cycle engine has the advantage of extreme simplicity, owing to the absence of valves or other external moving parts which would be likely to need adjustment and care. As the piston receives an impulse during each revolution, more power may be obtained from the same size cylinder than in the four-cycle type. It might seem that, since the two-cycle engine receives twice as many impulses as the four-cycle, twice the power should be obtained, but this is not so, as owing to the superior regulation of the four-cycle type the difference is much less. The more frequent occurrence of the impulses does, however, allow the use of a lighter flywheel and produces a smoother running engine with less vibration.

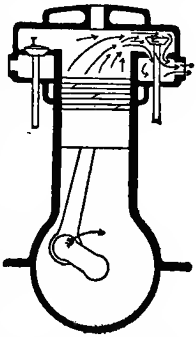


FIG. 9.— Four-cycle Engine on Exhaust Stroke.

The valveless feature of the two-cycle type, while giving simplicity, at the same time gives rise to some uncertainties and irregularities in the action of the engine. The action of the gas in the cylinder is somewhat uncertain; it is hardly to be expected that the inflow of gas will continue exactly long enough to fill the cylinder and no more; it is entirely possible either that some of the exhaust may not have time to escape, or that some of the fresh charge may pass over and out through the exhaust. Again, it is hardly possible for the incoming gas to entirely scour the upper parts of the cylinder, and some waste gas is sure to be caught, thus diluting the new charge. The driving out of the burned gas by the fresh mixture while some combustion may be still going on frequently results in the premature ignition of the new charge, the flame following down the transfer passage and igniting the reserve in the base. This produces a back explosion, causing an irregular action and even stopping the engine.

There are also some disadvantages which may be termed structural. While the working parts are very simple, they are entirely enclosed and not easily examined and adjusted. As the crank case for the usual type requires to be gas-tight, any leakage around crank-shaft bearings from natural wear causes a loss of crank-case pressure, and consequent loss of power. Any leak around the piston will allow the partially burned gases to pass down and deteriorate the quality of the fresh gas in the crank case. The lubrication of the parts in the closed crank case, which are exposed to the direct action of the fuel gas, is sometimes difficult, and the wear on these parts is consequently greater.

While there are two-cycle engines in which the enclosed crank case is dispensed with, an additional compression chamber must be provided, which adds complication and robs the engine of much of its simplicity.

The four-cycle type, although more complicated, is surer and more certain in its action, as the behavior of the gas is mechanically controlled. The idle stroke allows the cylinder a short time to cool between explosions. On account of the mechanical regulation there is less chance for waste of fuel and the economy is therefore greater than that of the two-cycle. As the flow of gas in the cylinder continues throughout the stroke, instead of in a sudden puff, the four-cycle engine may be run economically at a higher rate of revolution. No enclosed crank case is necessary and the working parts can be easily lubricated and taken care of.

On the other hand, the three idle strokes require a very heavy flywheel, and as the impulse occurs only on alternate strokes, the four-cycle engine must, for the same power, be larger and heavier than the two-cycle. Each impulse, or explosion, is much heavier than that in the two-cycle, and the tendency to vibration is consequently much greater.

While the two-cycle engine has some theoretical disadvantages, it practically has reached a high state of perfection, both as to reliability and economy, although in the latter respect it is probably not the equal of the four-cycle.

It may be stated as a general conclusion that for small, light engines where economy is not of great importance, and which receive little attention, the two-cycle type is to be preferred. For single-cylinder engines the two-cycle type is decidedly to be preferred, on account of the excessive vibration of the single-cylinder engine of the four-cycle type. For engines of large size, where fuel economy becomes of importance, together with increased reliability, the four-cycle type is probably preferable.

CHAPTER II

Two-Cycle Engines

Two-cycle engines seem to divide themselves into two more or less distinct classes, as shown in section by Figs. 10 and 11. The former type is of low rotative speed, moderate to heavy weight, and is generally fitted with the make-and-break spark mechanism. The latter is of the high-speed type, of moderate to light weight, generally fitted with the jump spark and is commonly of the three-port type.

The heavier type of engine is shown somewhat in detail in Fig. 10. The piston *P* is shown at its lowest position, its highest point being just above the line *c*. Above the line *c* the bore of the cylinder is slightly enlarged; this is called the counterbore, and is for the purpose of allowing the piston to overrun the edge of the working part of the cylinder bore and prevent a shoulder being formed at the upper end of the stroke as the bore wears. Unlike a steam engine, the piston does not travel to the top of the cylinder, but a considerable space, or compression chamber, is left to contain the gas compressed to the proper volume for ignition.

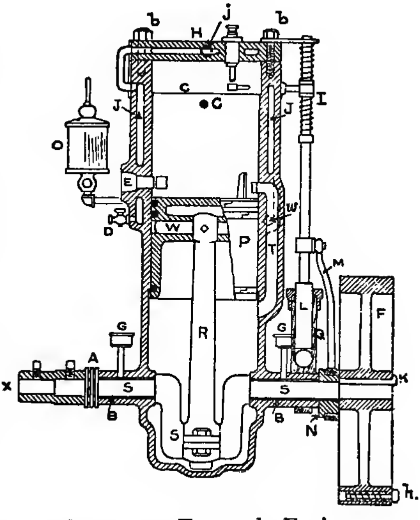


Fig. 10. — Two-cycle Engine.

The cylinder is surrounded by the water jacket *J*, through which water is circulated to carry off the excess heat which is generated in the cylinder, and which if not carried away would cause the cylinder and other parts to become overheated and perhaps damaged. The cylinder head *H*, which is also hollow for water circulation, is held in place by several bolts or studs *b*, *b*. The joint between the cylinder and head is filled with a thin sheet of packing to make it gas-tight. The water enters the jacket at *w*, circulates around the cylinder and through the head and passes out at *j*. The water may pass from the cylinder jacket to the head either through an outside pipe as shown, or through an opening directly upwards between the studs. The former method is preferable as, when the opening is cut in the packing, there is a chance for a leakage of water into the cylinder. In order to make the piston *P* gas-tight, it is provided with spring-packing rings as shown, usually three in number, which are set into grooves turned in the piston. They are turned to a diameter slightly larger than the bore of the cylinder and are sprung in, so that they press out against the walls of the cylinder and prevent leakage past the piston. The piston itself is a rather loose fit in the cylinder. Two of the rings are placed at the top of the piston and the other at the lower edge. This is to prevent leakage from one port to another. For example, when the piston is part way down, the gas in the base might be forced past the piston and out the exhaust port, were it not for this lowest ring. The joints on the rings are shown halved, which is much preferable to cutting them across at an angle as is sometimes done, as there is less chance for leakage when cut in this way. Piston and rings are of cast iron.

The piston or wrist pin *W* is a steel pin upon which the connecting rod *R* swings. It is held from turning by a set screw either in the piston or the top of the connecting rod.

The connecting rod *R* may be either of steel or bronze; the upper end of the rod consists simply of an eye, through which the wrist pin is inserted; the lower or crank-pin end is parted, and the under part fastened on with two or more bolts; this is necessary in order to get it into place and to allow the taking up of the wear. When the rod is of bronze, as is usually the case in small engines, the bearings are turned directly in the metal of the rod; when, however, a steel rod is used, either babbit or composition bearing surfaces must be inserted.

The crank shaft *S*, *S* should be made from the best of steel as it is subjected to great stress. It turns in bearings in the base, which are lined either with composition sleeves *B*, *B*, or babbit which is run into grooves provided for it. These sleeves or linings not only make a smooth bearing for the shaft, but allow the insertion of new ones when wear has taken place. On the end of the crank shaft is the flywheel *F*, of cast iron. It is held in place by a key *K* which is of rectangular section and is sunk half in the shaft and half in the flywheel hub. The handle *h*, for use in starting the engine, is contained in a hole in the rim of the flywheel, and is pulled out for use. It is encircled by a coiled spring which draws it in when released, preventing injury to the operator.

The pump *Q*, for circulating water through the jackets, is of the plunger type; it consists of the plunger *L* working in the barrel. This plunger is made water-tight at the upper end of the barrel by the packing gland as shown, and at the lower end are the usual two foot valves. The water is drawn in through one valve on the upward stroke and forced out through the other on the downward stroke, each valve allowing the water to pass in one direction only. The pump is operated by the eccentric *N* on the crank shaft, and the eccentric strap *M*.

The thrust bearing *A* takes up the forward pressure of the propeller and prevents the crank shaft being forced against the bearings by the pressure. It consists practically of two hardened-steel rings with steel balls running between them.

The igniter mechanism *I* is operated by an extension of the pump rod. At *D* is a drain cock to allow the water to be drained from the jacket in cold weather, as the freezing of water in the jacket would be likely to split the casting. At *C* is an opening from the cylinder, which is fitted with a pet-cock, for the purpose of relieving the compression when turning the engine over by hand.

An oil-cup *O* feeds oil into the bore of the cylinder, lubricating the piston and rings. A grease-cup *G*, *G* lubricates each crank-shaft bearing.

The coupling *X* allows the attachment of the propeller shaft; it is a sleeve of cast iron held on the shaft by set screws or keys.

In Fig. 11 is shown the general outline of the high-speed, three-port type. The general characteristics are the same as the previous example, but some details are different. In this case the cylinder and head are cast together, thus simplifying the water circulation; the joint between the cylinder and base castings being on the line of the center of the shaft. The pump is connected directly to the cylinder, the water passing through the stem; the outlet for the cooling water is at *j*. At *G*, *G* is a pair of bevel gears, one of which is fast on the crank shaft; the other is on the vertical shaft and drives the timer *T*. The spark plug is inserted at *P*.

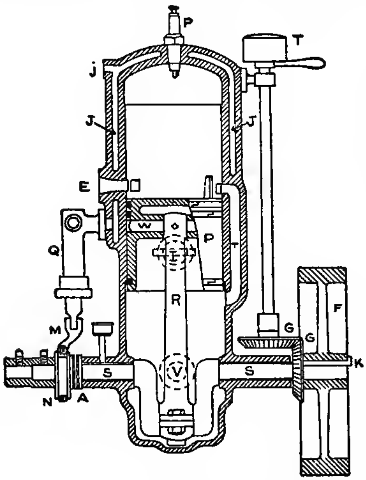


FIG. 11. — Two-cycle Engine.

The transfer passage and the exhaust port *E* are the same as before. The inlet port *I* is shown dotted on the farther side of the cylinder. The other inlet at *V* on the base is used in the two-port engine. Some few engines are fitted with both openings, allowing them to be used either two or three port as desired. This engine is arranged for jump-spark ignition, so that no igniter gear is shown, the spark plug *P* screwing into the head of the cylinder.

The several parts will not of course always be arranged in just the above relations; the transfer passage *T* is very often placed on one side, with the exhaust on the opposite side; the water pump may be placed either front or rear of the cylinder. Any of the several types of pumps later described may be used; the plunger pump may be placed horizontal and piped to the cylinder; in the case of the rotary or gear pump it may be driven by gears or sprocket chain. In at least one make of engine the gear pump is driven directly from the timer shaft.

Figs. 12, 13, and 14 show the outlines of three styles of standard makes of engines. In Fig. 12 the cylinder and upper part of the base are cast together; the lower part of the base being a separate casting joined to the upper base at the line of the shaft; the cylinder cover also is separate. The several parts are lettered the same as in the preceding cuts. In the medium and large sizes a hand-hole plate *h* allows access to the base for cleaning or adjustment. An opening in this plate is threaded for attachment of the vaporizer *V*. The exhaust pipe connection is on the rear of the engine at *E*. The water pump is just back of the fly-

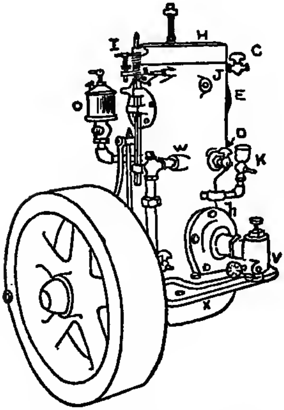


FIG. 12. — Two-cycle Engine.

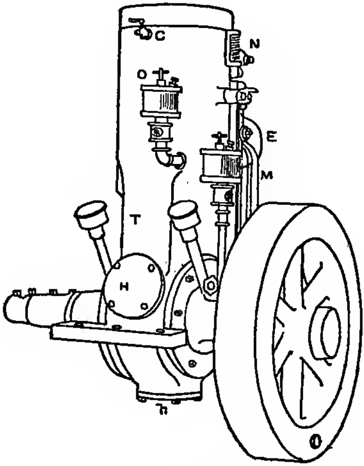


FIG. 13.—Two-cycle Engine, Heavy Type.

wheel and delivers the water to the jacket through the pipe *W*; the water discharges from the jacket at *J*. At *K* is a small oil-cup and cock for admitting oil to the base. The igniting gear is at *I*. In this type the sleeves for the crank-shaft bearings are held by being clamped between the upper and lower base castings. The engine is bolted to the bed by the flanges *X*.

In Fig. 13 an engine of somewhat similar type is shown, except that the cylinder and base are in one casting, and the shaft bearings are carried in plates bolted on front and rear of the base casting. This is a very strong construction, its only disadvantage being that in the event of damage to the cylinder the entire engine must be taken down. Access is given to the base through the hand-hole plate *H*, and an additional plate *h* on the bottom is placed there for constructive purposes principally. The transfer passage is on the side, as shown by the raised portion at *T*; the exhaust is on the opposite side at *E*. The oil-cup on the front of the engine is for the purpose of oiling the crank pin through a ring oiler, while the oil-cup *O* is the usual cylinder oil-cup.

Fig. 14 shows a high-speed, three-port engine similar to Fig. 11; in this case the cylinder, which has a solid head, is joined to the upper base casting by the flange at *F*. The upper and lower base castings are joined at the shaft line by the flanges at *f*. The inlet *I*, instead of being on the base, is higher up on the cylinder. This type of construction is very desirable on account of the comparative ease with which it may be overhauled; the cylinder may be removed without disturbing the working parts of the engine. Other parts are lettered the same as before. In some engines of this type the flange *F* is omitted and the cylinder casting is carried down to the base as in Fig. 12; this construction, however, makes overhauling rather difficult, as removing the cylinder practically knocks down the entire engine. On the larger sizes a hand-hole cover *H* gives access to the base.

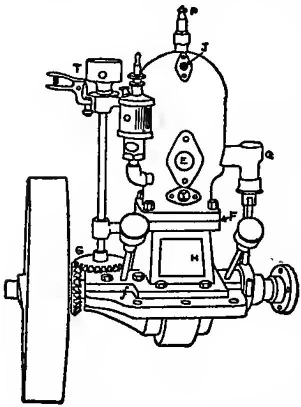


FIG. 14. — Light Two-cycle Engine.

Engines with Separate Compression Chamber. — There have been many attempts to overcome the disadvantages of the enclosed crank case necessitated by the usual two-cycle engine. This may be accomplished by performing the initial compression in some chamber other than the crank case. Fig. 15 represents one design for accomplishing this purpose. The piston is provided with a piston rod *C* which passes through a stuffing box *B* and connects with the crosshead *K* below. The crosshead *K* runs in guides, and carries the wrist-pin bearing for the connecting rod *R*. Surrounding the cylinder is the annular space *A*, which is connected with the space below the piston by the small ports *T*. The inlet port to the cylinder is at *I* and the exhaust port is at *E*. At *V* is a check valve in connection with the annular space *A*. As the space below the piston is made gas-tight by the stuffing box *B*, this space, together with the annular space *A*, fulfils the same purpose as the crank case of the ordinary engine. When the piston ascends a charge is drawn in through the check valve *V* to the chamber *A*, filling it and the space below the piston. On the next downward stroke the charge is compressed, and then passes into the cylinder through the inlet port *I* which is uncovered by the piston. The operation is thus the same as the ordinary two-port engine. As no enclosed crank case is necessary, good lubrication may be had, and the charge entering the cylinder will be clean and free from oil. On the other hand there are many more parts than in the ordinary engine, and the engine must be considerably higher above the shaft center.

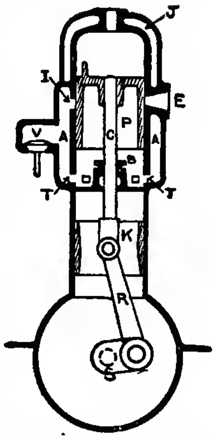


Fig. 15. — Two-cycle Engine with Separate Compression Chamber.

Oil Engine. — In Fig. 16 is shown a section of an oil engine operating on the two-cycle principle. Its form is similar to the usual two-cycle engine, with the exception, however, that no fuel is admitted to the base. Pure air is admitted through the third port *I*, compressed in the base, and forced through the transfer passage into the cylinder, where it is compressed. The hollow ball *B* is kept hot by the successive explosions and the heat generated during compression. At the proper time a small amount of oil is

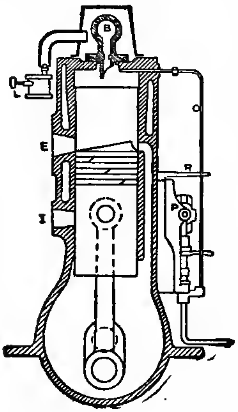


Fig. 16. — Oil Engine.

injected into the cylinder through the pipe *O*. This oil strikes the hot plate at the opening to the ball and is at once vaporized and burned.

The oil is fed by the pump P, which is operated by a side shaft somewhat similar to a cam shaft. This pump has an attachment for varying the stroke and consequently the amount of fuel fed, by which means the speed is regulated. The lamp *L* is arranged for heating the ball *B* for starting. This engine uses the igniter described in Fig. 53. Engines operating on this principle are described more in detail in the chapter on Oil Engines.

In another type operating on the two-cycle principle, each cylinder has a separate jacket surrounding the hot exhaust pipe,

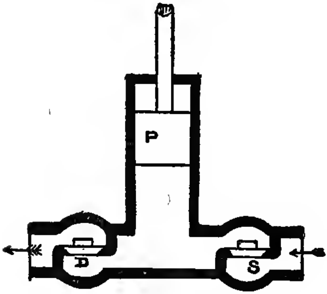


FIG. 17. — Plunger Pump.

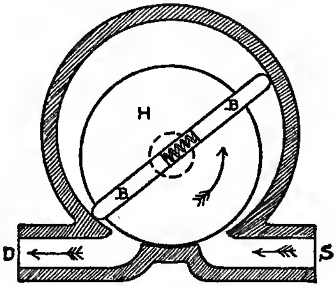


FIG. 18. — Eccentric Pump.

and communicating with the cylinder through a third port. This jacket is connected to a pressure tank holding the oil. The engine is started on gasoline and run until the exhaust pipe is well heated, when the kerosene is turned on. On striking the hot surface, the kerosene is at once vaporized and admitted to the cylinder through the third port. The gasoline is then cut off and the motor runs on kerosene, the air necessary for combustion entering through the usual check valve and being forced into the cylinder by the base compression.

Pumps. — The water pump may be one of several styles; the most common is perhaps the plunger pump shown in Fig. 17. The suction valve *S* lifts on the up stroke of the plunger *P*, allowing the barrel to fill. On the down stroke of the plunger the valve *S* seats and closes the inlet, while the discharge valve *D* opens and allows the water to discharge. This form of pump is on many accounts the best for use in connection with gas-engine work, especially where there may be some sand or grit in the water. It is easily kept in good condition and is very reliable. This form is the best where the water has to be lifted. It may be made in either vertical or horizontal form; the valves *S* and *D* must, however, have a vertical movement. In the pump, as shown in Fig. 11, the valve *D* may be in the form of a metal ball placed at the top of the vertical barrel.

The eccentric pump, shown in Fig. 18, consists of a circular outer shell containing the revolving hub *H*, which is set eccen-

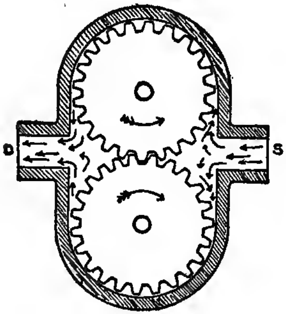


FIG. 19. — Gear Pump.

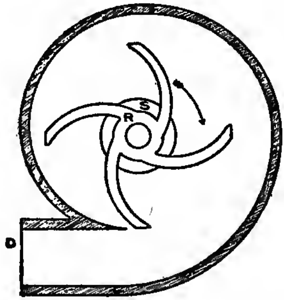


FIG. 20. — Centrifugal Pump.

trically; the hub *H* carries the two blades *B*, which are set out by the springs between so as to be always in contact with the inner circumference of the shell. As the hub *H* revolves the blades are carried around, drawing in the water through the suction opening *S* and discharging it through the opening *D*.

This form of pump, while it works well when new, has not a long life as the friction of the blades *B* against the side plates soon causes leakage, especially when the water contains grit.

When this pump is used it is run by a pair of gears or a bicycle chain. There may be either two, three, or four blades.

The gear pump illustrated in Fig. 19 consists of a pair of gears meshing together and fitting closely inside the casing. The gears are driven by one of the shafts, which extends through the side of the casing for that purpose. As the gears revolve in the direction of the arrows, the water which enters at *S* is caught in the spaces between the teeth and the casing and carried around the gears and discharged at the opening *D*. It should be noted that the water does not pass between the gears, but around the outside.

This form, while more durable than the preceding, is subject to some wear and will finally leak.

In Fig. 20 is shown the "centrifugal" pump; the rotator or impeller *R* has vanes curved somewhat as shown and revolves in the direction of the arrow. The water enters through the opening *S* along the shaft. The rapid rotation of the impeller rotates the water and also throws it outward by the action of centrifugal force so that the water is accumulated at the circumference and discharged from the opening *D*.

This form of pump is probably the best of the rotary forms, as it is not dependent upon the fit of the impeller between the side plates. For water containing grit it is well suited. It has a longer life than either of the two previous forms. The relative direction of rotation of the impeller should be noted; it must be such that the water is thrown outward by the centrifugal force and the curved blades, and finds its way around the diverging periphery until it reaches the discharge opening *D*.

CHAPTER III

Four-Cycle Engines

Fig. 21 shows a section of a common type of four-cycle engine. The working parts are similar to those of the two-cycle type, but are complicated by the addition of the valves and the means for operating them. The inlet valve *I* and the exhaust valve *E* open into small chambers connecting with the cylinder. The valves *I* and *E* have stems passing down through the casing to a point just above the cam shafts *A* and *B;* the lower end is squared to form a guide and is fitted with a roller *R*, to reduce friction. The square guiding piece is usually made separate, with the stem resting upon it, in order to allow the valve and stem to be readily removed without disturbing the guide and roller. The coiled springs *S*, *S* return the valves when they are raised by the cams. The cam shafts, or, as they are often called, the "half-time" shafts *A* and *B*, are driven from the crank shaft by the gears *L*, *M*, *N*. Since each valve only opens once for each two revolutions of the engine, the two cam shafts must revolve only one-half as fast as the main shaft; for this reason the gears *N* and *M* are twice as large as *L*. The cams are so placed on their shafts as to strike the roller *R* and raise the valve at the proper time.

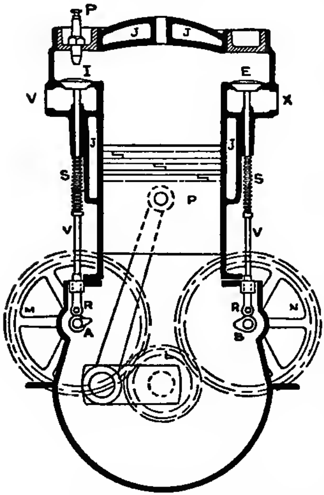


Fig. 21. — Outline of Four-cycle Engine.

The cylinder and head are surrounded by the water jacket *J*, *J*. Just above the valves are plugs, either bolted or threaded in place, which, when removed, allow the examination or removal of the valves. The carbureter is attached at *V* and the exhaust pipe at *X*.

The base in this type of engine is made of ample size and comparatively easy of access, as size is of little consequence. The sides of the base are usually covered by plates to keep out dirt and prevent the splashing of oil; these plates are usually easily removed, exposing the entire contents of the base for adjustment or examination.

A spark plug is shown at *P*, and the engine is also provided with the usual lubricators, compression and drain cocks already noted. The devices for regulating the electric spark and the water pump are also driven from one of the cam shafts. The valves may be on opposite sides of the cylinder as shown, or may be placed side by side on the same side of the cylinder, in which case they may be operated by the same cam shaft.

Referring back to Fig. 6, it is plain that the suction of the piston on its down stroke will tend to raise the inlet valve and draw in a charge. It is thus possible to dispense with the cam and gear on the inlet valve and allow it to be operated by the suction of the piston. The exhaust valve, however, must always be mechanically operated as it has to be lifted against the pressure in the cylinder. When the automatic inlet valve is used the arrangement is as in Fig. 22, the inlet valve *I* being inverted and directly above the exhaust valve *E;* the inlet valve *I* is held in place by the coiled spring *S*. This illustration shows a common arrangement for a single-cylinder engine. The half-time gears are inside the base, the cam *F* being driven by the gear *G* through the short shaft *A;* on the end of the valve stem is the roller *R*, bearing on and lifted by the cam *F*. In order to allow access to the

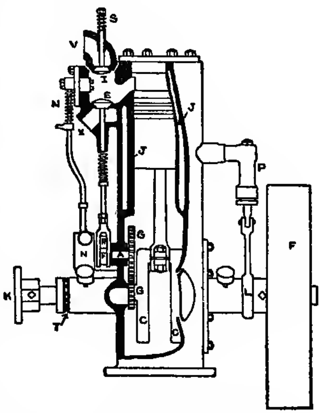


FIG. 22.— Diagram of Four-cycle Engine.

valves the part containing the inlet valve is made removable, making both valves accessible.

The flywheel, crank shaft, and other working parts are similar to those of the two-cycle engine. The igniter gear *N*, *N* is operated from the cam shaft. At *P* is the cooling water pump and eccentric. The ball-thrust bearing is at *T*, and at *K* is the coupling, which is of the flanged type. The propeller shaft has a similar flange, and the two are held together by bolts through the flanges. This is a much stronger coupling than the sleeve coupling, before described. The cylinder is surrounded by the water jacket *J* and has the usual compression cock and oil-cup.

The cylinder, valve chest, and base are a single casting, the head being bolted on and the shaft bearings being contained in separate flanged castings, bolted to the sides of the base. The gears *G*, *G*, being inside the base, are well lubricated by the splashing of the oil in the base.

In Fig. 23 is shown a representative single-cylinder motor; the valve chest is on the front of the cylinder and the exhaust valve is operated by the gears *G*, *G*, shown just back of the flywheel. The inlet valve is just below the spring *S* in the removable cap, and is automatic. The entire cover is also removable. This particular engine has a frame open at the ends which allows the main bearings to be fitted with oil-cups *O*; this form of base makes all bearings accessible.

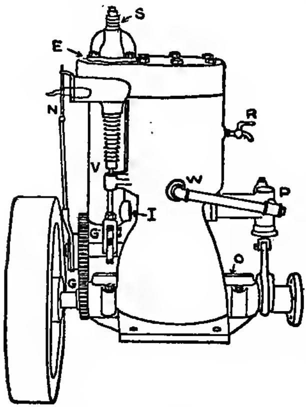


FIG. 23. — Heavy Type, Four-cycle Engine.

The water pump *P* discharges into the jacket through the pipe *W*, the outlet from the jacket being on the opposite side of the valve chest. At *V* is a special vaporizer. The exhaust is at *E*. The igniter gear *N* is operated from the cam shaft.

In this engine the cylinder, base, and bolting flanges are one casting; the upper half of the main bearing boxes being removable for the insertion of the shaft. The cover and valve chest also are a single casting bolted to the cylinder.

In Fig. 24 another style is shown, the valves and valve gear being on the side of the cylinder. The edge of the cam-shaft gear can just be seen behind the flywheel; the cam shaft and cam are contained in the casting *X* which is bolted to the side of the base. The automatic inlet valve is contained in the removable bonnet *I*, the outside pipe leading down with an elbow at V, where the carbureter or vaporizer is attached. The exhaust is at *E*.

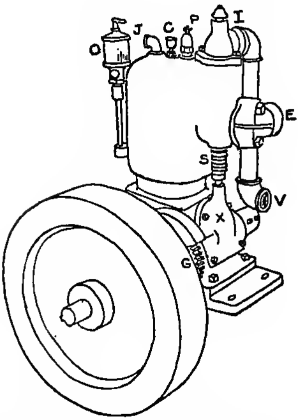


FIG. 24. — Single-cylinder Four-cycle Engine.

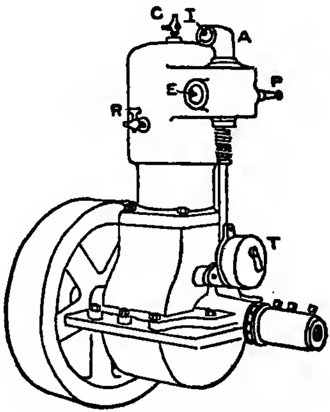


FIG. 25. — Light Four-cycle Engine.

The water pump is on the rear of the engine, the cooling water discharging at J. At *P* is a spark plug for jump spark ignition. The compression or priming cock, *C*, has a sort of tunnel-shaped opening to allow a small amount of gasoline to be run into the cylinder to facilitate starting. Cylinder, head, and valve chest are in one casting, which is bolted to the upper part of the base. Side plates *X* on the base give access to the interior.

Fig. 25 shows a light, high-speed engine; the valves are on the back of the cylinder and the gears are inside the base. The carbureter is attached to a pipe leading to the elbow *A* which contains the automatic inlet valve. The timer T for the ignition is on the end of the cam shaft, and the spark plug is at P. At C is the priming cock and R the relief or compression cock. The base is in two parts, split on the line of the shaft; the cylinder, head, and valve chests are a single casting bolted to the upper base. No side plates are fitted in this engine, as the base is kept tight to allow of oiling by splash.

Single-cylinder engines are almost entirely built with the automatic inlet valve. With two or more cylinders, however, both automatic and mechanically controlled inlet valves are used. There seems to be no particular rule governing the use of either; it may be said, however, that while the automatic inlet works well on slow-turning engines, as the speed increases it is liable to become uncertain and irregular in its action. For high-speed engines the mechanically controlled inlet valve is much to be preferred.

Arrangement of Valves. — While there is no special rule as to the arrangement of the valves, certain systems have come to be accepted as good practice. The more common forms are shown in Fig. 26. In the "L" head type A the two valves are located in a pocket at one side of the cylinder, being placed either side by side, or one above the other. In this type both valves are driven from a single cam shaft, which is naturally the simplest and cheapest arrangement. The size of the valves, and consequently the port areas are limited by structural considerations, as the length of the pocket can be little, if any, longer than the diameter of the cylinder. This arrangement is therefore likely to be used on the slower turning types of engines where the speed of the gases is moderate.

When the two valves are on opposite sides of the cylinder as in B, we have the "T" head type. As only one valve must be accommodated on each side, the diameters of the valves can be as large as desired. This arrangement is suitable for quick turning engines where the valve areas must be large to allow the gases to flow rapidly. Two cam shafts must be used, but inasmuch as it is becoming increasingly common to fit a magneto, generator, or starting motor, the additional cam shaft is made use of for driving these instruments.

Another very satisfactory arrangement of valves, termed the "valve in the bead" type *C* is also shown. The valves are placed in the head of the cylinder, opening directly into it. As shown at the left, the two valves are placed side by side in a longitudinal direction and are actuated by rocker arms, which are in turn operated by rods leading down to the valve lifters.

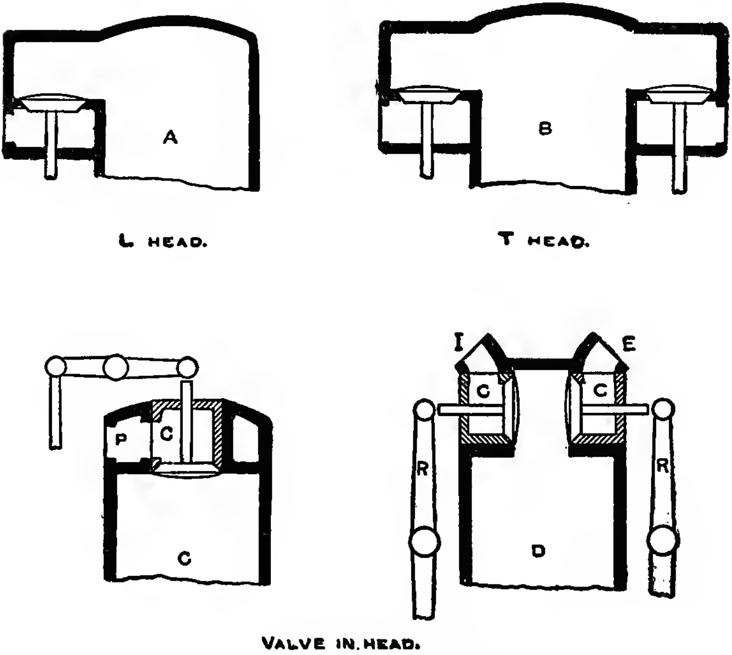


FIG. 26.—Types of Valve Arrangements.

This arrangement allows a very direct passage of the gases to and from the cylinder, also permitting a very simple cylinder casting, which is readily molded and machined, and easily kept cool. The valves are carried in cages *C* which are inserted into the bead and connect with the inlet or exhaust port *P*. Only one cam shaft is required. While the size of the valves is limited by the cylinder diameter, the direct passage for the gases seems to offset any deficiency from this cause.

Another arrangement of the valves in the head is shown at *D:* in this case the valves move horizontally and are actuated by the long vertical rocker arms *R*, *R* pivoted on the sides of the cylinders, the lower ends of which carry rollers bearing on the cams. Two cam shafts are used. This arrangement allows a very small compression space where a high compression is desired, and is used on some special types of engines.

CHAPTER IV

Vaporizers and Carbureters

Before the fuel can be used in the cylinder of the engine it must be converted into vapor and mixed with the proper proportion of air to form an explosive mixture. The principle of the operation of both vaporizers and carbureters is the picking up of the fuel in a finely divided state by a current of air. In practice the fuel is made to flow from a small orifice directly into the current of air which is drawn in by the suction stroke of the engine. Means must, of course, be provided for regulating the relative proportions of fuel and air, as the proper mixture is much more effective and economical than one which is either too weak or too rich. All carbureters or vaporizers to properly perform their duties must have means for regulating the air and fuel supplies. The simplest form of vaporizer, or mixing valve, as it is sometimes termed, is shown in diagram in Fig. 27. It consists of a circular brass casting, containing the lifting valve *V* and its seat, and the openings *A* and *I*. It is attached to the crank case of the engine by the threaded end *I*. The fuel enters at *F*, flowing around the needle valve *N* and into the small opening at *O*, which is covered by the valve *V*. The valve *V* has a stem extending upward and fitting into the guide in the cover *C*; this stem makes the valve lift squarely and assures its seating correctly after being raised. The spring *S* is added to return the valve to its seat quickly. The needle point *N* may be turned in or out by means of the thread *T* and the thumb nut *W*, thus regulating the flow of fuel. It should be noted that the valve *V*, when seated, covers the opening *O*, thus preventing the escape of the fuel.

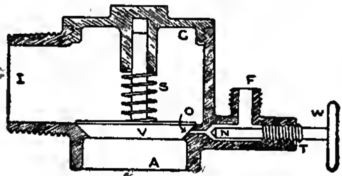


Fig. 27. — Simple Vaporizer.

This form of vaporizer is most commonly fitted to two-cycle, two-port engines, for use with gasoline. The suction created in the crank case by the upward stroke of the piston causes the valve *V* to lift and the air to rush in through the opening *A*. The raising of the valve *V* uncovers the opening *O* and allows the fuel to flow out into the current of air, which at once absorbs it. The mixture passes into the crank case and is ready for use. When the piston reaches the top of its stroke the suction ceases and the valve *V* returns to its seat, aided by the pressure of the spring *S*, cutting off the fuel and preventing the escape of the mixture on the downward compression stroke. This valve *V* is the check valve referred to in Chapter I.

This type of vaporizer, having no means for adjusting the air supply, is not very sensitive. While owing to its simplicity it is well suited to small engines, it is not sufficiently sensitive for engines of the larger sizes.

A more approved type of mixing valve is shown in Fig. 28. Its main features are the same as of that just described, but in addition it has the thumb wheel *R*, the threaded stem of which screws down on to the top of the stem of the valve *V* and thus regulates its lift. It also has a throttle valve *T*, which consists of a disc which may be turned so as to partially or wholly close the passage.

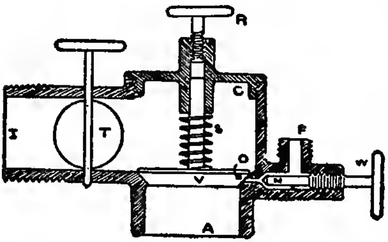


FIG. 28. — Vaporizer.

The proportions of the mixture may be varied thus: the fuel supply may be varied by the needle point *N* and the thumb wheel *W*, giving a weaker or richer mixture. The air supply is regulated by the thumb screw *R;* as the latter is screwed down the lift of the valve, and consequently the air supply, is decreased. These two adjustments allow the regulation to suit the varying conditions under which the engine is run. The speed of the engine is regulated by turning the throttle *T* more or less, thus varying the amount of mixture passing through without varying its proportions. The same result can of course be obtained by manipulating the screws *R* and *W*, but in adjusting them for any particular speed the best proportions of the mixture may be lost and a readjustment required for ordinary running. The cap *C* is threaded to allow access to the interior.

Vaporizers of this type are suited to engines of the two-cycle, two-port type, which require a check valve on the crank case. For three-port and four-cycle engines some form of float-feed carbureter may be used to advantage. While there is no difference between the functions of vaporizers and carbureters, those just described are commonly called vaporizers, or mixing valves, while those governed by a float and having no check valve are usually called carbureters.

In Fig. 29 is shown a diagram of a simple form of float-feed carbureter. It consists of a cylindrical chamber containing the float *F*, which is guided by a stem above and below. Just outside of the float chamber is the air passage *A-I*, containing the vertical fuel tube *X*. The fuel enters at *G*, filling the float chamber and passing into the fuel tube through the regulating needle valve *N*. At *V* is a small valve attached to the float, which closes the opening at *G* as the float rises, shutting off the fuel supply. The level of the fuel is thus kept steady at a certain point in the float chamber and fuel tube, and is so adjusted as to not quite overflow from the opening *O* of the fuel tube.

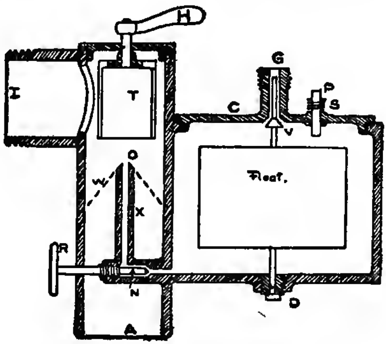


FIG. 29. — Float-feed Carbureter.

The air, drawn in by the suction stroke of the engine, rushes past the opening *O* and draws up and absorbs a small amount of the fuel. At *W* is a cone of fine wire gauze, which catches any fuel not carried away by the air current, and holds it in suspension ready to be taken up on the next stroke. The carbureter is fastened to the engine by the threaded end *I*.

At *T* is the throttle, consisting of a sort of shutter which may be turned by the handle *H* and partially or wholly close the outlet opening *I*, thus varying the amount of mixture passing to the engine, and consequently the speed. The fuel supply is regulated by the needle valve *N* as before. The float *F* is made either of copper or of cork. At *P* is a small plunger which, when pressed, forces the float down and admits an amount of fuel to flood the chamber and fuel tube and make certain of a plentiful supply of fuel for starting. The cover *C* unscrews to allow access to the float chamber.

In operation, as the fuel is used up by the engine, the level in the float chamber drops slightly, lowering the float *F* and finally opening the valve *V* and allowing the fuel to flow in, restoring the level. This raises the float, closing the valve *V* and stopping the flow. Thus the level of the fuel in the fuel tube is kept steady and the same amount is drawn in at each stroke.

Fig. 30 shows a further application of the float principle. In this case an annular or "doughnut" shaped float is used, which floats freely just above the long end of a lever *L*, which is pivoted at *P*. The short end of this lever is forked and rests under the projection on the fuel valve *V*. The fuel enters at *G* as before, and flows out through the small openings to the outlet *O*, where it is picked up by the current of air entering at *A*. The throttle *T* is a disc regulated by a short lever as before. At *A* is a flat auxiliary air valve held in place by the spiral spring *S*, which admits more air as may be needed. In operation, as the fuel is used up the level falls in the fuel chamber, allowing the float to settle and finally by its weight press down the end of the lever *L*. This raises the valve *V* and allows fuel to enter and raise the level in the float chamber, lifting the float clear of the lever and allowing the valve *V* to settle by its own weight aided by the small coiled spring, closing the fuel supply. The fuel flow is regulated by the needle valve *N*. It is found that if the fuel supply is regulated for slow speed, the increased suction at high speed will draw in an undue amount of fuel, making the

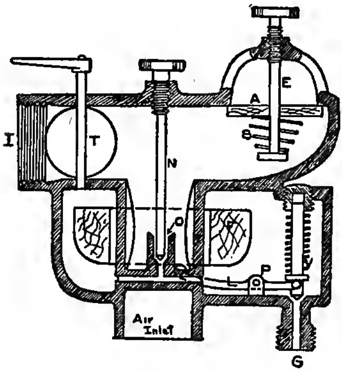


FIG. 30. — Central Flow Float-feed Carbureter.

mixture too rich. For this reason the auxiliary air valve *A* is fitted; it is so adjusted that the increased suction at high speed will draw it from its seat and admit a certain amount of pure air to dilute the mixture to the proper point. The amount of air admitted by the auxiliary air valve may be regulated by changing the tension on the spring *S*, by means of the threaded spindle *E*. Increasing the tension on the spring will decrease the lift of the valve, and consequently decrease the amount of air admitted, and vice versa.

It will be noticed that the air passage is contracted opposite the opening *O;* this is for the purpose of reducing the area of the passage and increasing the velocity of the air current and making the action of the carbureter more positive at low speeds.

The carbureter is secured to the engine by the threaded end *I*. The air inlet is also often threaded and a pipe fitted to allow the air to be drawn from some warm part of the engine, as around the exhaust pipe. The use of warm air tends to steady the action of the carbureter, particularly in rough or foggy weather when the air drawn in would otherwise be more or less moist. As the moist air will take up less fuel than the warm air, the amount of mixture would vary from time to time, making the speed of the engine unsteady; this is prevented by warming the air.

Another carbureter operating upon a similar principle, but of different application, is shown in Fig. 31. In this case a horseshoe-shaped float is used, which is rigidly connected to the short lever, pivoted at *P*, controlling the fuel valve *V*. The air enters at the upper opening and passes through the space *B* under the auxiliary air valve *A*. When more air is required at high speed the suction draws in the auxiliary valve and increases the opening. The air valve is held in place by the spring *S*, the tension on which can be regulated by screwing the threaded stem *R* in or out.

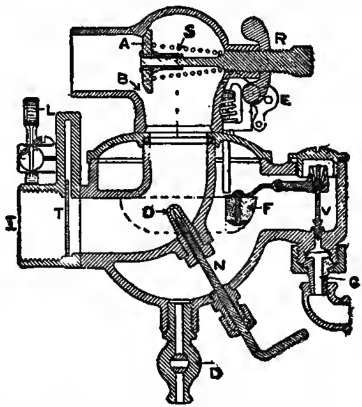


FIG. 31.— Float-feed Carbureter.

The fuel opening *O* is placed in a small projection into the air passage in order to bring it into the center of the current of air. At *T* is the throttle, consisting in this case of a thin plate, which may be moved by the lever *L* so as to partially or wholly close the opening. The threaded end *I* serves to attach it to the engine. At *E* is a "tickler" consisting of a small bent lever and a plunger, which may be pressed down to depress the float and produce a slight overflow from the opening *O* for starting the engine. A pet-cock is fitted at *D* to drain off any sediment that may collect.

The carbureter shown in Fig. 32 is constructed on a slightly different principle. The level in the float chamber is adjusted somewhat higher than the fuel opening *O*, so that a small puddle is formed about the orifice in the bottom of the U-shaped air passage. The air passage is contracted just at this point, increasing the velocity of the air current. The air in passing over the surface of the puddle absorbs some of the fuel. This device is claimed to give a constant mixture owing to the fact that as the speed of the engine increases more of the puddle is carried away, leaving less surface exposed, so that when the increased velocity of the air current would naturally absorb a greater amount, there is less surface for it to draw from. The mixture cannot become too rich and no auxiliary air valve is necessary. At high speed the puddle is entirely carried away and the fuel sprays out. An annular float is used, rigidly connected to a short lever pivoted at *P*. Other parts are similar to those of the carbureters already described.

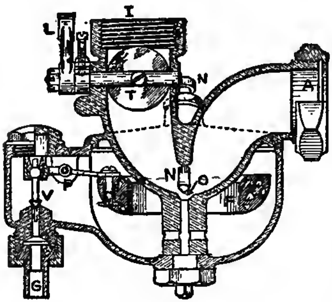


FIG. 32.— Carbureter of the "Puddle" Type.

Although the actual details of different carbureters may differ considerably, the principles governing their action will be found to be similar to the above, and the several parts will be found in one form or another.

Comparing the carbureter last described with that shown in Fig. 29, it will be seen that if this carbureter is tipped sidewise the relation of the orifice *O* to the level in the float chamber will vary, causing an irregular flow of fuel from the orifice. This is what would take place when the boat rolls in a seaway. This irregularity is avoided in the types with the circular float, termed "central flow" type, as no matter what the angle of the carbureter the center of the float is always at the orifice.

Among the advantages of the float-feed carbureter over the mixing valve are: The check valve is done away with, avoiding the noise and the loss of the suction necessary to raise it. A more uniform mixture is obtained, as the fuel is always at the same level; this is particularly so in a sea, as there is a sufficient body of fuel in the float chamber to draw upon, at times when the boat is pitching and the tank might be momentarily lower than the engine, interrupting the flow. The speed is more readily controlled and the engine may be run at a slower speed where the suction would not be great enough to lift the check valve. The float-feed carbureter cannot be fitted directly to a two-port, two-cycle engine, as there is no valve to hold the base compression, but may be used by fitting a check valve between, such as are regularly sold for that purpose. It may be fitted directly to the three-port type.

Check Valve for Two-port Engine. — Fig. 33 shows a very convenient form of check valve for use when it is desired to use a float-feed carbureter on a two-port, two-cycle engine. The stem of the conical seated valve *V* is carried in the projection *N* from the inside of the shell. It is held against its seat by the coiled spring *S*. The large thread is screwed to the engine and the small end carries the carbureter. The suction is thus in the direction of the arrows. The valve *V* should be made as light as possible so as not to introduce unnecessary friction.

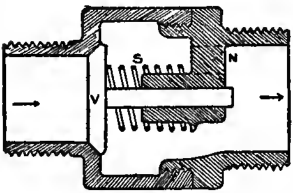


FIG. 33. — "Check Valve" for Two-cycle Engine.

This valve may to good advantage be incorporated in the inlet to the carbureter, as is to some extent done.

Fuels. — The carbureters already described are primarily designed to operate on gasoline as a fuel. While under certain conditions they may vaporize alcohol or even kerosene, they cannot be said to be generally suited to these fuels.

Kerosene is far less volatile than gasoline and to so vaporize it that it can be ignited by the electric spark special devices must be used to preheat it to a considerable degree. For this purpose the heat of the exhaust is usually used. The various devices, although varying in detail, are in effect little more than jackets or annular chambers around the exhaust pipe through which the fuel is passed, thereby becoming heated by the hot exhaust pipe. Arrangements are made to start the engine on gasoline and change to kerosene when the engine has become thoroughly heated.

The device illustrated in Fig. 34 is a fair example of this form of device. It is cut into the exhaust pipe *E E* so that the exhaust

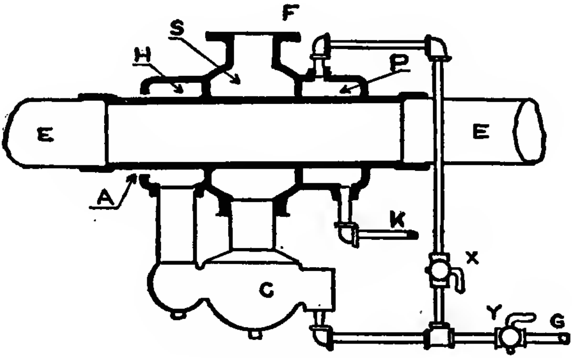


FIG. 34.—Kerosine Vaporizer.

gases pass directly through it. The flange *F* is bolted to the intake manifold in place of the regular carbureter, which is connected below the device at *C*. There are three annular chambers *P*, *S*, and *H*. The kerosene enters through the pipe *K* to the chamber *P*, where it is heated moderately. It passes out of the top of the chamber through the pipe as shown, through the shut-off *X* and the *T*, to the carbureter in the usual way. At the same time air is drawn into the chamber *H* through the slots *A*, and heated thereby. This air then passes out through the air pipe to the carbureter *C*, where it takes up the hot kerosene. This mixture then passes into and through the chamber *S*, where it is mixed and further heated on its way to the intake manifold. Gasoline for starting is brought in through the pipe *G* having the shut-off *Y*. The engine is started on gasoline with the shut-off *X* closed; when it is heated up the gasoline is shut off and the valve *X* opened, allowing the kerosene to flow.

The engine shown in Fig. 23 has a device of this kind shown at *V*. Devices working on this principle can only be used on four-cycle engines, where the fuel does not pass through the base.

This principle is often incorporated in a special form of exhaust manifold, having annular spaces around the central pipe which carry out the functions above described.

The use of a single carbureter for both fuels requires that the contents of the bowl be exhausted or drawn off before the fuel can be changed. For this reason, a dual carbureter having two float chambers, with a single air passage; or two separate carbureters may be used.

In connection with devices of this nature provision is often made for injecting a small quantity of water into the cylinder with the object of preventing the formation of carbon, but if the vapor is kept sufficiently hot this appears to be unnecessary.

This form of arrangement can be made to operate well on kerosene, but will not take care of the heavier oils which require a greater degree of heat to ignite and can only be burned in engines carrying a high compression built specially for this fuel.

CHAPTER V

Ignition Devices

In order that the compressed charge of fuel may explode and do work upon the piston, it must be ignited. In the case of the gasoline engine and some kerosene engines the electric spark is used. Two forms of electric ignition are used, viz.: the "make-and-break" or "touch" spark system and the "jump" spark system.

"Make-and-break" Ignition. — The principle upon which this system depends is the formation of a spark when an electric circuit is broken. A property of the electric current, which need not be discussed here, causes a current to flow for a short time after the circuit is broken; it thus will jump across a short space and form a spark. This property is accentuated by the use of a spark coil as described in the next chapter.

The operation of the make-and-break spark may be illustrated by Fig. 35. The point *P* is electrically insulated from the metal of the engine; the "flipper" or rocker arm *F* is on a short shaft and may be turned slightly to make an electric contact between it and the point *P*, completing the circuit. The two points are brought together while the piston is on its up stroke, allowing the current to flow for a short time. At the time of ignition the two points are quickly drawn apart by a spring or some other means, breaking the circuit, and the spark occurs. It can thus be seen that the idea is to provide a means whereby an electric circuit may be "made" and "broken" inside the compression space at the proper time.

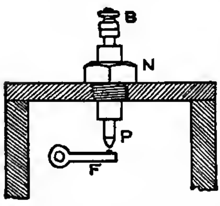


Fig. 35. — Sparking Points for "Make-and-break" Ignition.

The mechanism for operating the make-and-break ignition is well illustrated in Fig. 36. The lever *L* is on the outer end of the shaft carrying the flipper *F*. The rod *R* moves in the guides *G*, *G*, and is moved up and down by the same eccentric which operates the water pump, the connection being made at *E*. On the rod *R* is the sliding collar *C* and a pivot carrying the tappet *T*. The screw *A* is in line with the projection on the tappet *T*. In operation the collar C is pressed down by the spring *S* on to the lever *L*, forcing the latter down and separating the points inside the cylinder. The eccentric operating the rod *R* is so placed upon the shaft that the rod moves in exact time with the piston. As the piston, and consequently the rod *R*, moves upward, the tappet *T* strikes the collar *C* and lifts it out of contact with the lever *L*. The lever *L* is then raised by the small spring, bringing the sparking points into contact and allowing the current to flow. As the rod *R* rises still further, and comes nearly to the top of its stroke, the tail of the tappet *T* strikes the screw *A*, throwing this end down and the upper end out, and allowing the collar *C* to snap off and be forced rapidly down by the spring *S*. The collar strikes the lever *L*, throwing it down quickly and breaking the contact in the cylinder. As the rod *R* descends, the tappet *T* snaps over the collar *C* and is ready for the next stroke. The contact is thus broken suddenly, the more suddenly the more effective the spark. By turning the screw *A*, the tappet *T* may be made to strike it earlier or later, thus changing the time of ignition. An engine having this particular mechanism is shown in Fig. 12.

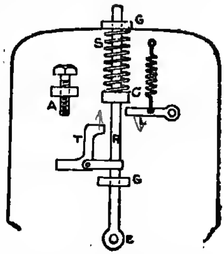


FIG. 36.—"Make-and-break" Ignition.

A section of the plug *P* is shown in Fig. 37; the large collar *C* is threaded and screws into the cylinder cover. Through the center of this collar is the insulated sleeve *I* of mica or fiber. The pin *P* is threaded through the insulated sleeve and held in place by the lock nut *N*. On the top of the pin are binding nuts for the electric wires.

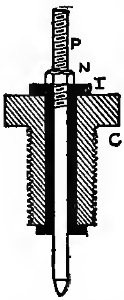


FIG. 37.—Insulated Terminal for "Make-and-break" Ignition.

The sparking points require cleaning at intervals, which is accomplished by removing the entire upper combination; the flipper can then be cleaned through the hole thus opened in the cover.

Another form of gear is shown in Fig. 38 which is easier to take care of than the preceding. Both insulated point and movable flipper are mounted on a sort of plug which is bolted to the side of the cylinder, with the sparking points on the inside. The rod *R* and tappet *T* are similar to the other. The rod *I* is insulated from the body of the plug and extends a short distance beyond the back. The spindle *B* carries the flipper *F* on its rear end and the lever *L* on the front end. On the same spindle *B*, but free to turn, is the flat hammer *H*; the circular spring *S* presses the hammer *H* down against the lever *L*. As the rod *R* rises, driven by the eccentric, the tappet *T* strikes the hammer *H*, turning it and the lever *L* until the flipper is in contact with the insulated rod *I*. The lever *L* can turn only a short distance, so that as the tappet *T* rises still higher it carries the hammer *H* away from the lever *L*, separating them by a considerable angle, against the pressure of the spring *S*. As soon as the tail of the tappet *T* strikes the screw *A*, the upper end is drawn in and the hammer forced down quickly by the spring, striking the lever *L* and quickly separating the points.

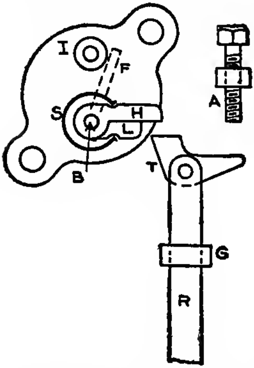


FIG. 38. — Igniter Gear for "Make-and-break" Ignition.

The two mechanisms just described are both used on two-cycle engines, as they are driven from the shaft and operate on every revolution; their operation also is independent of the direction of rotation of the engine.

Similar gear is used on four-cycle engines; in this case the sparking points are placed as near as is convenient to the inlet valve so as to be always in the purest mixture. The gear must be operated from the half-time shaft. In Fig. 39 is shown a very simple form of gear; it consists of a removable plug carrying the insulated point *I*, the flipper *F*, and the lever *L* as before. The lever *L* has a hole in the end through which passes the rod *R*. The lower end of the rod is guided at *G* and rests upon the cam *K* on the end of the cam shaft. As the cam *K* revolves the rod is gradually raised, lifting the lever *L* until the points are in contact. The lever *L* then remains stationary; the rod, however, continues to move, compressing the spring *S* and raising the head *H* considerably above the lever *L*. When the cam has turned sufficiently, the lower end of the rod *R* drops off the step and the rod is forced down by the spring *S*, the head *H* striking the lever a sharp blow and separating the points. The time of ignition is varied by moving the end of the rod to the right or left, causing it to drop off the step earlier or later. As this gear will only work in one direction the cam *K* must be provided with a ratchet to prevent damage when the engine is turned in the opposite direction to which it runs.

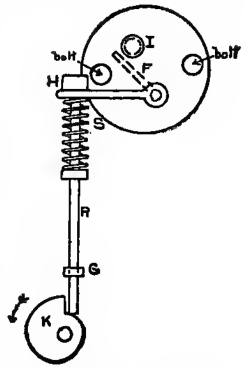


Fig. 39. — "Make-and-break" Igniter.

Gears similar in action to the above are on some engines arranged entirely on the top of the cylinder cover, and operated by shafts and bevel gears. This makes the gear very compact and allows it to be protected by an ornamental cover.

These illustrations will serve to show the principles on which the gears operate. A successful gear should have the following qualities, viz.: it should separate the parts quickly, as the strength of the spark depends upon the speed of separation; it should be simple, with as few parts as possible; some means should be provided for changing the time of ignition while the engine is running, as the best time for ignition will vary for different speeds; it should be easy to get at and clean the sparking points; the points should be tipped with platinum or some hard metal, as the steel points are rapidly worn away by the heat, and become fouled.

Spark Coil. — The type of coil used in connection with the make-and-break ignition is shown in Fig. 40. It consists of a bundle of soft iron wires *C*, encircled by a coil *W* of several layers of rather coarse wire. The ends *E*, *E* are of wood and carry the binding posts *B*, *B*, to which the ends of the coil *W* are fastened. The coil is connected into the battery circuit, and the electric current simply passes through it. The electrical action of the coil may be sufficiently explained by saying that the passing of the current around the iron core greatly intensifies the spark at the breaking of the circuit.

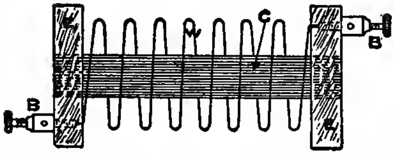


FIG. 40. — Diagram of "Make-and-break" Spark Coil.

Jump-spark Ignition. — This system of ignition is very simple in appearance, the only mechanism on the engine being the commutator or timer, a device for making and breaking the battery circuit when the spark is desired. The coil used in connection with this system is similar to the usual type of induction coil, having primary and secondary windings. The circuit in the primary or battery wire is made and interrupted by the timer and a spark occurs in the secondary wire, which is connected to the spark plug.

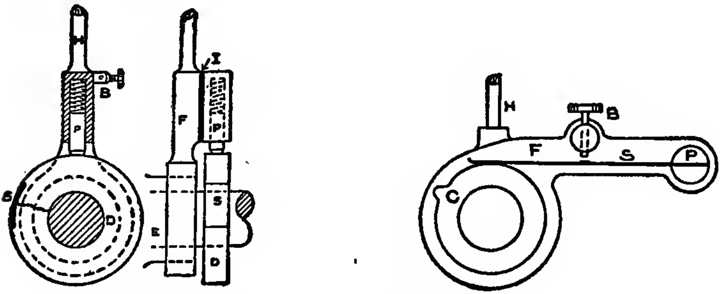
The simplest form of timer is shown in Fig. 41. It consists of a small frame *F* which is supported by the end of the engine bed *B* and can be rotated upon it.

The small plunger *P* is carried in a holder which is insulated from the body of the frame by the insulating material *I*. A spring behind this plunger forces it out against the insulating fiber disc *D*, which is fastened to the engine shaft and revolves with it. A small brass segment *S* is fastened on the circumference of the disc and is in electrical connection with the shaft by the wire or clip. The binding post *B* takes one end of the battery circuit; the other end being grounded on the engine. When the plunger *P* rests upon the fiber the circuit is not complete and no current passes, but as the segment *S* passes under the plunger, the circuit is completed for a short time through the engine shaft and body of the engine, and then broken again. By turning this device one way or the other the time of the spark may be changed.

This timer is very simple and compact and works very well on small two-cycle engines. If two cylinders are to be fired another plunger would be fitted directly opposite the present one.

Another simple form of timer is shown in Fig. 42. The casting *F*, carried by the engine frame, has a projecting arm, at the end of which is the post *P*. On the shaft is the cam *C* having the projection or "nub" on its face. The contact spring *S* is carried by the post *P* and rests normally on the round face of the cam *C*. At *B* is a binding post which is insulated from the main body and which carries the adjustable contact screw. The contact screw is adjusted to leave a slight space between it and the spring *S*. One battery wire is attached to *B* and the other to the engine. In the position shown no current will pass; at the time of ignition, however, the nub on the cam will pass under the spring and force it up into contact with the point of the contact screw, completing the circuit and breaking it again as the cam passes on. The handle *H* is used to revolve the whole mechanism, thus varying the time of ignition by causing the cam to strike the spring earlier or later.

The timers just described are for single-cylinder engines, but



FIGS. 41–42. — Simple Timers.

may be adapted to double cylinders by duplicating the mechanism in a diametrically opposite position. Timers of this type are well suited to two-cycle engines.

The more pretentious timers are made entirely independent of the engine shaft, as in Fig. 43. They are operated from an independent shaft, as the cam shaft of a four-cycle engine, or, in a two-cycle engine, from a shaft driven by gears from the engine shaft as in Fig. 11. This timer is somewhat similar to that last described, the action of the cam *C* and the spring *S* being the same. In this case, however, the entire base is made of fiber, thus insulating both posts *B* and *P*. A wire to each post passes through the holes *H*, and a removable cover is fitted over the whole. By means of the eye *E* to which a link is fitted, the whole timer is kept from turning, but may be turned slightly when desired, to vary the time of ignition. This timer is shown on the engine in Fig. 25 on the rear end of the cam shaft.

Fig. 44 shows a timer for a two-cylinder engine on somewhat the same principle as the last. The posts *B*, *B* are insulated from the body of the timer by the insulating sleeve *I*. The contact points *P* are forced out by the coiled spring *S*, but are in electrical contact with the posts *B*.

The lever *L* is pivoted at *E* and at its outer end carries the friction roller *R*. The flat spring *F* presses the lever *L* out so that the roller always bears on the face of the cam *C*. As the projection on the cam *C* passes under the roller the contact is made

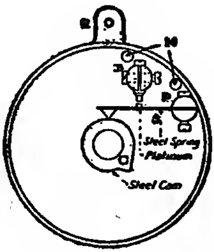


FIG. 43. — Single-point Timer.

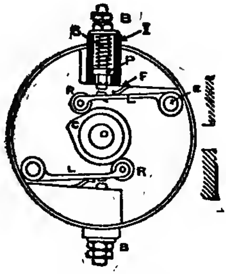


FIG. 44. — Two-point Timer.

with the point *P*. The roller is added to reduce friction. The springs behind the points *P* are introduced in order to have a firm contact between the points without undue pressure on the lever *L*.

The entire timer is covered with a cap.

This timer, with the contact points placed opposite one another, is arranged for use on an engine where the impulses occur at regular intervals. When used on a four-cycle engine having the arrangement of cranks shown in Fig. 80, which gives irregularly occurring impulses, the contact points, instead of being placed opposite, are located on the quarters, or at right angles. This allows for the idle strokes between the impulses.

A timer for four cylinders is shown in Fig. 45. The contact here is a rubbing contact between the projection *P* on cam *C* carried by the timer shaft, and the steel ball *B* which is pressed out by the coiled spring *S*. The rubbing contact gives excellent results, as any corrosion of the points is quickly rubbed off by the friction. The ball holders must be insulated from each other and from the body of the timer, either by insulating sleeves or an entire ring of insulating material; both methods are common. By means of the arm *A* the timer is prevented from turning, and its position also is regulated.

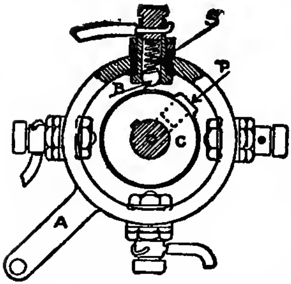


FIG. 45. — Four-point Timer.

Spark Plugs. — In order to utilize the spark produced in the coil by the action of the timer, some form of spark plug is necessary; different forms of plugs are shown in Fig. 46. The principle of all is essentially the same: the outer shell *S* has a threaded end and screws into the metal of the cylinder; inside of this shell is a core *C* of insulating material such as porcelain, mica, or lava; through the center of the insulating core passes the metal stem *R* having a binding post on the upper end. Points from the core and the shell are brought out to within about $\frac{1}{32}''$ apart. As the body of the plug is screwed into the cylinder and the wire carrying the ignition current is attached to the binding post at the top of the inside rod, the circuit is complete except for the gap at the points,

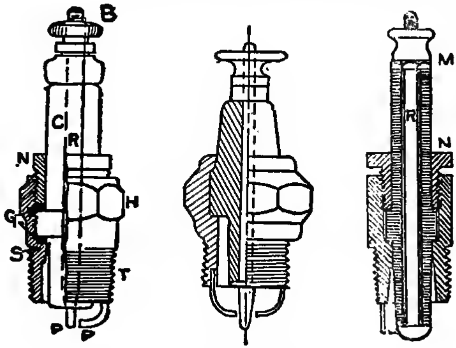


FIG. 46. — Spark Plugs.

and it is the jumping of the current across this gap that causes the spark.

Plugs are made in a large variety of forms — but the principle of all is the same. The core may be either molded in place or secured by a threaded sleeve as at N, the joints being made tight by the washers or gaskets G. It is of the greatest importance that the joints between the various parts of the plug be pressure-tight, as otherwise a loss of compression will occur. The insulation at the same time must be perfect, as the secondary current is of very high voltage and will penetrate the usual forms of insulation. One of the most serious difficulties with spark plugs is the deposit of soot around and on the sparking points, causing a short circuit and preventing the formation of a spark. Various shapes are given to the points and to the ends of the core and shell with the idea of lessening this deposit, the most common design being to leave an annular space around the core, between it and the shell or the rod. The several sketches are self-explanatory.

Jump-spark Coil. — Fig. 47 shows a diagram of an induction coil such as is used in jump-spark ignition. It is similar in principle to the ordinary induction or medical coil. It consists of a core C, of soft iron wires, about which is wound the primary coil, shown by the heavy line helix. The primary winding consists of a few layers of heavy wire, whose electrical resistance is very small. Outside of the primary winding, and very thoroughly insulated from it, is wound the secondary winding, shown by the light line helix. The secondary winding consists of a great many turns and layers of very fine wire, of very great electrical resistance. By the electrical principle of induction, each time the current is made or broken in the primary winding, a current will pass through the secondary. If then the ends of the primary winding be connected through the timer and a battery, and the ends of the secondary winding are connected through a spark plug, a spark will pass in the plug each time the primary circuit is made or broken by the timer. There must be no direct connection between the primary and secondary coils, the action of one coil on the other being by induction only, with no passage of current from one coil to the other. A coil of this description gives one spark for each make or break in the circuit. It is called a "non-vibrator" coil, or transformer. In order to cause a series of sparks to pass at each break in the primary circuit, the vibrator is added. The two ends of the secondary winding are connected to the binding posts *S*, *S*, and the ends of the primary winding are connected, one to the upper binding post *B*, and the other to the post *A*. The post *E* carries the vibrator spring *V*, on the end of which is the iron disc *D* standing opposite to and a short distance away from the end of the iron core *C*. The post *A* carries an adjusting screw against which the vibrator spring *V* bears. The post *E* is connected with the lower binding post *B*. If now the connections are made to the binding posts *B*, *B*, a circuit may be formed through the primary binding post *A*, adjusting screw, vibrator spring *V*, and post *E*, and a current will pass through the primary winding, causing a consequent passage of current in the secondary. The flowing of the current around the iron core magnetizes it and causes it to attract and draw towards it the iron disc or armature *D*. This draws the vibrator spring out of contact with the screw *A* and breaks the primary circuit, causing a current to pass through the secondary in the opposite direction. The breaking of the primary current also causes the core to lose its magnetism, thus releasing the disc *D* and allowing the vibrator to spring back into contact with the screw *A*, when the action is repeated. This automatic interruption of the primary circuit, which is very rapid and independent of that of the timer, causes a series of currents to pass rapidly in the secondary.

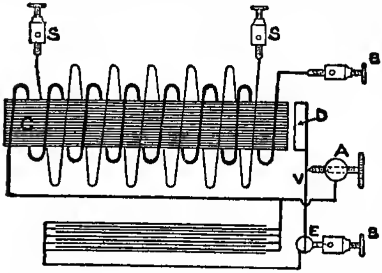


FIG. 47.—Diagram of "Jump-spark" Coil.

Owing to certain electrical effects, the spark which passes when the primary circuit is completed is not as strong as that which passes when the current is broken, and it is the "break" spark which is made use of.

The current in the primary winding is of low voltage and relatively large volume, while that in the secondary is of extremely high voltage but very small volume. The relative proportions of the two currents are regulated by the size and amount of wire in each coil. The condenser, shown below the coil, consists of layers of tin-foil, insulated from each other, alternate sheets of which are connected to two terminal wires, which terminal wires are connected, as shown, with the posts *A* and *E*. The action of the condenser is entirely electrical, and need not be considered here, except to say that it intensifies the spark. The entire coil is enclosed in a box with only the binding posts and vibrator in sight.

Coil and Plug Combined. — Fig. 48 shows a combination of spark coil and plug which is designed to be fastened directly to the cylinder. The spark coil is supported upon the end of the plug, and the ends of the secondary winding are connected directly to the sparking points *P*, *P*. The primary winding is connected to the binding posts *B*, *B*. The whole is enclosed in a mica-covered case which is protected by a brass cage. A screw thread *T* allows the whole to be screwed into the cylinder in place of the regular spark plug. As only the primary winding is exposed, this system is claimed to be waterproof. The primary current is interrupted by a separate vibrator operating on the same principle as that of the usual type of coil. This system requires a separate coil for each cylinder, although all the coils are operated from a single vibrator. This system is therefore apt to be more expensive than the usual system, although very satisfactory for use in exposed positions.

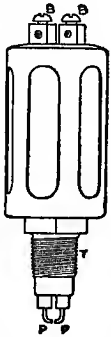


FIG. 48. Combined Coil and Plug.

Primary Batteries. — To furnish the primary current, for starting at least, some form of electric battery must be used. There are several forms of wet cells on the market, but they all are likely to require considerable attention. It is probable that the dry cell is the best for all-around boat use. While they are sometimes unreliable, if care is used in their selection and they are carefully kept free from moisture, good service can be obtained from them.

The cells should be tested when bought, and from time to time during their use, and any which may have run down should be replaced by new ones, as a single weak cell in a set will retard the action of the good ones. In testing the cells, the ammeter should be kept in contact only long enough to obtain the reading, as it forms a direct short circuit, and if held in place for any length of time will soon ruin the cell.

For ignition use the cells are connected in "series," that is, the carbon of one to the zinc of the next, and so on.

From four to six cells should be used in each set; if fewer are used the spark is likely to be weak, and if more are used the current is of such intensity that the contact points of spark coils or igniter are rapidly burned away.

Dry cells should be fitted in duplicate sets so that one set may be recuperating while the other is in use.

Even when a magneto is fitted, the batteries must be relied upon for starting, after which the magneto may be switched in.

When dry cells are used alone, considerable economy may be had from a series-multiple connection. In this method several sets are made by connecting four or five cells in series. These sets are then connected up in multiple. Although more cells are required it is claimed that this method of connection results in final economy.

Storage Battery. — This form of battery is one of the best for ignition purposes, as it is very reliable as long as it is charged. It must, if used alone, be taken on shore for charging, which is something of a care. A very satisfactory arrangement is the fitting of a dynamo in connection with the storage battery, and so connecting them that the dynamo charges the battery, while the current for ignition is being drawn from it. In this way the battery acts as a sort of reservoir for the current, and makes the ignition independent of the engine and dynamo speed, and also avoids the inconvenience of taking the battery ashore for recharging. At the same time the engine can be started on the current from the battery. This arrangement also allows the use of a certain amount of current for lighting purposes, or if the dynamo and storage battery are large enough, the entire boat may be lighted. This is fully explained under wiring.

Dynamos and Magnetos. — There is little fundamental difference in the action of a dynamo and a magneto. Both generate a current of electricity by the revolution of an armature containing many turns of wire within a magnetic field. The points of difference are found in the construction, in that the magnetic field of the dynamo is maintained by the passage of the current through coils of wire which are wound on the fields; in the magneto, permanent magnets are used for field magnets. The current generated may be either "direct" or "alternating." The former is of constant amount and always flows in the same direction: the latter or alternating current flows first in one direction and then

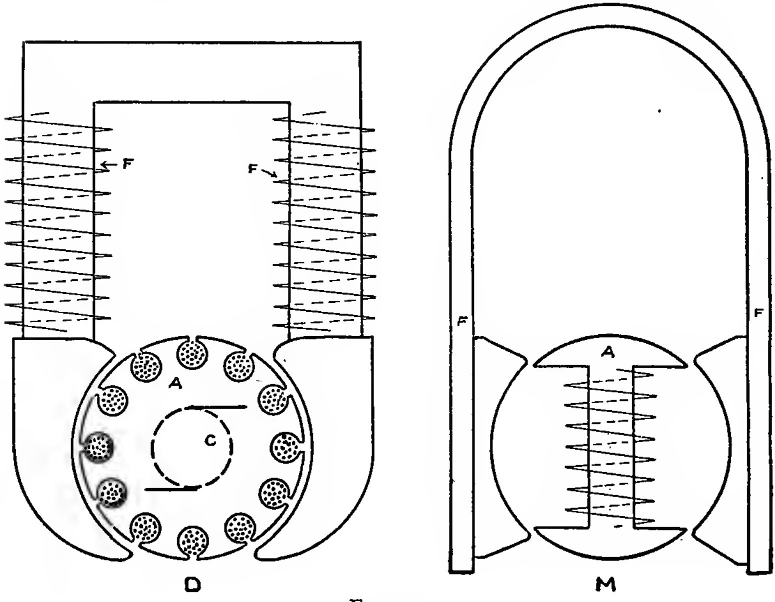


FIG. 49.

in the opposite, at rapidly recurring intervals, and also varies in intensity at every point in the cycle. The dynamo may be arranged to put out either a direct or alternating current, while the magneto gives only alternating current.

For use with small engines, as an alternative to the batteries, the simplest forms of magneto or dynamo are used, being usually driven by a belt or friction wheel from the fly wheel. For use with the make and break system either may be usually used, while for a jump-spark system and a coil like Fig. 47 the direct-current dynamo must usually be used.

The fundamental difference between dynamo and magneto is shown in Fig. 49. The armature of the dynamo shown at *D* has a series of slots running lengthwise with a coil of wire through each. The ends of these coils are connected to a commutator *C* at one end of the armature, from which the current is collected by brushes. The windings of the field coils are shown at *F*. As far as general construction goes it is the same for dynamo and motor and under most conditions these are interchangeable.

The magneto sketched at *M* has a so-called "shuttle" armature, with only a single coil; there is no commutator, but collector rings may be fitted. The permanent magnets are shown at *F*.

Magnetos. — Magnetos are used in such a variety of forms that it is not possible to attempt a description of all, but in all cases the same general principles apply. The best and perhaps least complicated form of magneto is the so-called "high tension" type. This instrument is entirely self-contained, generating, transforming and distributing the current without the aid of outside coils. This form must be gear driven from the engine shaft, and exactly timed with it, as the distribution of the ignition current to the plugs is dependent upon it. It is usually geared from the cam shaft, as this gives a convenient place of attachment to the engine.

Fig. 50 shows an elementary section of a high-tension magneto. The armature *A* revolves in ball bearings between the poles of the permanent magnets *M*, usually made up of two or more separate magnets for constructional reasons. The armature carries two separate coils, a primary winding, made up of a few turns of coarse wire, and a secondary winding, of many turns of fine wire. The armature is of similar construction to the coil of Fig. 47 and does the same work. The current in the primary coil is generated by its revolution in the magnetic field of the magnets: this primary current is then periodically interrupted, which induces currents in the secondary coil. The secondary coil is placed on the armature simply for convenience in construction, the fact of its revolving having no electrical effect of value. These windings are shown at *P* and *S* respectively, a condenser, is also fitted as

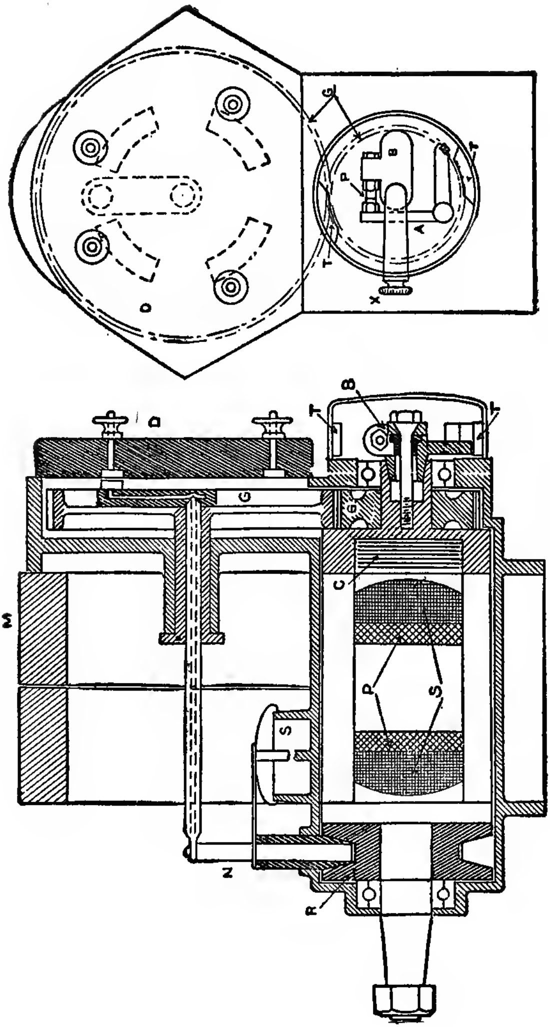


FIG. 50. — High Tension Magneto.

shown at *C*. The arrangement for interrupting the primary circuit is shown at the right in the circular box called the breaker box. On the end of the armature shaft, is a plate carrying the breaker block *B* and the pivoted breaker arm *A*. The block *B* is insulated from the plate and carries one of a pair of contact points *P;* the other point is carried in the end of the pivoted arm *A*. The contact is made or interrupted by a slight movement of the arm *A*. This mechanism revolves with the armature. The enclosure, which is circular in form, remains stationary and carries on its inside surface two diametrically opposite projections or trips *T*. The end of the breaker arm in its revolution rides up on these trips and separates the points at *P*. As one end of the primary coil is attached to the insulated block and the other end to the metal of the armature, the primary circuit is complete until interrupted by the separation of the points *P*, which causes a current to flow in the secondary winding.

On the opposite end of the shaft is a slip ring *R* to which one end of the secondary winding is attached, with a collector brush *N* to which the secondary current is delivered. In the case of a single cylinder motor it could be wired direct to this brush.

Motors of more than one cylinder are served by an additional distributor mechanism. A gear *G* on the armature shaft meshes with a larger gear *G*, carried by the frame of the magneto. In front of the larger gear is a stationary distributor plate *D* of fiber shown in the front view, on which are arranged in a circle a number of equidistant contact pieces equaling the number of cylinders to be fired. Attached to the large gear is an insulated contact, which in revolving passes over each of the contacts on the distributor plate *D;* connection is made from the brush *N* through the hollow shaft to the contact on the gear *G*. In this way the secondary current is sent to each cylinder in turn. In Fig. 49 it will be seen that there are two points in a revolution of the armature where a current will be generated. This is the reason for two trips in the breaker; it is for this reason also that the distributor arm revolves at a slower rate than the armature shaft, for a four-cylinder engine one-half as fast. The interrupter mechanism is so arranged as to break the circuit at the point of Fig. 49, as at this point the primary current is strongest. An elementary circuit diagram for this form of magneto is shown in Fig. 51, the grounded lines representing the completion of the circuit by the metal of the engine.

At S is a safety gap consisting of two points a short distance apart, one of which is connected to the brush N. This gap provides a ground for the current in case of a broken external circuit and prevents damage to the armature. At X is a spring making contact with the insulated block B by which the primary circuit

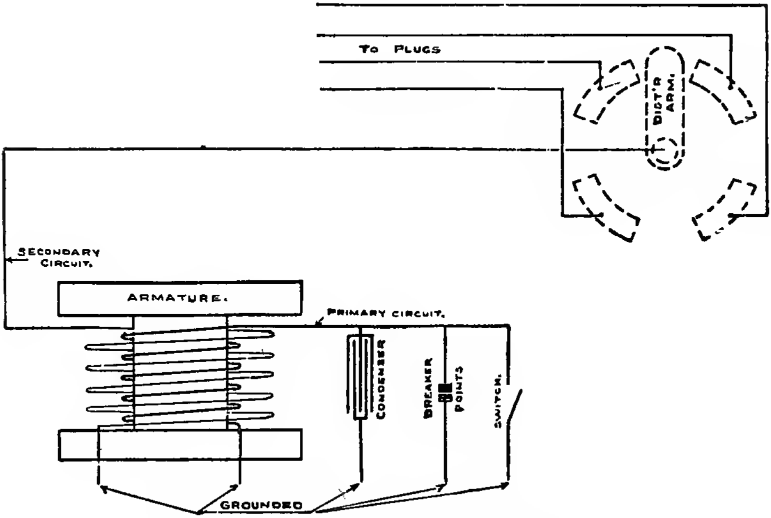


FIG. 51.—Circuits in High Tension Magneto.

is grounded, stopping the action of the magneto. The taper and nut on the end of the shaft fasten the coupling or gear for driving it.

As before stated, the high-tension magneto is a complete and self-contained system of ignition. It will, however, give a current only when the armature is turning at a fair speed. A small motor may often be turned by hand at a high enough speed to start on the high-tension magneto directly, but this is plainly impossible with a large engine. For this reason some form of battery ignition must be used for starting or a starting motor fitted. Many varieties of magneto are in use which allow the use of batteries and transformer coil for starting. The high-tension magneto may be so modified as to allow this, without altering its action or the wiring connections. This form is the "dual" system, and the modifications consist of the addition of an extra interrupter arm in the breaker box and the necessary wiring to and from a transformer coil. This extra interrupter is necessary as the regular interrupter is closed except at the moment of the break, which would be too great a drain on the battery. The transformer coil is similar to that of Fig. 47 but without the break mechanism, that on the magneto taking its place. When the battery is in use the armature coils are idle, only the breaker being used. The current from the battery passes to the primary of the coil through the breaker, and the high-tension current produced in the secondary by the interruption of the primary circuit is brought back to the distributor arm of the magneto and sent to the proper cylinder. The engine can thus be started on the batteries, and the magneto current cut in after the engine has started.

The "low tension" magneto is similar in action to the dual; the armature, however, has only a single coarse winding and generates only a current of low voltage, about the same as that of the battery. A transformer coil must always be used; but the secondary current is distributed by the magneto as before. Connections are made to cut in a battery for starting.

There are so many variations in the arrangement of the circuits that no diagrams except for the high tension can be given, but individual diagrams can always be obtained from the makers of any particular magneto.

The speed of the magneto is governed by the number of cylinders. For four-cycle motors these speeds are as follows:

2 cylinder motors,	cranks as Fig. 74	cam shaft speed	
2 " "	" " " 73	crank " "	
3 " "		$\frac{3}{4}$ crank shaft speed	
4 " "		" " "	
6 " "		$1\frac{1}{2}$ " " "	
8 " "		2 " " "	

For two cycle motors the speed is doubled.

Ignition by Hot Bulb. — In the case of engines burning fuel oil, which does not vaporize and cannot be passed through a carbureter or similar device, the "hot bulb" igniter shown in section in Fig. 52 is used. It consists, as the name implies, of a chamber or bulb *B*, of spherical or other convenient shape formed in or fitted to the cylinder head. The cylinder head can be kept hot without detriment to the action of the engine, and as the ignition depends upon the heated condition of the device, the head is the logical place for it. When this form of ignition is used air alone is drawn into the cylinder and compressed as usual. The bulb is first heated by a torch or other external means. At about the point of maximum compression the fuel is injected in through the nozzle *N*, and upon striking the hot surface of the bulb is at once ignited. The heat taken up by the bulb during the explosive stroke keeps it hot for the next injection of fuel; the heat due to the compression also adding some heat to it.

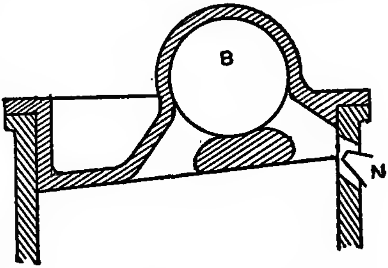


FIG. 52. — Section of "Hot Bulb" Igniter.

This class of igniter is used in crude oil engines. There are many different shapes of bulb adopted, but the above fairly represents the principle.

CHAPTER VI

Wiring

Single Cylinder, Make and Break.—The wiring for the make-and-break system is the simpler of the two, and will be considered first. It is shown in diagram in Fig. 53. If one wire of the circuit is fastened to the metal of the engine and the other to the insulated point of the igniter, there can be no passing of current except when the points are in contact inside the cylinder. The insulated point is shown at *I;* at *G* is the other wire of the circuit attached to the engine base. The circuit is completed through the batteries and the coil *C*. The batteries are connected, the zinc of one cell to the carbon of the next, and so on. The switch *S* is inserted to open the circuit when not in use and prevent waste of batteries. When the switch is in contact the circuit is complete except as made and broken at the sparking points. When duplicate sets of batteries are used, a three-point switch is fitted in place of the switch *S*, allowing either set to be used at will, as is shown at *T* in Fig. 54.

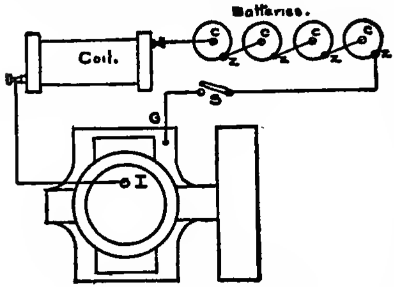


Fig. 53.—Single-cylinder, "Make-and-break" Ignition.

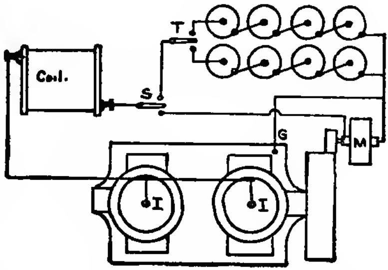


Fig. 54.—Double-cylinder, "Make-and-break" Ignition.

Double Cylinder, Make and Break.—This figure also shows the connections for a two-cylinder engine, the only addition being the extension of the wire from the coil to the insulated post of both cylinders. If a magneto is used in addition, shown at *M*, it is connected in parallel with the batteries, one terminal being connected to the ground wire and the other to the three-point switch *S*. This three-point switch allows the use of either batteries or magneto as desired. In operation, the batteries are used for starting and the magneto switched in circuit after the engine has fairly started.

Single Cylinder, Jump Spark.— The typical connections for a jump-spark coil to a single-cylinder engine are shown in Fig. 55. The coil of the four-post type is shown at *C* with the two primary binding posts *B*, *B* and the secondary binding posts *S*, *S*; the spark plug is shown at *P* and the insulated post of the timer at *T*. The batteries are connected in series as shown; one battery terminal is grounded at *G* on the metal of the engine; the other battery terminal is connected to one of the primary posts *B*; from the other primary post *B* a wire is run to the insulated post *T* of the timer. It is plain that the primary circuit is complete except as made or broken by the timer *T*. One of the secondary posts *S* is wired to the spark plug *P* and the other to a ground wire at *G*; thus the secondary circuit is complete except at the sparking points of the plug. From the previous description of the action of the coil, it will now be seen that whenever the primary or battery circuit is made or broken by the timer, a spark, or series of sparks, will take place at the sparking points of the plug *P*.

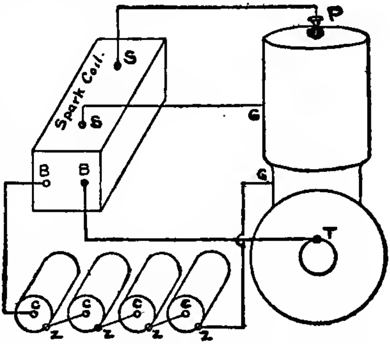


Fig. 55. — Single-cylinder Engine with Four-terminal Coil.

In Fig. 55 one of the secondary posts is grounded on the engine and a wire also runs from the post *B* to the timer. In place of running both of these wires, the post *S* may be grounded on the wire from post *B*, as in Fig. 56.

As this last method of connection joins the post *B* and *S* together, it is becoming the practice to join them inside the box and run the lead to a single post *C*, making a three-post coil as shown in Fig. 57, the connections being practically the same as in the preceding figure.

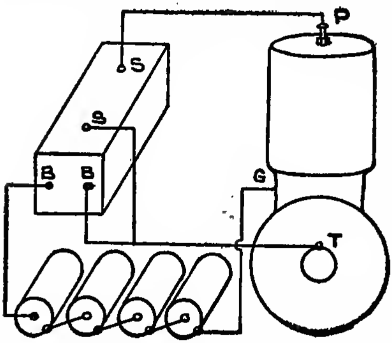


FIG. 56. — Single-cylinder Engine Fired by Four-terminal Coil.

In Fig. 58 is shown the additional connections for a double set of batteries and a dynamo. It is similar in principle to that of Fig. 54.

Some types of double-cylinder engines can also be fired from a single four-terminal coil, the wiring being as shown in Fig. 59. The timer has a single terminal but a double-pointed cam, giving two contacts for each revolution of the timer. A secondary wire is run from each secondary post to one of the spark plugs. This occurs twice in each cylinder during the cycle, and the sparks are so timed that one fires the charge and the other occurs at a time when the contents of the cylinder are not inflammable, as during the exhaust. Thus the first series of sparks will fire the charge in cylinder No. 1, and have no effect in cylinder No. 2, while the next series will fire No. 2 cylinder and be ineffective in No. 1. This method may be used in a four-cycle engine of the double-opposed type, or a vertical engine with the pistons moving together.

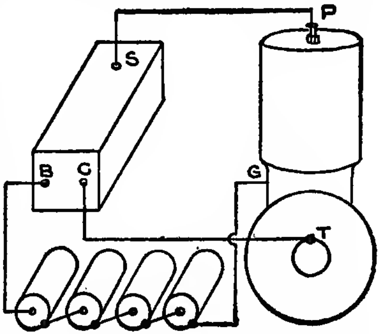


FIG. 57. — Single-cylinder Engine Fired, by Three-terminal Coil.

The usual practice, however, is to use a separate coil for each cylinder as in Fig. 60 where connections are shown for four-post coils. For three-post coils the connections are shown in Fig. 61, which figures are self-explanatory. For more than two cylinders the connections would be simply an extension of the above.

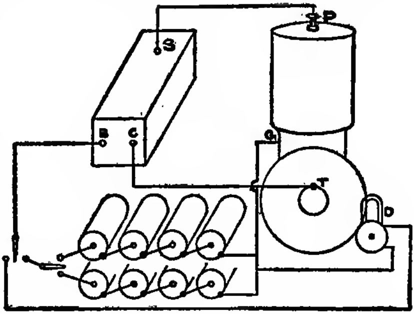


FIG. 58. — Wiring Diagram with Magnets.

Duplex Coils. — Where more than one coil is necessary it is usual to combine them all in one box for simplicity and compactness. There are many ways in which the binding posts may be arranged, Fig. 62 showing a common form for two cylinders. A single ground wire is used connecting with both coils inside the box. One battery terminal is used, the other battery wire being grounded. There are two posts *C*, *C* for connection, one to each post of the timer. The two secondaries *S*, *S* are each connected to a plug. This is a six-post duplex coil.

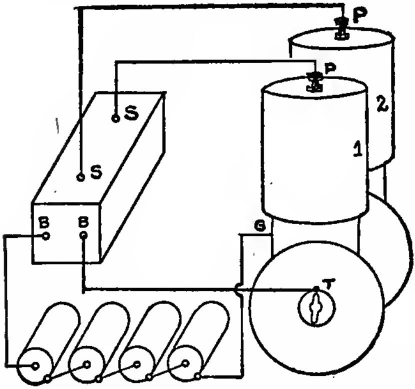


FIG. 59. — Two-cylinder Engine, Fired with Single Coil.

Another form of duplex coil, a five-post coil with connections, is shown in Fig. 63. No ground wire is used, one battery wire being grounded and the other connected to the *B* post. The posts *C*, *C* are wired to the timer and posts *S*, *S* to the plugs.

Coils for three cylinders are triplex coils and for four cylinders quadruplex coils. The posts *C* and *S* only are increased with the number of cylinders, the *B* and *G* connections remaining single.

In Fig. 64 the wiring is shown for a four-cylinder engine; it is similar in principle to Figs. 62 and 63, the coil box containing four units and there being four posts on the timer. The post *G* and the ground wire may or may not be used according to the interior arrangement of the coil.

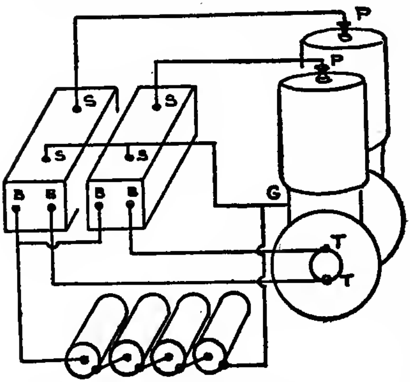


FIG. 60. — Two-cylinder Engine with Separate Coils.

As here shown, the cylinders are fired in regular order; as a fact, however, this is not possible with the usual arrangement of cranks as shown in Figs. 77 and 78. The order of firing for four-cycle engines may be either 1, 3, 4, 2 or 1, 2, 4, 3, and for two-cycle engines either 1, 3, 2, 4 or 1, 4, 2, 3, according to the direction of rotation. To make this variation one of the wires, either primary or secondary, is crossed over to the proper post, according to the circumstances.

The usual orders of firing for a six-cylinder engine are 1, 5, 3, 6, 2, 4 or 1, 4, 2, 6, 3, 5; others are possible also.

Advantages of Each System. — In the case of the make-and-break system the principal advantage is the simplicity of the wiring and the use of the low-tension current. There is far less trouble from leakage of the low-tension current, and less perfect insulation is required. On

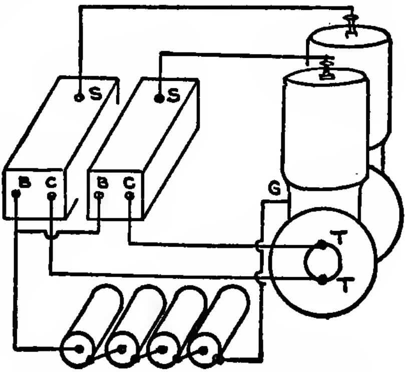


FIG. 61. — Two-cylinder Engine with Separate Three-terminal Coils.

the other hand, the igniter gear is apt to be rather complicated, with many small parts which wear and become noisy. The moving parts in the cylinder also are likely to become dirty or worn and give trouble. At high speeds the action of the gear is apt to be rather erratic, as the springs may not act quickly enough between strokes, and even when in good condition it is noisy. For engines in working boats, or others which are given little care, this system is well suited, as it is, on the whole, less sensitive than the jump-spark system.

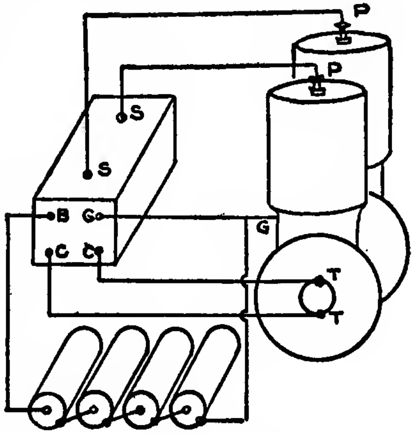


FIG. 62. — Two-cylinder Engine with Duplex Coil.

The jump-spark system makes a very simple engine possible, as the only parts of the engine are the timer and the spark plug. No complicated igniter gear is necessary, requiring oiling and care. Trouble at the sparking points is easily remedied by replacing the plug with another and cleaning up the first at leisure. The timer also is simple and easily kept in good order. On the other hand, the wiring is more complicated and must be most carefully done. The current in the secondary wires is of extremely high voltage and special insu-

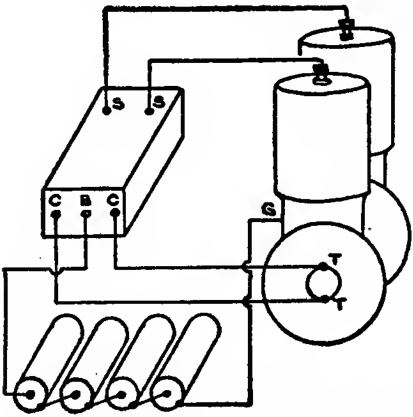


FIG. 63. — Two-cylinder Engine, with Five-terminal Coil.

lation must be used to prevent leakage. The coil and secondary wiring must be protected from moisture, which is sure to cause a short circuit. It is quite uncomfortable if the current becomes short-circuited through any part of the body. With care, however, these points may be easily guarded against, and the jump-spark system becomes very simple and satisfactory. While the electrical outfit is more expensive than that for the make-and-break system, the cost of the complicated igniting gear is saved, so that on the whole the cost is probably not more than that of the other system. For cabin boats where the engine is protected from rain and spray, the jump spark is well suited, but there is no reason why it may not, with proper precautions, be used, if desired, in almost any circumstances.

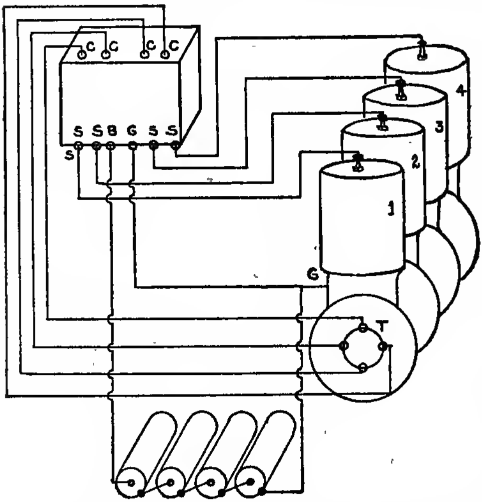


FIG. 64.—Four-cylinder Engine with Four-unit Coil.

The separate independent coil system has many of the advantages of the jump-spark system without the disadvantage of the exposed secondary wiring. It is, however, possibly more expensive on account of the separate coil for each cylinder. As only the primary wiring is exposed, which is far less susceptible to moisture, for open boats this system on the whole gives good satisfaction.

Distributor. — This is a device by which a single coil may be made to fire any number of cylinders, the secondary current being sent from the single coil to each cylinder in turn. It is somewhat like the usual timer in appearance and action, and is shown in principle in Fig. 65. A primary contact maker, *C*, consists of a cam having as many projections as there are cylinders, in this case four; these projections rub past the insulated contact point *I*, and thus make and break the primary circuit. There will thus be four passages of the primary current for each revolution of the cam *C*. A single coil is used, the wiring of which is substantially the same as for a single-cylinder engine in Figs. 55 and 57. One primary wire is grounded and the other is connected to the insulated point *I*. The secondary wire, instead of running to the spark plug, is connected to an arm *A* which revolves on the same shaft as the cam *C*, but is insulated from it. The arm *A* in revolving makes contact with the plates *P P P P*, from which wires run to the spark plugs. It is so arranged that whenever one point of the cam *C* completes the primary circuit, the arm *A* is in contact with one of the plates *P* and delivers to it the resulting secondary current. Thus the arm *A* will distribute the secondary current to each of the plates *P*, in turn. The number of plates, *P*, and the number of points on the cam *C* must be the same, and equal to the number of cylinders to be fired.

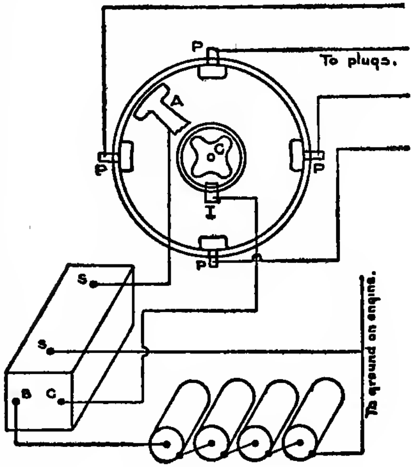


FIG. 65.—Diagram of "Secondary Distributor."

By comparing this figure with Fig. 64 the simplicity of the wiring is evident. Although not used as much as the preceding system in marine work, the distributor may be made to give good results with proper care.

Wiring for Individual Coils.—Fig. 66 shows the wiring for four cylinders for the individual combined coil and plug described in the previous chapter. Only the primary circuit is to be considered, as the secondary circuit is self-contained in the apparatus.

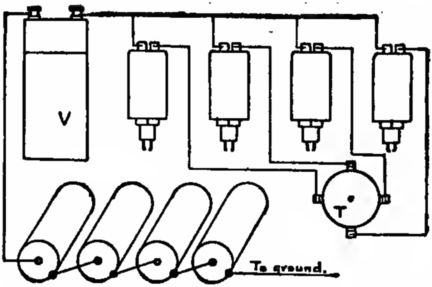


FIG. 66.—Wiring Diagram for Individual Coils.

The vibrator for all coils is shown at V; it consists of a small magnet and vibrator similar in operation to that of the usual coil. One battery terminal is grounded on the engine; the other terminal is connected to one pole of the vibrator. From the other vibrator terminal a wire leads to one terminal of each coil. From the timer T, which has as many posts as there are coils, a wire is run from each post to the remaining post of each coil. The primary current is thus sent through the timer to each coil and plug in turn. The wiring for this system is somewhat similar to that of the make-and-break system of Fig. 54.

The simplicity of the wiring for the high-tension magneto is shown in Fig. 67. Only the leads from the distributor block ter-

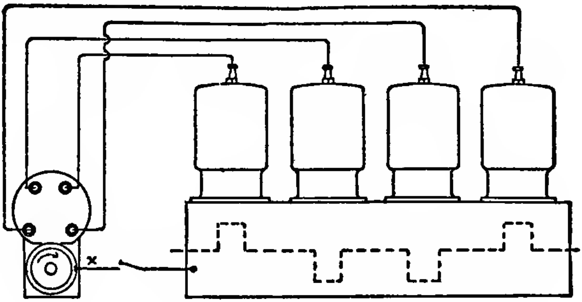


FIG. 67.—Wiring Diagram for High Tension Magneto.

minals to the cylinders are required, although these must be arranged according to the order of the firing of the cylinders. A lead from the grounding terminal to the metal of the engine with proper switch is run for stopping the action of the magneto.

Storage Battery in Connection with Dynamo. — To obtain the best effect from either storage battery or dynamo, they should be used in conjunction. The dynamo normally furnishes the current required, the storage battery being connected into the circuit, so as to take its share of the current, this being continuously under charge when the dynamo is running at speed. If the dynamo slows down or stops, the storage battery automatically takes up the load. Referring to Fig. 68 the usual connections for such a system are shown. The generator *G* is connected to the main lead wires; the storage battery *B*, the lamp circuit *L*, and the ig-

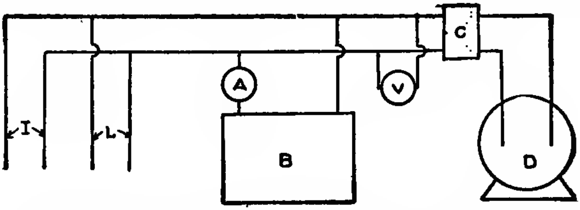


FIG. 68. — Wiring Diagram for Dynamo and Storage Battery.

nition circuit *I* are connected across the leads. In normal operation all of these draw their share of the current from the dynamo *D*. As the voltage of any dynamo is dependent upon its speed of revolution increasing or decreasing with the speed, should the voltage of the dynamo fall below that of the battery it will discharge back through the dynamo. To prevent this, a cut out *C* is connected across the circuit. This cut out is an automatic magnetic switch which remains closed as long as the voltage delivered by the dynamo is greater than that of the battery, but which opens when the voltage of the dynamo current drops, cutting it out of the circuit. When this takes place the circuit is still complete through the battery and lamps as can be readily figured. At *A* an ammeter may be put into the circuit to show whether the battery is charging or discharging. A volt meter *V* is connected across the circuit to show the dynamo voltage.

If in addition to the lamps and ignition circuits an electric starting motor is used, the leads should be taken directly off the two terminals of the battery, as much heavier wire is required for this than for the lights and ignition.

CHAPTER VII

Oil Engines

Engines working on crude or fuel oil must be operated on a different principle from those already considered. Gasoline vaporizes readily and is ignited by the electric spark; kerosene also can be ignited after being vaporized by the application of heat; crude or fuel oil, however, being heavy and unrefined does not vaporize at ordinary temperatures, and special treatment is required as a high degree of heat is necessary to ignite it. To obtain this high temperature advantage is taken of the fact that when air, or any gas, is compressed, it becomes heated, as is noticed in the quite common case of the tire pump, the barrel of which becomes hot when in use. In order to obtain this high pressure, the compression space is made as small as possible in comparison with the cylinder volume, thus raising the compression pressure and consequently the temperature. All heavy oil engines make use of this principle to a greater or less degree. The simplest of these engines is the so-called "surface ignition" type or as it is sometimes termed the "semi-Diesel," although the latter name is not looked upon altogether with favor.

An example of the simpler form of oil engine is shown in Fig. 69; this engine much resembles the two-cycle gasoline engine both in construction and operation, having the closed crank case *C*, transfer passage *T*, and exhaust port *E*. No carbureter is used and no spark plugs. Pure air is drawn into the crank case on the up stroke of the piston, through check valves in the crank case cover plates *A*; this air is compressed in the base on the next downward stroke of the piston and transferred to the cylinder where it is compressed on the next up stroke. In the head of the cylinder is a bulb, plate, or plug, on the principle of Fig. 52, which has previously been heated. At the proper point on the up stroke a small amount of fuel is injected through the fuel nozzle *F*. The oil strikes the hot surface, vaporizes, mixes with the air and ignites at or near the top of the stroke. The heat of the hot surface, combined with the heat of compression, vaporizes the oil and then ignites it. At the end of the next downward or power stroke the exhaust valve is uncovered and the burned gases escape to the muffler. The incoming air scours the cylinder of burned gas and drives out the remaining exhaust products. The bulb, or plate, retains sufficient heat to ignite the next charge with the aid of the heat of compression. It will be seen from the sketch that the head is not water jacketed as it is necessary to keep it as hot as possible, although a light cover is worked over the top of it.

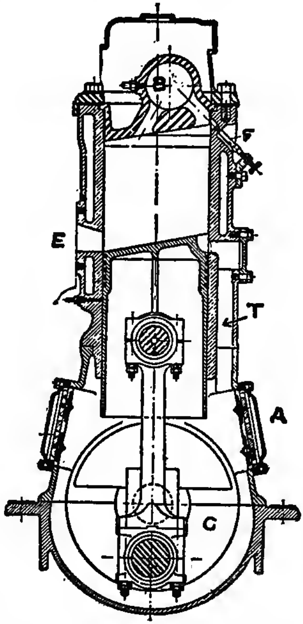


FIG. 69. — Section of Oil Engine.

The speed of the engine is regulated by the amount of oil fed into the cylinder at each stroke. This is taken care of by a special form of pump with arrangements for varying the amount fed per stroke. The spray nozzle *F* is of a variety of shapes, all of which are designed to break up the oil into small particles and inject it into the cylinder in a fine spray which is most easily ignited. The time of injection of the fuel must be nicely timed according to its quality and the pressure of compression, to assure that it will vaporize and ignite at the most favorable point of the stroke. Arrangements are provided in connection with the fuel pump to vary the amount of fuel fed per stroke and also the timing of the same. As the ignition is dependent upon both the heat of the bulb and the compression pressure, considerable variation of the two is found. The higher the compression, the lower the temperature of the bulb can be, which is advantageous for operating reasons.

The term "semi-Diesel" has probably arisen from the fact that the compression is utilized in part to produce ignition, although the term "surface ignition" is a stricter definition.

Engines working on this principle have the comparative simplicity of the two-cycle gasoline engine in comparison with the full Diesel engine. For small powers they can be lighter than the Diesel, and as no fuel is injected into the cylinder until after the exhaust port is covered, there is no loss from this source and the economy is therefore good.

For starting the engine the bulb or other device must be heated by external means; a system of torches is a common arrangement for this purpose, although in some cases a special form of plug is used which can be electrically heated.

The Diesel engine makes full use of the heat of compression, without other means of ignition. The action is in some ways similar to that of the surface ignition type but carried a step further, the compression pressure being so great that no hot plate or other device is necessary. Engines working on this principle may be either of two- or four-cycle type, although for such sizes as might fall within the scope of this work the four-cycle type is commonly used. A representative engine of the four-cycle type is shown in Fig. 70. This will be seen to bear some resemblance to the four-cycle engines already described, except that no carbureter or spark plugs are fitted. In the place of these there is an additional valve *F* in the head of the cylinder. The valves are arranged as in sketch *D* of Fig. 26; the inlet valve *I* is actuated by the rocker arm *R*, the lower end of which carries a roller which bears on the cam *C;* the exhaust valve *E* on the opposite side has

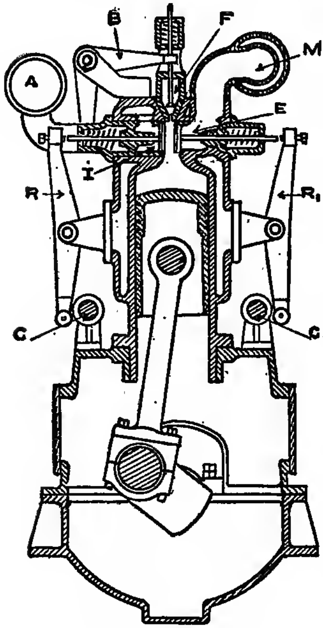


Fig. 70. — Diesel Engine.

the same arrangement of rocker arm actuated by the cam *C*. Pure air only is taken into the cylinder from the air pipe *A* running along the tops of the cylinders; the exhaust valve *E* opens into the exhaust manifold as usual. In the top of the cylinder head is another smaller valve *F* through which the fuel is fed; this valve is controlled by the bell crank lever *B*, the down turned end of which is in contact with another rocker arm similar to *R*, which is in turn actuated by a special cam on the cam shaft. The chamber around the valve *F* is in connection with the fuel pump and also an air supply which is kept at a pressure much higher than that of the compression. In operation the air is drawn in during the suction stroke and compressed as usual; the fuel is fed into the chamber *F* in the proper amount by a small pump; at about the time of maximum compression the fuel valve *F* is opened by the cam and rockers, and the fuel blown into the cylinder against the compression by the air pressure. The high pressure of the compression has so heated the air in the compression space that the oil is at once ignited, after which the power stroke and exhaust stroke follow as usual.

In this sketch, which is in approximate proportions, it will be noted that the parts are, in comparison with the cylinder bore, much heavier than in the gasoline engine; this is due to the greater pressures employed and the consequent greater stresses.

It is in no way essential that this particular arrangement of valves should be used; this has been chosen for illustration as representing a successful type and also showing well the relation of the various parts. It is quite customary to arrange the valves side by side in the head with the fuel valve to one side; but in every case it is usual to place the valves in the head as in this way the strongest construction can be had; also the compression space can easily be kept small as is necessary if a high compression is to be had.

It is necessary for the operation of this type that a continuous supply of high-pressure air be available for fuel injection, and also a supply at moderate pressure for starting, as described later; this is supplied by an air compressor driven off the crank shaft at the forward end of the engine.

Large engines are being built on the two-cycle principle. The action as regards compression and fuel injection are the same as just described; near the lower end of the stroke, however, the piston uncovers ports through which the burned gases escape as in the two-cycle gasoline engine. Valves in the head then admit a considerable volume of air which blows out the remaining gases and furnishes pure air for the next compressive stroke.

In Fig. 71 is shown a descriptive section of an oil engine working on a slightly different principle in regard to the feeding of the fuel. The usual inlet and exhaust valves *V* are located in the head side by side and actuated by the rocker arm *R* and another directly behind it. The fuel feeding arrangement is as follows: a sort of plug is set into the head which carries a fuel valve *F*, which is held up against its seat by the spring *S* and a needle valve *N* which closes the small passage leading to the fuel valve *F*. The fuel enters at *O* into the space around the stem of the needle valve *N*. Below these valves is a sort of cup *C* having a ring of small holes *H* slightly above the bottom. The fuel valve *F* is depressed by the lever *L* which bears against the projection *T* on the side of the rocker arm *R*. Thus whenever the rocker depresses the inlet valve *I* it also depresses the lever *L* and opens the fuel valve *F*.

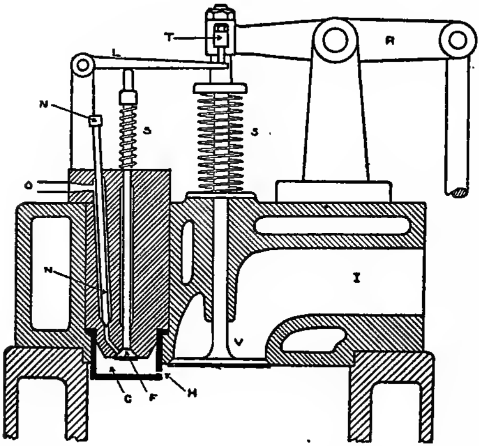


FIG. 71.—Section Through Head of Oil Engine.

The operation is as follows: on the suction stroke the inlet valve is open and air is drawn into the cylinder, at the same time the fuel valve *F* also opens and a small amount of fuel flows out and is caught in the cup *C*. At the end of the downward suction stroke both valves close and the air is compressed in the cylinder and heated to a high temperature thereby. The pressure and heat pass through the holes in the cup *C* to the oil within, vaporizing a small amount which explodes, forcing the remainder of the charge through the small holes, at about the time of greatest compression, into the heated air in the cylinder. The charge then burns as in the Diesel engine, the expansion and exhaust being carried out as usual.

Regulation of speed and power is obtained by adjusting the needle valve *N* to allow a greater or less flow of fuel per stroke. The extreme simplicity of this system is apparent; no high-pressure air is used for fuel injection and the fuel is nowhere under pressure until the time of ignition. This type is very well suited to small powers and engines of this type are built in much smaller sizes than in the Diesel type, as the necessary complications of the latter would make it unprofitable to build in small sizes.

The action of the fuel in engines of the Diesel and surface ignition types is somewhat different from that of gasoline in the gasoline engine. In the gasoline engine the explosive charge is compressed and at the time of ignition actually explodes, giving a maximum pressure several times that of the compression. In the oil engine, however, the ignition of the fuel is more gradual and extends over an appreciable part of the stroke; the maximum pressure is therefore not raised greatly above the compression pressure, and the impulse is comparatively steady over about the first tenth of the stroke, after which the pressure falls by the expansion to the exhaust.

Oil engines are usually built with several cylinders, as high as eight being used; this is done to promote smooth operation and ease of handling and avoid unnecessarily large cylinders.

CHAPTER VIII

LUBRICATION

ONE of the most important considerations in any engine is the question of lubrication. The life of the engine depends very directly upon the efficiency of the lubrication. Insufficient lubrication may cause great damage to an engine in a short time. The pistons especially must be well oiled, as a lack of lubrication under the conditions of extreme heat which exist in the cylinder is likely to cause the piston to stick and finally cut the surface of the cylinder.

Oil-cup. — The simplest means of feeding oil is shown in Fig. 72, which is a plain oil-cup. It is screwed into place by the thread *T;* the screw cap *C* allows it to be filled with oil, which feeds down to the bearing through the hole in the stem. This style of cup may be used on bearings where there is no outward pressure against the flow of oil. There is, however, no means of regulating or stopping the flow of the oil.

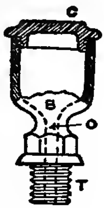


FIG. 72. Oil-cup.

Sight-feed Oiler. — For feeding oil against pressure the sight-feed oil-cup shown in Fig. 73 is used. A section of glass tube *G* is closed at the ends by the covers *C* and *B*. The central tube *T* projects from the lower cover and on its upper end has a thread on which the cover *C* screws. A ring of packing is placed under the edges of the glass tube and the cover *C* screwed tightly down, making a tight joint. The threaded stopper *F* allows it to be filled with oil, which flows through openings *O* into the central opening and down to the bearing. In the stem a piece of small glass tube *H* is inserted and sight holes are placed in the sides of the stem, through which the flow of oil may be observed. A small tube *A* leads from the lower chamber to above the level of the oil, to admit the pressure to take the place of the oil which is fed out and prevent the formation of a partial vacuum above the oil, which might finally prevent its flow.

Inside the stem T is the small plunger V, which is pressed down by the coiled spring S. The finger lever L is pivoted to the top of the rod V; when this lever is horizontal the rod V is free and is forced down into its seat below, closing the opening and stopping the flow of oil. When the lever is raised to a vertical position the square end bears upon the cap R and raises the plunger V, allowing the oil to feed. The cap R may be screwed up or down on the threaded end of the tube T, varying the amount which the plunger V is raised and thus regulating the flow of oil. Raising the cap R increases the flow, and lowering it decreases it; the drops of oil can be seen through the glass H, and the cap R raised or lowered until the drops fall at the proper frequency. The ball inside the lower stem is designed to prevent a sudden inrush of pressure, by being carried up and closing the opening above. When the engine is not running the lever L is turned down and the supply stopped.

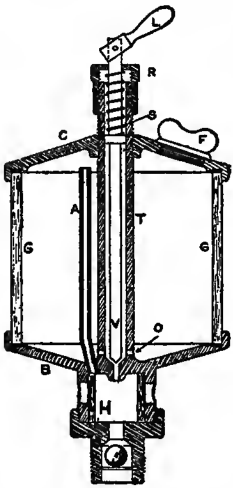


FIG. 73. — Sight-feed Oil-cup.

Grease-cup. — For feeding grease, the grease-cup, Fig. 74, is used; it consists of a flat disc D which is threaded on the edge; a cover C is threaded internally to screw on to the disc. The cover is filled with grease and then screwed down over the disc D, the pressure forcing the grease out through the hole O and on to the bearing. The cover can be gradually screwed down until all of the grease is forced out. Grease is used where the pressure on the bearing is great, or where the viscosity of the grease is an advantage. The use of grease on the main bearings of the two-cycle engine is almost universal, as it fills the space between the shaft and the bearing and prevents the reduction of the base compression, by the escape of the gas along the shaft.

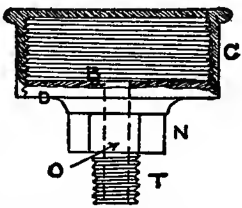


FIG. 74. — Grease-cup.

Oiling of Cylinder.—The cylinder is lubricated by oil delivered on to the inner cylinder walls from a sight-feed oiler or other device, so placed as to deliver the oil at about the middle of the piston travel. The piston has a series of grooves turned in its circumference, which collect the oil and distribute it over the entire surface. The lubrication of the piston is very important, and on account of the high temperature only the best oil should be used. A poor oil will burn and the resulting carbon will deposit in the counterbore, passages, and on the spark plug, and will become heated and fire the charge on the compression stroke, causing pre-ignition. The carbon on the plugs also prevents the passage of the low-tension current of the make-and-break system and furnishes a path for the high-tension current of the jump spark, thus interfering with the action of either.

Piston Pin Lubrication.—The piston pin requires, and usually receives, but little lubrication. An axial hole is usually drilled through the pin, with a radial hole opening into the bearing. Oil from the cylinder wall is scraped up, and works its way along the hole and into the bearing. It is not likely that much oil reaches the bearing in this way, but as the angle of oscillation of the rod is small, not much oil is required.

Crank-pin Oiling.—This bearing does the heaviest work of all the bearings in the engine; and it is at the same time the most difficult to properly lubricate, especially on two-cycle engines with the enclosed base. There are several ways of oiling this bearing, the most common of which is the splash system illustrated in Fig. 75. On the lower side of the connecting rod is the small scoop *S*, and directly over it is the hole *O* leading to the bearing surface. The base of the engine is partially filled with oil, a small portion of which is scooped up at each revolution and carried to the bearing. This is the most common way on small two-cycle engines, and while it does very well, there are some disadvantages connected with it. The incoming vapor, where gasoline is used for fuel, absorbs a small amount of oil with each charge, and carries it away through the cylinder, not only weakening the charge, but affecting the lubrication.

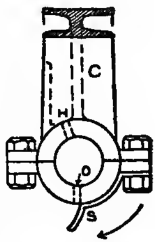


FIG. 75.—Crank-pin Oiling.

Where the connecting rod is made as in Fig. 75 with an I section, one side of the I may be walled in, making a sort of pocket from which the oil hole H reaches the bearing. Oil is fed into this pocket at intervals through an opening in the crank case, or continuously by a tube leading from a sight-feed oil-cup above.

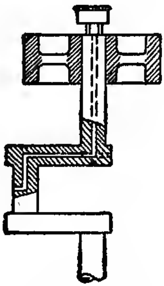


FIG. 76.—Oiling Crank-pin.

A very reliable way of crank-pin lubrication for single-cylinder engines is as shown in Fig. 76, a small hole is drilled through shaft, crank, and pin to the surface of the pin. A grease-cup is fitted in the end of the shaft outside the fly-wheel. In this way the grease is fed directly to the bearing; grease is especially well suited to use in the crank-pin bearing on account of the high pressure upon it.

Fig. 77 shows another satisfactory form of crank-pin oiler. It is a shallow receptacle forming a sort of ring, which is fastened to the side of the crank. It is drawn out at one point, at which there is a hole connecting with the axial hole in the crank pin. Oil is delivered into the lip by the tube T from an oil-cup above. As the shaft turns, the oil is thrown by the centrifugal force to the circumference of the ring and finds its way to the bearing through the hole O. In this way a continuous feed may be had.

Multiple Sight-feed Oilers. — Where there are several sight-feed oil-cups to be fitted they are often combined into one large reservoir, with several sight-feeds leading from it. This is a considerable saving of space and of labor, as one filling of the reservoir serves for all.

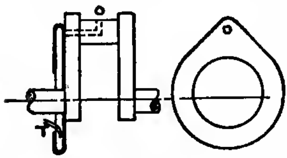


FIG. 77.—Crank-pin Oiling.

The cylinder oilers are, however, often kept separate, as the oil suitable for the cylinders is likely to be different from that used in the bearings.

Mechanical Lubrication.—For oiling a number of points the mechanical lubricator shown in Fig. 78 is almost universally employed; it consists of a rectangular reservoir containing a series of small pumps all operated from a single shaft which is in turn driven off some rotating or oscillating part of the engine. Pipes lead from each pump to the desired point. The amount of oil pumped per stroke is regulated individually, and sights are provided to observe the feed.

The oiling of multi-cylinder engines is a more complex problem. The crank-pin bearings in moderate speed engines are lubricated on the principle of Fig. 75, small troughs being provided in the base for the scoops to dip into. These troughs are fed by a small pump drawing the oil from a reservoir in the base. The oil is picked up by the scoops and what does not enter the crank-pin bearings is spattered about in the base, part of it finding its way to the cylinder walls, and to such cam shaft or other bearings as may be within the base. It is usual in slow-speed engines to fit either a sight-feed or force-feed oiling system to take care of the main bearings, with possibly a lead to each cylinder wall in addition.

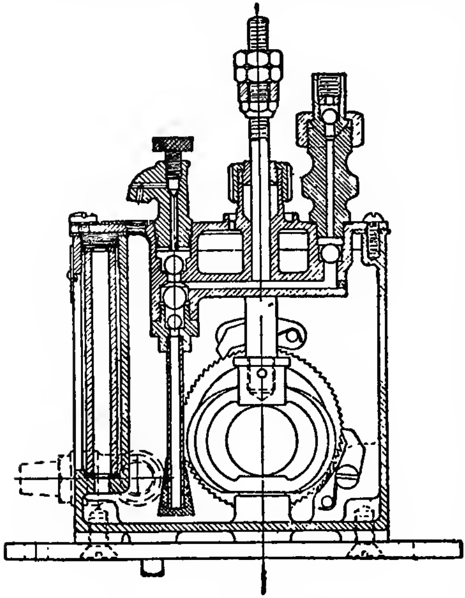


FIG. 78.—Forced Feed Oiler.

In small, medium duty, high-speed engines, the entire oiling of the engine may be taken care of by the splash system, it only being necessary to see that the oil in the reservoir is maintained.

High-speed engines of larger sizes, where the duty is more severe, may be fitted with force-feed oiling throughout. The main shaft bearings are taken care of on the principle of Fig. 76, the oil hole, however, running the entire length of the shaft. A ring is cut around the end shaft bearing, registering with a hole into the drilled shaft as in Fig. 79. The oil is delivered to this opening under a considerable pressure and in such volume as to flow through the hollow shaft and force out at each bearing, returning to the reservoir. A mechanical oiler may be used in addition, to supply such bearings as may not be exposed to the oil spray. In connection with this system some form of gauge or indicator must be fitted to assure a continuous supply of oil, as a failure of the supply with this sytem is much more serious than with the other systems where there is a greater surplus.

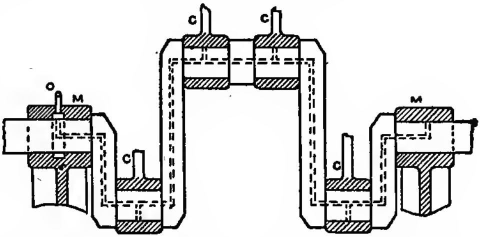


FIG. 79.—Oiling Through Bottom Crank Shaft.

Oil engines cannot be lubricated by the splash system, as the air in the base would carry a portion of it into the cylinders with liability to pre-ignition and other troubles. One of the several forms of forced feed is therefore adopted, the mechanical oiler having the preference.

CHAPTER IX

Multiple-Cylinder Engines

Engines of more than one cylinder are necessary and desirable for a number of reasons. It is evident that when the limit of power of a single cylinder is reached, more cylinders must be added according to the power desired. Even when this consideration does not apply there are others which make at least two cylinders desirable, even for moderate power. In a single-cylinder engine the parts must be relatively heavy, and the stopping and starting again of these parts at each end of the stroke causes a throw which is felt as a vibration. A two-cylinder engine may be so arranged that one set of working parts is moving upwards while the other is moving downwards, thus neutralizing the throw of each and practically stopping the vibration. The impulses in the several cylinders may be made to occur at different points in the revolution, thus reducing the interval between the impulses. Thus in a two-cylinder engine there will be twice as many impulses in each revolution as in the single cylinder. This gives a more even turning effect on the shaft and, in consequence, a steadier running engine; as the interval is shorter between the impulses a lighter flywheel can be used. The weight, power for power, of a double-cylinder engine is less than that of a single-cylinder, owing to the lighter weight of the flywheel and other parts. In the case of the disablement of one cylinder there is the possibility of running on the remaining cylinder or cylinders.

While for marine work single-cylinder engines are built as large as eight or ten horse-power, they are so large as to be rather cumbersome and suited only to working boats. For use in pleasure boats, engines should be built with multiple cylinders when above five horse-power. There are several makes of engines with double cylinders as small as three horse-power, which, as to weight and reliability, are superior to those of a single cylinder.

The original method of constructing a multiple-cylinder engine was to couple two or more single engines together with couplings between. This is a cumbersome method and takes up a great amount of space, and is seldom used now.

Several combinations may be made in the arrangement of the cylinders, those for the two-cylinder engine being shown in Figs. 80, 81, and 82. Fig. 80 is for two vertical cylinders with the cranks opposite, one set of parts moving upwards while the other moves downwards; the parts are thus practically in mechanical balance. When this arrangement is used in a two-cycle engine, the impulses or power strokes will be regularly distributed, with two power strokes for each revolution. When applied to a four-cycle engine the impulses will not be regularly distributed, but will occur on adjacent strokes with an interval of two strokes, or one revolution, before the next two.

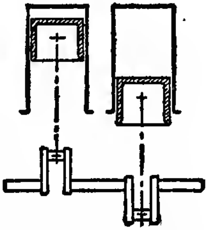


FIG. 80. — Arrangement of Cranks on Two-cylinder, Two-cycle Engine.

In Fig. 81 the cranks are both on the same side of the shaft and the working parts move together. This arrangement is in very bad mechanical balance, and counterweights on the opposite ends of the cranks are required to balance the weight of the working parts. This arrangement would not be used in a two-cycle engine, but in a four-cycle engine so distributes the impulses that they occur regularly, one during each revolution. As this arrangement is used to some extent it is considered that the poor mechanical balance is more than offset by the advantage of the regularly occurring impulses.

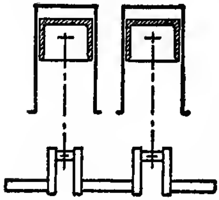


FIG. 81.—Arrangement of Cranks on Two-cylinder, Four-cycle Engine.

Fig 82 shows an "opposed" motor, the cylinders being placed horizontal, on opposite sides of the shaft, and travel in opposite directions, both moving towards or away from the shaft at the same time. The parts are in almost absolute mechanical balance. When this arrangement is used in a two-cycle engine both cylinders act together, the impulse occurring in both cylinders at the same time. In a four-cycle motor the impulses occur regularly, once during each revolution. This arrangement has some advantages; it lies very low in the boat, and may even be placed under a transverse seat; while for auxiliary work it is particularly convenient as it may many times be placed under the standing room floor where there is little head room.

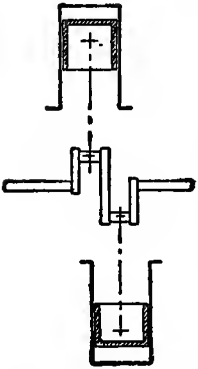


FIG. 82. — Arrangement of Cranks for "Opposed" Engine.

Three-cylinder engines are arranged as in Fig. 83, with the cranks spaced on thirds around the circle, or 120 degrees apart. This arrangement gives a good mechanical balance, and a regular distribution of the impulses in either the two- or four-cycle engine. Although the three-cylinder engine is little used in automobile work, it is quite popular in marine work.

Figs. 84 and 85 show the arrangement of the cranks in four-cylinder engines. The former is the usual arrangement for the two-cycle engine; the cranks of cylinders 1 and 2 are opposite, as are also those of cylinders 3 and 4, with the two pairs at right angles. The cranks are thus spaced equally around the circle as shown in the small circle at the right. With this arrangement the parts are well balanced, and the impulses occur at equally spaced intervals, each cylinder coming to the top of its stroke and receiving its impulse in turn. There are four impulses for each revolution.

The arrangement for a four-cylinder, four-cycle engine in Fig. 85 differs in that the two pairs of cranks are in the same plane. This arrangement is made necessary by the fact that the four-cycle engine has an impulse only on alternate revolutions. The positions of cranks 3 and 4 may be reversed, bringing 1 and 3 up and 2 and 4 down, but the former is considered the better arrangement. This arrangement gives four

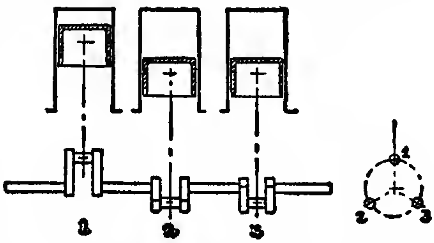


FIG. 83. — Arrangement of Cranks for Three-cylinder Engine.

impulses for two revolutions, or two impulses for each revolution, occurring regularly.

It will be readily seen that in any engine of more than two cylinders, while one cylinder is on the compression stroke, one of

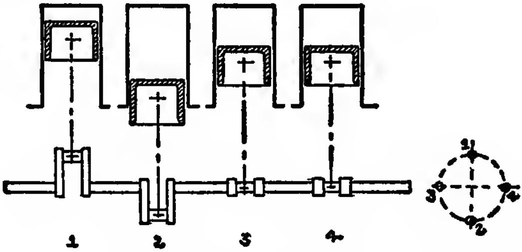


FIG. 84.—Arrangement of Cranks on Four-cylinder, Two-cycle Engine.

the other cylinders is receiving its impulse; the work of compression is thus overcome more directly, and the duty removed from the flywheel, which may thus be made lighter.

For higher powers or for reasons of lightness and better balance, six, eight, or even twelve cylinders may be used. Six-cylinder engines consist of two units like Fig. 83. Eight cylinders are disposed in two ways, in the simpler they are set in tandem, like two units of Fig. 85, but with the planes of the crank of one set at right angles to that of the other. This arrangement makes a long engine although accessible. When saving of space is desirable, the *V* type shown in Fig. 86 is adopted. This may be likened to two four-cylinder engines side by side but inclined at a right angle, using only one shaft; the connecting rods of opposite cylinders being attached to the same crank throw. The shaft is the same as that

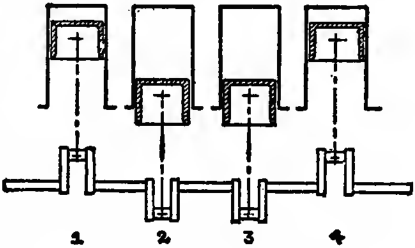


FIG. 85.—Arrangement of Cranks on Four-cylinder, Four-cycle Engine.

of Fig. 85 but with two rods taking hold of each pin. This arrangement allows a very short engine, which is also well balanced for high-speed work. Consideration will show that for even timing the planes of the two sets must be at a right angle.

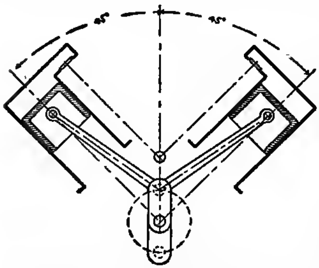


FIG. 86. — Arrangement of Crank for Eight-cylinder Engine.

Twelve-cylinder engines are made up of two six-cylinder units inclined as above, but on account of the extra cylinders the planes of the two sets are at an angle of 60°.

While the first multiple-cylinder engines were built by coupling together two or more single engines on a common bed, this method is bulky and clumsy, and is now little used. The usual method is to provide a common base, to which the several cylinders are bolted, bringing them much nearer together and making the engine much more compact.

The simplest form of two-cylinder engine is shown in Fig. 79, it is made up of two cylinders like that of Fig. 12, bolted to the one-piece base. Provision must, of course, be made to keep the crank cases separate, which is accomplished by a special center bearing between the two cranks. This particular engine is of the two-port type, with two vaporizers, *V*, *V*, joined to a common fuel pipe *F*. The water pump is at *P*, the discharge *W* from which is divided and branches to each cylinder. The cooling water outlet is at *J*. It will be seen that the pipe *W* and the outlet *J* are in the middle of the pipe leading to the cylinders; this is done to maintain an equal path through both cylinders and assure each obtaining its share of the cooling water. The igniter gears for the make-and-break spark are shown at *N*, *N* and are both connected by rods to the lever *L*, so that the time of ignition may be kept the same in

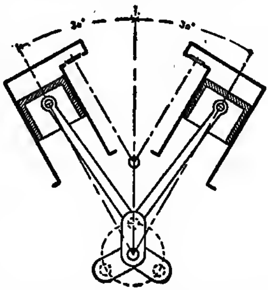


FIG. 87. — Arrangement of Cranks for Twelve-cylinder Engine.

both cylinders. This engine may be fitted with a single vaporizer, or carbureter, in the same manner as Fig. 89, if a check valve is fitted in the pipe at the entrance to each crank case. Both cylinders exhaust into the common exhaust pipe *E*. This is a very simple way of building a two-cylinder engine, as nearly all of the parts are the same as in the single-cylinder.

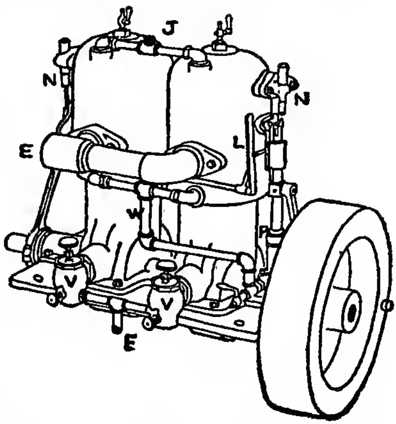


Fig. 88.—Two-cylinder, Two-cycle Engine.

Fig. 89 shows a two-cylinder engine of the three-port, jump-spark type. A single carbureter *C* is used with a branch pipe leading to the third port of each cylinder. The suction to the water pump is at *S*, the discharge being through the pipe *D* leading to the cylinders on the opposite side of the engine. The outlet from the cylinders is at *W*. The timer *T* has a terminal for each cylinder and is similar in construction to that of Fig. 41. At *O*, *O* are oil-cups feeding the crank pins by means of ring oilers like that in Fig. 42. Similar oil-cups on the opposite sides of the cylinders feed oil onto the bore of the cylinder.

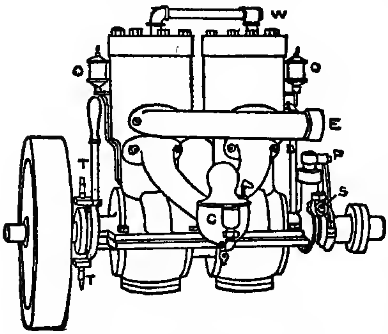


Fig. 89.—Two-cylinder, Two-cycle Engine.

In the engine shown in Fig. 90 the two cylinders are combined in a common casting. This engine is of the two-cycle three-port type. The inlet *I*, from the carbureter, opens into a chamber cored in the casting, with which the third ports communicate. The exhaust E opens from a similar cored chamber. The pump P is in this case a rotary pump driven by the sprocket chain B and delivering water through the pipe D, which, after circulating around the cylinders, overflows at W.

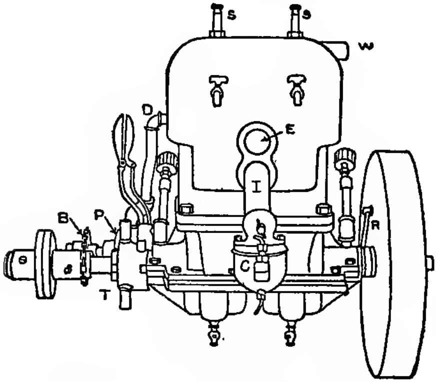


FIG. 90. — Two-cylinder, Two-cycle Engine.

The two-pole timer is at T. There are some advantages of this method of construction as it allows a very compact engine and also saves some weight. In the event of trouble with one cylinder, however, both must be disturbed, and in case of damage to one cylinder the entire casting is spoiled, so that repairs are likely to be more expensive with this type of construction.

In Fig. 91 a usual type of two-cylinder four-cycle engine is shown. The parts are lettered as before. The cam shaft is contained inside the base and, in addition to driving the valves, drives the two igniters N, N, and the pump P. The discharge from the pump is piped to the cylinders on the further side, and the overflow W is piped down into the common exhaust pipe E. The inlet pipe I from the carbureter C branches to each cylinder.

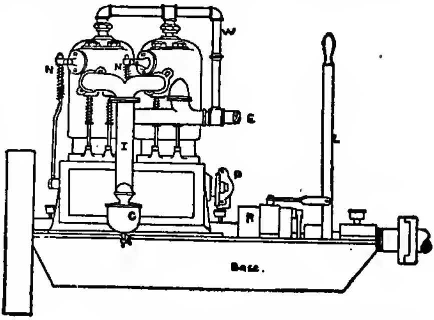


FIG. 91.—Two-cylinder, Four-cycle Engine.

In a multiple-cylinder engine, great care is taken to have equal distances from the carbureter to the inlet of each cylinder, as only in this way can all cylinders be made to take the same amount of mixture.

In other than small engines it is customary to provide a subbase *B*, either of cast iron or of angle iron, which carries the engine and also some form of reversing gear. This subbase keeps all parts in line and has flanges for bolting down to the bed in the boat.

Three- or four-cylinder engines are of the same general design with the additional cylinders added. In the case of the engine shown in Fig. 90, one of three cylinders has the three case in a single casting, while the four- or six-cylinder is composed of two or three two-cylinder units.

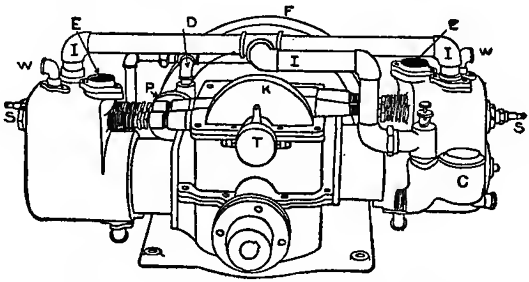


FIG. 92.—Two-cylinder "Opposed" Engine.

In Fig. 92 is shown the two-cylinder opposed motor having the arrangement of cranks in Fig. 75. The carbureter *C* is attached to the inlet pipe *I* which branches to the two cylinders; it should be noted that this inlet pipe leads to a point midway between the cylinders before branching in order to keep equal lengths of pipe to each. The exhaust from each cylinder is at *E*, *E*. The timer *T* is on the end of the cam shaft, the gears driving which are inside the casing, at *K*. The pump *P*, of the rotary type, is also driven from the cam shaft by an independent gear or sprocket chain. The discharge from the pump branches at *D* to each cylinder, entering on the lower side and flowing out at *W*, *W*. The flywheel *F* is on the further side of the engine. In the heads of the cylinders are the spark plugs *S*, *S*. The several flanges are shown, by which the parts are bolted together.

A four-cylinder engine of a style similar to Fig. 21 is shown in Fig. 93. The inlet and exhaust valves are on opposite sides of the cylinder and are operated by independent cam shafts driven by the gears *B* and *C* respectively. These two gears are driven from the crank shaft through the gear *A* on the crank shaft and the idle gear *G*. The idle gear *G* is inserted on account of the distance between the crank shaft and the cam shafts, to gear direct necessitating unduly large gears. The inlet valves are on the left of the engine, their chambers connecting with the inlet manifold *I* which is bolted to the sides of the cylinders. The carbureter *V* is attached to an elbow at the middle of the inlet manifold. A similar manifold on the opposite side of the engine connects with the exhaust chambers. The cylinders are separate and are bolted to the base by the flanges shown.

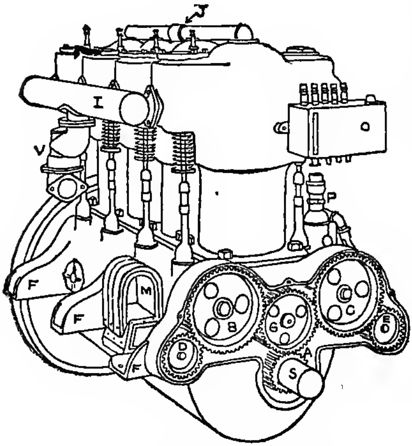


FIG. 93. — Four-cylinder, Four-cycle Engine.

The small gear *D*, driven by the gear *B*, drives the magneto *M*, and a similar gear *E* on the opposite side drives the plunger pump *P*. The cooling water leaves the cylinders by the pipe *J* which is bolted along the tops. The pump *P* delivers the water to the cylinders through a similar pipe on the farther side of the engine. At *O* is a forced feed oiler as already described.

In place of the usual flanges for carrying the engine, the cross-bearers *F*, *F*, *F* are provided. The gears are covered by a plate which, together with the case already in place, entirely encloses them.

Starting Arrangements. — While small engines are easily started by a crank or even by the rim of the flywheel, large engines must have some more powerful means. For this purpose a ratchet wheel is fitted on the end of the shaft outside the flywheel and a long lever used for turning the engine over. The ratchet allows the engine to run away from the lever when it starts.

In place of the compression relief cocks which are fitted on the small engines, large multi-cylinder engines, which are designed to be started by hand, may be provided with a device to lift the exhaust valves slightly from their seats, thus reducing the compression. This is accomplished by a small lever and supplementary cam, the valves being allowed to seat as soon as the engine starts.

In the more refined engines of the medium duty type, used in pleasure boats, electric starting systems are now quite commonly used. The system consists of a motor connected to turn the engine over by current from a storage battery, the battery being kept up to charge by a generator driven by the engine. The motor and generator may be separate units or may be combined in a single unit acting as either motor or dynamo. In the latter case the motor generator is geared direct to the engine shaft as in Fig. 94 and runs continuously. Where two instruments are used the generator is geared direct and runs all the time, while the starting motor is so arranged as to run only when it is required. The former is termed the single-unit, and the latter the two-unit system. The generator is run off either the cam shaft or the main shaft by gears or silent chain; the starting motor, when a separate machine is usually arranged to connect with a gear cut on the rim of the flywheel. The end of the motor shaft carries a small gear which meshes with the gear on the flywheel rim; normally the gear stands at one side out of mesh, but when in use is drawn into mesh by mechanical or electrical means and automatically shifted out of mesh when the engine has started.

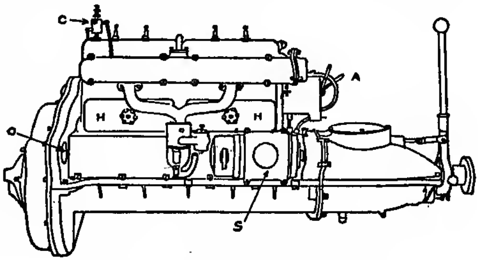


FIG. 94.—Four-cylinder Engine.

In the case of large, multiple-cylinder engines, notably those using oil fuel, compressed air is used for starting. A reservoir of compressed air is maintained which is admitted to two or more of the cylinders, turning the engine until the other cylinders take up the cycle. This is accomplished by a sort of revolving distributing valve, working in the same manner as the timer, which passes the air to the proper cylinder in turn, or, as is done in engines of the Diesel type, by means of a separate set of valves on the starting cylinders, worked by special cams on the cam shaft, which may be thrown into or out of engagement. The pressure in the air tank is maintained by a pump or air compressor. In the case of small oil engines the air compressor is usually operated by means independent of the engine, but in larger engines the direct connected compressor is fitted for this purpose.

In Fig. 96 the extra lifters for the air-starting valves are shown just to the right of the rocker arms of the middle two cylinders. Extra cams on the cam shaft can be moved into place to operate these lifters and at the same time the cams are moved from under the fuel valves, leaving them closed while the air is on. The shifting of the cams is accomplished by fingers extending from the shaft just below the cam shaft, operated in turn by the vertical lever. All starting systems employ one or a combination of the above principles.

Fig. 94 shows a sketch of a most refined type of engine; the cylinders are cast in one block and all the moving and working parts are entirely enclosed, including flywheel and reverse gear. Covers, easily removable, are provided for inspection and adjustment. Plates *H*, *H* also cover the valve tappets. This form of construction is very cleanly as no oil is thrown and dirt is kept out of the bearings. A single-unit electric starter shown at *S* is geared to the shaft by a silent chain. Provision is made for fitting a double-unit system, in which case the generator is placed as above and the starting motor geared with teeth on the rim of the flywheel, the shaft extending into the front gear case through the hole *D*. The spark and throttle controls are shown at *A*. Arrangements are also made for the insertion of a hand-starting crank at the front of the gear case.

Fig. 95 illustrates the general appearance of a heavy oil engine of two cylinders; separate crank cases are provided in order to assure tightness and the bearing between each two cylinders is readily accessible. This construction is not, however, essential, as some makes are built with separate cylinders and a common base, the compression being obtained by partitions in the base. The oil pump *P* is directly behind the flywheel; fuel pipes leading from it to the head of each cylinder. The governor *G* acts directly upon the fuel oil pump, which is also controlled by the hand gear *H*. At *W* is the usual water pump worked off an eccentric on the shaft. The reversing gear *R* is set into the same bed with the engine to assure the alignment. The mechanical oiler *O* is in this particular case supported on the reverse gear, and operated by the lever *L*, but it is usually disposed on some part of the crank case or cylinders; small pipes, not shown, lead from this oiler to the main bearings and cylinder bores. The exhaust chamber *M* is disposed on the back of the cylinders. The same construction is followed in engines having a greater number of cylinders.

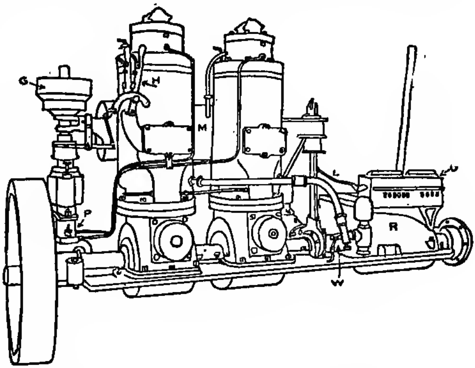


Fig. 95.—Two-cylinder Oil Engine.

An example of a small four-cycle Diesel engine with four cylinders is shown in Fig. 96. It has the usual outlines of the gas engine, with the addition of an air compressor at the after end. The valves are in the sides of the head as in *D* of Fig. 26, operated by the rocker arms shown. The sketch shows the intake side of the engine, the air supply pipe *A* running along the tops of the cylinders. Two rocker arms are shown for each cylinder; the left-hand one actuates the admission valve, and the right-hand one the fuel valve, through a bell crank lever which is behind the air duct. The tops of the fuel valves can be seen at *F* above the air duct. The cam shaft is shown plainly, extending from the case *G* alongside the crank case. At the front of the cylinders is the fuel pump *P*, which in an engine of this design is of the greatest importance as practically the entire regulation of the speed and power is dependent upon it. The air compressor *C*

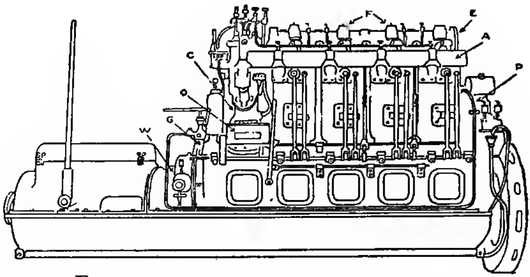


FIG. 96. — Four-cylinder Diesel Engine.

is run off an extra throw built in the crank shaft; its purpose is to supply air for starting and fuel injection. At *O* is the mechanical lubricator, driven by chain from the cam shaft. The water pump *W* is driven from the main shaft as usual. Engines of this type are built up to eight cylinders.

CHAPTER X

Reversing Mechanism

Unlike the steam engine, the gas engine of the usual design has no ready means of reversing. Although most two-cycle engines and some four-cycle engines will run equally well in either direction, the means of accomplishing it are slow and not always certain. Some few engines have permanent means for reversing them, which work very well, but the majority of engines must be stopped and started in the opposite direction. It is possible to reverse a two-cycle engine by a proper manipulation of the timing of the spark, as is explained under the handling of engines; it cannot, however, be relied upon in emergencies. This fact, and the fact that most four-cycle engines can be run in one direction only, necessitate the adoption of some form of independent reversing device. Small engines fitted in light boats may conveniently run without any reversing gear, but for engines of more than five or six horse-power some form of reversing gear should be fitted. One of the greatest advantages of the independent reverse gear is that it allows the engine to be run free of the propeller and shafting, thus making the engine easy to start.

Reversible Propeller. — The simplest form of reversing device is the reversing propeller, as shown in Fig. 97. It is fitted with a mechanism for changing the angle of the blades, causing them to act in the opposite direction without changing the direction of rotation of the shaft. In this case the propeller shaft *S* is made hollow and is fastened to the hub *H* of the propeller. Inside of the shaft is the round rod *R*, which is enlarged and made square inside the propeller hub. On one side of the square end of the rod is a diagonal groove *A*. The blade *B* has a collar *C*, which fits under the projections *D*, *D* of the hub, holding the blade in place while allowing it to turn. The face of the collar *C* bears evenly on the flat of the rod *R*, so that all parts are held snugly in place. On the under face of the collar *C* is a pin *P* which projects down and fits into the slot *A*. If now the rod *R* is moved along the shaft, the pin *P* will slide in the slot *A* and thus turn the blade. When the rod has been moved into its extreme right-hand position, the pin *P* will have moved to *P′*, having swung across the center line into the opposite position and caused the blade to take an opposite angle to its former one and to exert its force in the opposite direction. At some point about midway between these two the blade will be practically at right angles to the shaft and will turn idly without exerting any force. By turning the blades slightly either way a slight force will be exerted; thus any speed may be obtained from full speed in either direction down to nothing. This allows the boat to be readily maneuvered, and even stopped entirely, without touching the engine. The other blade is operated in the same manner by a slot and pin on the opposite side of the rod *R* so that both blades move together. On the inboard end of the rod *R* is an attachment connected with a lever for moving the rod in and out.

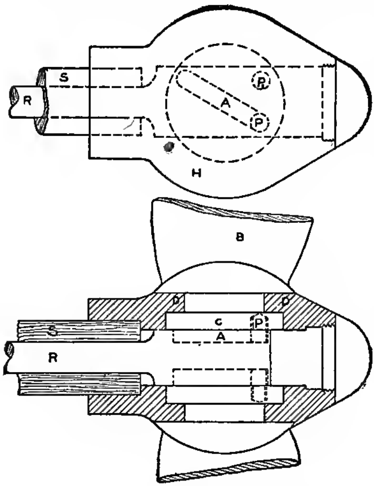


Fig. 97. — Diagram of Reversing Propeller.

This form of propeller is a cheap and fairly satisfactory way of controlling the speed where the power is small. If properly constructed it may be made nearly as strong as a solid wheel; many reversible propellers on the market to-day are, however, poorly designed and constructed, and care must be taken in the selection of this type of propeller. It should also be noted that the shape of the blades is correct for one angle only, and for all others is more or less unsuited; for this reason, unless the correct position happens to be hit upon for the full speed position, a certain loss of power is apt to follow. A reversible propeller is thus likely to waste more power and give less speed than a solid propeller. The usual reversible propeller should hardly be used for over ten horse-power; above this some form of mechanical gear should be fitted.

Reversing Gears. — For the present purpose reversing gears may be divided into two general classes, those using bevel gears and those using spur gears. Fig. 98 shows a diagram of a bevel gear reversing device. The engine shaft *E* is prolonged and carries on its end the large bevel gear *A*. The propeller shaft *P* carries a similar gear *B*. The frame *F* encircles the shaft *E* and has bearings carrying the bevel pinions *C*, *C*, which mesh with the gears *A* and *B*. The frame *F* has two locking devices, one of which locks it to the shaft *E* and causes both to revolve together; the other device locks it to the engine frame, holding it stationary while allowing the engine shaft to revolve.

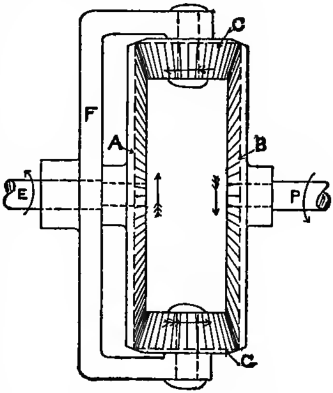


FIG. 98. — Diagram of Bevel-gear Reversing Gear.

Suppose now that the frame *F* is locked to the engine shaft and turning with it; the gears *A* and *C*, *C* are locked together rigidly, and drive the gear *B* in their own direction. The whole mechanism is thus locked together, and the shafts *E* and *P* turn in the same direction. This is the forward speed. If now the frame be released from the shaft *E* and locked to the engine bed so that it cannot turn, the gears *C*, *C* will be brought into action. If the shaft *E* and gear *A* continue to revolve in the direction as shown by the arrows, a little consideration will show that the gears *C*, *C* turn in the direction of their arrows, turning gear *B* and shaft *P* in the direction of its arrow, which is opposite to that of the shaft *E*. This is the reverse motion. If now the frame *F* is left free, the shaft *E* may turn and the gears *C*, *C* will roll idly upon the gear *B* without turning it and the shaft *P* remains stationary. The frame *F* also revolves idly with the gears *C*, *C*. This is the neutral gear which allows the engine to be started without turning the propeller. As the gears *A* and *B* are of the same size, the motion will be transmitted from one to the other by the gears *C*, *C* at the same rate; that is, the shaft *P* will always turn at the same rate as *E*, so that the reverse speed is the same as the forward speed.

A reversing gear using spur gears and pinions is shown in Fig. 99. On the end of the engine shaft *E* is the spur gear *A*, and on the end of the propeller shaft *P* is a similar but somewhat larger gear *B*. The case *G* encloses these gears and has bearings for the shafts *E* and *P*. A bearing on the side of the case *G* carries the pinion *D*, which is in mesh with the gear *A*. The pinion *C*, also carried by a bearing in the case, meshes with the pinion *D* and also with the gear *B*, thus forming a complete connection between gears *A* and *B*. As before, the case *G* is arranged to be either connected to revolve with shaft *A* or to remain stationary. Suppose now that the case is made to turn with the shaft *E*; this locks the gears inside of the case and drives *A* and *B* together, thus driving the propeller shaft in the same direction as the engine shaft. Suppose now that the case *G* is released from the shaft *E*, and locked to the engine frame so as not to turn. The inside gears then come into action, the gear *A* driving the pinions *D* and *C* and thus the gear *B* and the propeller shaft, but in a direction opposite to that of the shaft *A*. This may be followed out by referring to the arrows on the gears.

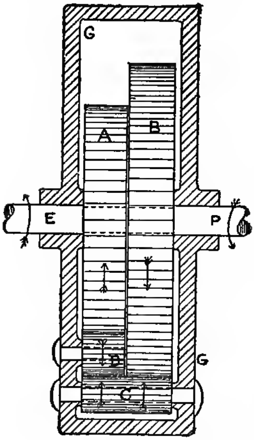


FIG. 99.—Diagram of Spur-gear Reversing Gear.

If the case *G* is left free, while the shaft *E* turns, the pinion *C* will simply roll around on the gear *B* without turning it, but revolving the case *G* slowly. The engine can thus run idle. While in the bevel gear mechanism both shafts always turn at the same rate, it is not so in this case, owing to the difference in size of the gears *A* and *B*. This difference is necessitated to accommodate the idle gear *D*. Since the gear *B* is larger than the gear *A*, it will not turn as fast, so that the speed of the propeller shaft when reversed will be considerably less than that of the engine.

In practice the reverse speed is about three-fourths the ahead speed. This difference is of little account in actual running, as it is seldom necessary to have extreme power in reversing.

In the actual gear the pinion *D* is placed to one side so that the gear *A* is relatively larger than shown.

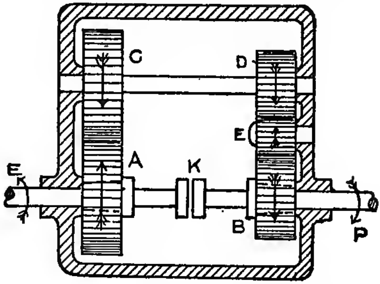


FIG. 100. — Diagram of Spur-gear Reversing Gear.

Another form of gear, shown in Fig. 100, requires the use of individual clutches. The engine shaft *E* is connected by an internal friction clutch with the gear *A*, and propeller shaft *P* with the gear *B* in a similar manner. At *K* is another clutch connecting shafts *E* and *P*. For forward gear the clutches to the gears *A* and *B* are disconnected and the clutch *K* is thrown in. For the reverse gear the clutch *K* is thrown out and those to gears *A* and *B* are connected, the driving taking place through the gears *A*, *C*, *D*, *E*, *B*.

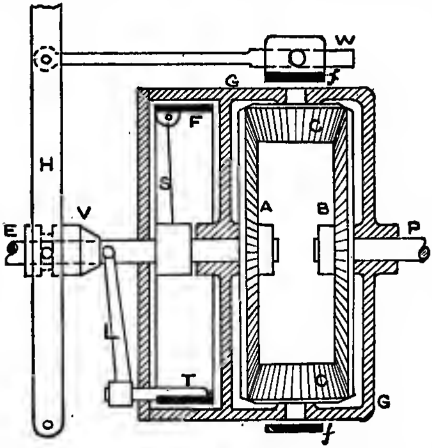


FIG. 101.— Bevel-gear Reversing Gear.

In Fig. 101 is shown a section of a reversing gear employing bevel gears. Inside of a prolongation of the case *G* is the internal friction band *F*, which is fastened to the arm *S*, which is in turn fastened to and driven by the engine shaft *E*. The band *F* is normally clear of the case, but by means of a tumbler *T* it may be expanded to grip the inside of the case and cause it to revolve with it. At *V* is a tapered collar, which slides on the shaft *E*. The lever *L*, on the end of which is the tumbler *T*, normally bears against the shaft, but as the collar *V* is moved to the left it rides up on the taper and thus turns the tumbler *T* and opens the friction *F*. Another friction band *f, f* encircles the drum and is secured to the frame of the engine. It also is normally clear of the drum, but may be drawn together by the wedge *W* so as to clasp the drum. The lever *L*, which is pivoted at the foot, is provided with a collar which fits into the groove in the sliding block *V*. The wedge *W* also has a rod attaching it to the lever *L*. The rods and levers are so adjusted that as the cut shows both friction bands are free, and the shaft *E* can revolve freely. If the lever *H* is moved to the right, the lever *L* is moved outward, turning the tumbler *T* and opening the friction *F* for ahead gear. If the lever *H* is moved to the left, the wedge *W* is drawn in, tightening the band *f, f* and causing the drum to remain stationary for reverse gear. The gears *A, B, C, C* are the same in action as already described in Fig. 98.

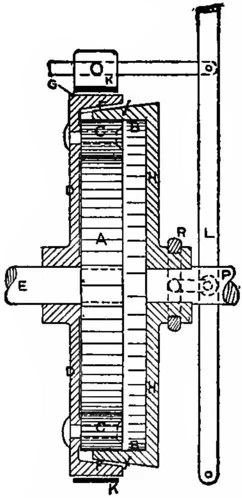


FIG. 102.— Spur-gear Reversing Gear.

In Fig. 102, is shown a spur-gear reverse similar in principle to that of Fig. 99, but using an internal gear and a cone friction. The engine shaft *E* carries the spur gear *A;* a shallow case *D*, which is free on the shaft *A*, carries the pinions *C, C*, of which there are several, to distribute the wear. The case has a conical friction surface *F* on the inside of the rim and a parallel friction surface on the outside. The propeller shaft *P* is fastened to a drum *H*, which on the outside of its rim has a conical friction surface *f, f*, and on the inside has an internal gear *B* which is in mesh with the pinions *C, C*. A ring *R*, fitting into the grooved collar and connected to the lever *L*, allows the shaft and drum to be moved in or out. The friction band *K* is tightened by a wedge, holding the drum stationary when desired. If the shaft *P* and the drum *H* are moved to the left, the conical frictions *F* and *f* will be brought into contact, locking the gear and driving both shafts together. If the band *K* be tightened, holding the drum *D* stationary, the gears will come into action and the shaft *P* will reverse. As shown in the sketch, both frictions are free and the engine turns idly. In this gear the entire propeller shaft and propeller must be moved in shifting the gear, which movement must be allowed for.

In another form of gear, shown in Fig. 103, the engine shaft *E* carries a sprocket and chain *C;* the drum *D* carries the gear *A* to which is attached the other sprocket. The propeller shaft carries the gear *B* which is similar to *A*. At *F F* is the go-ahead friction band as before, which is expanded by the levers *L* and conical sliding piece *G*. At *f*, *f* is the astern friction band which is tightened by a short lever and circular wedge at *W*. These are operated by the hand lever *H* as before. The gear as shown is in the neutral position. For ahead motion the lever *H* is moved to the left, throwing in the ahead friction, while for astern motion the lever *H* is moved to the left, throwing out the ahead friction and tightening the astern friction band.

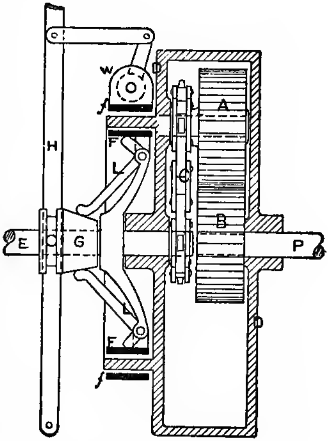


FIG. 103.— Reversing Gear, using Sprocket Chain.

A spur-gear clutch with a different form of friction is shown in Fig. 104. The case with the gears and the reversing friction are similar to those already described. For the go-ahead friction, however, a series of discs is used. These discs are fastened alternately to the shaft *E* and to the case. Those *D*, *D*, *D* fit on the squared part *S* of the shaft and therefore turn with it, while those *d*, *d* are held in place on the drum by the splines *T*, *T*, which fit into corresponding grooves in the discs. All the discs are free to move along the shaft. The small levers *L*, *L* bear against the outer disc *D* and the collar *K* on the shaft. By means of the conical sliding piece *V* the levers *L* are pressed outward, bearing against the disc *D* and pressing them all closely together. There is thus a friction surface over all of each disc, giving a very powerful and simple go-ahead friction. The reverse friction and the hand lever *H* operate the same as before. This form of friction is well suited to high powers, on account of its simplicity and the large surface. The number of discs is regulated according to the power to be transmitted.

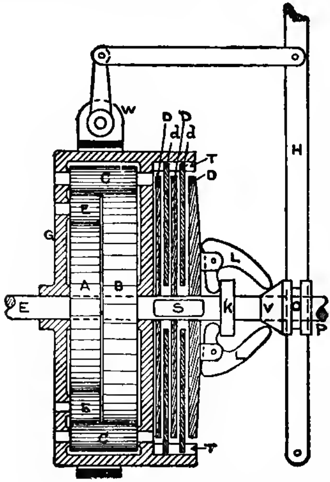


FIG. 104. — Spur-gear Reversing Gear, with Disc Clutch.

The principal requisites of any reversing gear are: The gears should be in mesh at all times to avoid the danger of stripping them when the power is thrown in suddenly. The gears should run in oil to reduce friction and wear. It must be so arranged that both frictions cannot be put in action together, which would damage the gear. The gears should be in action only in the reverse motion.

Reversing Engines. — As before stated, the majority of two-cycle engines will run equally well in either direction according as they are started. The engine may be reversed while in motion, as follows: the ignition current is broken and the engine allowed to slow down, the spark is retarded so as to take place well over on the up stroke. After the engine has slowed down sufficiently, the igniting current is again switched on, but at the moment when the piston is ascending. The resulting impulse prevents the piston reaching the top of its stroke and sends it down in the reverse direction. The spark is then returned to the proper running position, and the engine continues to run. While this can usually be done, it is not always to be depended upon, and is moreover a considerable strain on the crank shaft of the engine.

The engine shown in Fig. 90 has an automatic device for accomplishing this purpose. The lever *R* is pivoted on the rear face of the flywheel; on the front end of the base is a ring which is insulated from the base, but is connected by a wire with the timer contact. The timer contact is so arranged that when the spark is advanced or retarded to the utmost, the contact is broken by an insulated segment. While in rotation, the arm *R* is thrown out by centrifugal force in opposition to a spring. To reverse the engine it is only necessary to retard the spark as far as possible, thus breaking the circuit and allowing the engine to slow down. When it has slowed down to the proper point the spring draws the arm *R* inwards, until it finally bears on the insulated ring and remakes the circuit. This causes ignition to take place again, but as the spark has been retarded the ignition occurs on the up stroke, sending the piston down in the reverse direction. This device operates very satisfactorily and surely, as it allows the engine to slow down to the proper speed before reversing, and thus also lessens the strain on the parts.

Four-cycle engines are made reversible by fitting a double set of cams, either set of which may be brought into action by shifting the cam shaft in its bearings, or similar means. In some Diesel engines two cam shafts are used, either of which may be brought into use.

CHAPTER XI

Propellers

Of the many problems which the marine engineer or launch builder has to deal with, the question of propellers is one of the most difficult and in some respects the least satisfactory. The conditions are so varied that calculations are difficult and not always satisfactory. The size and pitch of a propeller for any given purpose are very largely determined by experiment and from experience with other propellers.

The principal characteristics and definitions regarding the propeller are as follows:

Diameter. — The diameter is the diameter of the circle described by the tips of the blades.

Pitch. — The pitch is the distance which the propeller would advance in one complete turn, considering it to be a portion of a screw turning in a solid medium.

Pitch Ratio. — This is the ratio of the pitch to the diameter and is obtained by dividing the pitch by the diameter. Thus if a 24-inch wheel has a pitch of 30 inches, the pitch ratio is $30 \div 24 = 1.25$.

Disc Area. — This is the area of the circle swept by the tips of the blades; thus the 24-inch propeller above will have a disc area of $\frac{1}{4} \times 24 \times 24 \times \frac{22}{7} = 452$ square inches.

Expanded Blade Area is the actual area of the faces of the blades.

Surface Ratio. — The surface ratio is the ratio of the blade area to the disc area, and is obtained by dividing the blade area in square inches by the disc area, also in square inches. If the blade area of the 24-inch propeller were 150 square inches the surface ratio would be $150 \div 452 = .33$.

Slip. — The slip is the difference between the distance which the propeller actually advances per revolution and the distance which it would advance if it were turning in a solid medium. For example, if the pitch of a propeller is 30 inches, but it only advances 24 inches per turn, the slip is 30 − 24 = 6 inches per turn, or in per cent, as it is usually figured, 6 ÷ 30 = 20 per cent. As a further example, suppose a propeller of 30-inch pitch, turning 300 turns per minute, drives a boat at 6 miles per hour. The nominal advance of the propeller would be $\frac{30}{12} \times 300 = 750$ feet per minute. The advance of the boat in feet per minute is $\frac{6 \times 5280}{60} = 528$. The slip is then $750 - 528 = 222$ feet per minute; or, as a percentage, $\frac{222}{750} = 29.6$ per cent.

A right-hand propeller is one which when looked at from astern revolves right-handed, or in the direction of the hands of a clock. A left-hand propeller is the reverse. Propellers are usually built right-handed unless for special conditions.

The most important characteristic from the power standpoint is the blade area. A square inch of blade area will absorb a certain amount of power at each rate of revolution. A certain blade area may be obtained by a relatively wide blade on a small diameter or by a narrow blade on a relatively large diameter. In the former case the surface ratio is greater than in the latter. There are certain limits for this surface ratio beyond which it is not advisable to go; well-proportioned propellers will have surface ratios somewhere among the following:

For two blades, surface ratio, .20 to .25.
For three blades, surface ratio, .30 to .40.
For four blades, surface ratio, .35 to .45.

This means that for the 24-inch wheel having three blades, disc area 452 square inches will have a blade area varying between $452 \times .30 = 136$ square inches, and $452 \times .40 = 181$ square inches, depending upon the power to be absorbed by it. The blade area should not be made greater than these proportions for ordinary use, as the blades then become so wide as to interfere with the action of one another. There are, of course, certain unusual conditions which may require extreme proportions and a resulting loss in economy of propulsion may be accepted.

In general terms the blade area fixes the amount of power which the propeller can deliver, while the pitch, combined with the turns per minute, governs the speed. The two are, however, very intimately connected, and a change in one is likely to have an effect upon the other. To illustrate, a propeller may have a small blade area and so great a pitch that the blades act like fans and simply churn the water; this propeller will absorb the power but does little effective work. While the power of the engine is used up, but little effort is exerted in propelling the boat. This propeller would be improved by decreasing the pitch to a reasonable amount and adding blade surface to absorb the power.

The other extreme is illustrated by a propeller of large blade area and very small pitch, so that the blades are almost flat; in this case the blades tend simply to revolve edgewise through the water and the power is absorbed by surface friction. The engine turns at a high rate but has little effect on the motion of the boat. This propeller will be improved by increasing the pitch and reducing the blade area.

Either too large a blade area or too coarse a pitch will tend to slow the engine down below its proper rate of revolution and thus prevent the development of the required power. On the other hand, either too small a blade area or too fine a pitch will allow the engine to run away or "race" without benefit to the speed of the boat.

If the blade area is correct for the power of the engine, the pitch will, within certain limits, take care of itself. This explains why many engine builders can furnish a certain propeller wheel with each engine regardless of the conditions under which it is to be used. The same propeller will usually be furnished for all circumstances, whether for a heavy working boat which can only be driven at a low speed, or for a light launch, and it will appear to work equally well in both cases. This is due to the difference in the slip; in the first case the wheel is working with a large slip and in the latter case with a small slip, but with fair efficiency in each case.

While it might seem that a perfect propeller would work without slip, such is not the case, as, since the forward thrust is obtained by the forcing back of the stream of water, some slip is necessary. The amount of slip is not necessarily a measure of the efficiency of the propeller. A propeller may work efficiently at a high slip, but the revolutions of the engine are unnecessarily high, perhaps beyond the point of efficient working of the engine. The average slip for a good working propeller may be taken at from 15 to 20 per cent. A slip of 30 per cent or above will usually indicate that a different propeller would probably give better results.

The shape of the after end of the hull has a marked effect upon the slip and efficiency of the propeller; a very full stern will impede the flow of water to the propeller and thus reduce its efficiency. For this condition a propeller of large diameter should be used, with narrow blades which will reach out into the less disturbed water.

Efficiency of Propellers. — The propeller does not utilize in the propulsion of the boat all the power which is delivered to it by the shaft. There are several ways in which power is lost, the most important of which are skin friction and eddy making. The efficiency of the propeller may be defined as the proportion of the power given to it which it uses effectively in propelling the boat. Expressed as a percentage, the usual efficiency of a propeller is between 50 per cent and 70 per cent; that is, for every 10 H.P. delivered to it, from 5 to 7 H.P. is actually used in driving the boat.

There are several causes affecting the efficiency of the propeller which can be taken advantage of, viz.: The surface of the blades should be ground smooth and even, to reduce surface friction as far as possible. The thickness of the blades should be no greater than is required for strength, and the edges should be sharp and even. At unduly high speeds of rotation the water is forced back by the propeller faster than is possible for a continuous flow, and a partial vacuum is formed under the stern, drawing it down and retarding the speed. The pitch and surface must be suited to the power and speed, to avoid excessive slip. The form of the under-water body should be such as to give a free access of water to the screw to replace that which has been forced back. The propeller should be kept as far as is convenient from stern post or deadwood, and should have an immersion of its upper tip of at least a quarter of the diameter, in order to avoid the churning up of the surface.

Measuring Propellers. — To measure the blade area of a propeller a center line is drawn down the middle of the face of the blade, from hub to tip. The length of the blade along this center line is then divided into several equal parts, and lines drawn across the blade as shown in Fig. 105. The width of the blade on each of these lines is then measured, including the tip. These widths are all added together and the average taken; this average is then multiplied by the length of the blade. This gives the area of one blade, which must be multiplied by the number of blades.

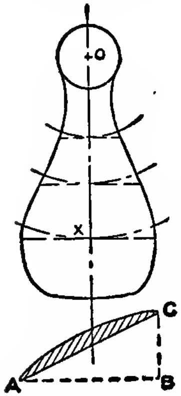


FIG. 105.—Measuring Propeller.

To measure the pitch, the propeller is laid upon a flat surface with the shaft exactly vertical. The pitch at any point X may be found as shown in the lower sketch; AC is the width across the blade; CB is a vertical line at one edge and AB is the width projected on to a horizontal line. By considering the sketch it will be seen that in turning the distance AB the advance is an amount equal to BC. Now the circumference of a circle through X is equal to $OX \times 2 \times \frac{22}{7}$, and since the pitch is the advance for one turn, the pitch will bear the same relation to the distance BC that the circumference of the circle bears to AB or

$$\text{Pitch}: \; BC = \text{Circumference}: AB \text{ or}$$

$$\text{Pitch} = \frac{BC \times \text{Circumference}}{AB}$$

In many propellers the pitch may vary at different points along the blade, in which case the average pitch may be taken.

CHAPTER XII

Installation

Foundation. — Before the motor can be installed in the boat some suitable bed or foundation must be provided. It may be built in any one of several ways according to the form of the boat and the shape of the engine base. The simplest form of bed, and one which is used often for single-cylinder engines, is made simply of two planks placed on edge athwartships and so shaped as to fit the contour of the inside of the hull. They are firmly fastened in place and the engine rests across them with the flywheel overhanging and parallel with the forward one. The engine is held in place by lag screws through the holes in the flanges. This bed will answer the purpose in a heavy boat where heavy bearers can be used, but in a boat of moderate weight the strain is not properly distributed, but is concentrated in one spot, which is likely to cause trouble.

The most approved form of bed consists of a pair of fore and aft bearers extending under the flanges on either side of the engine base and resting in turn upon several cross timbers or floors. In light boats the cross timbers may be dispensed with and the bearers may rest upon and be fitted to the plank and frames. A bed of this type is shown in Fig. 106, the cross timbers or floors being shown at *F*, *F*, *F* and the fore and aft bearers at *B*. The bearers *B* are notched down over the floors *F* to give additional stiffness and are fastened by long bolts driven down through from the top. The cross-braces *C* are fitted, where possible, to give transverse stiffness; they must, of course, be fitted where they will be clear of the projecting under part of the base. In this style of bed the strain and vibration of the engine are distributed over a considerable length of the boat so that they are less marked.

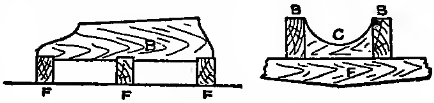


Fig. 106.— Engine Bed.

One of the most difficult points in installing the engine is in so setting it that its shaft is in line with the propeller shaft so that everything may turn freely without straining. In the first place the foundation must be built to the proper height and angle. A cord or thin wire is passed through the shaft hole, stretched tightly and adjusted so that it is as near as possible in the center of the hole and also in the center line of the boat. It is then fastened in place, the forward end being secured to an upright well forward of the proposed bed. This line then represents the center of the shaft. The distance *D* of the flanges of the bed, above or below the shaft center, is then measured from the engine, and also the widths *w* and *W*, as shown in Fig. 107. The bed is then built with its upper edge parallel with the cord or wire and at the distance *D* above or below as the case may be. The inside measurement *w* on the bed should be slightly greater,

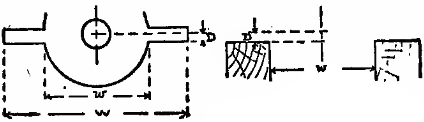


FIG. 107. — Base Measurements.

about $\frac{1}{2}$ inch, than the engine base, to allow some leeway for adjustment in setting. If the bed is carefully laid out and true to the measurements, little trouble will be found in getting a good alignment of engine and shaft.

The engine may now be set into place on the bed, and the propeller shaft put in position. It is in coupling the propeller shaft to the engine that care is required to obtain the true line between the two shafts; if this line is not correct, not only is an undue amount of friction developed, but the parts are subjected to a continued strain. If flange couplings are used they may be of great help in obtaining the alignment. The two parts of the coupling are brought nearly together, within about $\frac{1}{16}$ inch, as in Fig. 108. The space between the faces, as *S*, *S*, is now tried at points all around the circumference by inserting a thin steel wedge or case knife and noting the distances which it enters. By shifting the engine slightly on the bed this distance may be made equal all around the circumference so that the wedge or knife will always enter the same distance. This adjustment may take a little time and it may even be necessary to remove the engine and trim the bed somewhat; it is, however, necessary that it be true. When the adjustment is satisfactory the coupling bolts should be put into place, but without drawing the two parts together; the engine should now be given half a turn and the spacing between the flanges tried again. If it remains true the flanges may be brought together and the bolts tightened up. The whole should now turn over with very little more friction than the engine alone.

If a sleeve coupling is used as in Fig. 11, the method must be less direct. The shaft should be tried in the coupling before the engine is placed in the boat to make sure that it fits. After the engine has been put on board, the shaft is inserted into the coupling and oscillated a few times with a gentle end pressure. If the shaft and coupling are not in line the sharp edge of the latter will leave marks on the smooth shaft, and by their position one can judge what change must be made in the alignment.

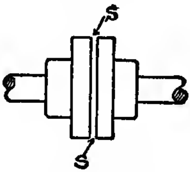


FIG. 108.—Lining-up Coupling.

The engine is held in place by lag screws. Care must be taken in boring for them to bore directly in the center of the hole in the base, as otherwise there is a chance of throwing out the alignment when screwing down the lag screws. The base also must bear evenly on the bed with no spaces between the two. Any space between them should be filled with thin wood shims lightly driven in just before the lag screws are finally set up. When everything is finally set into place the alignment should again be tried by turning the engine over several times to make sure that there is no undue friction.

Piping for Exhaust.—This is the largest pipe in the outfit and would best be fitted first. It should be run of pipe the same size as the exhaust fitting on the engine and should be as direct and with as few bends as possible. In a two-cycle engine especially, the power developed may be considerably reduced by any undue resistance in the exhaust. When bends must be used they should, if possible, be made from 45-degree instead of 90-degree ells, as the resistance of the former is much less than of the latter.

The muffler may be placed wherever convenient, a common location being under the after deck with the outlet leading outboard above the water line. The exhaust pipe should run to the muffler as directly as possible; a union should be fitted where the exhaust pipe joins the engine and another where it connects to the muffler, this allowing the exhaust piping to be readily taken down. Galvanized iron piping and fittings should be used for the exhaust pipe. When the engine is near the middle of the length of the boat the exhaust piping may be run along under the floor or inside the lockered seats. A very good practice is to lead the exhaust pipe out through the bottom of the boat by a special fitting, along the bottom to a point near the stern, where it again enters the boat by another special fitting and connects with the muffler, which leads outboard as before. This method avoids the loss of space and the heat of the exhaust pipe, which in the case of a cabin boat is a considerable item. The water surrounding the pipe quickly cools the exhaust, reducing the pressure and making the final exhaust almost noiseless. When it is desired to have the outlet from the muffler below the surface of the water, a pipe shaped like an inverted U should lead from the muffler as high as the deck will allow before leading outboard; this is to prevent the entrance of water into the muffler when the boat is in a heavy sea. Joints in the exhaust pipe should be smeared with a mixture of graphite and oil before screwing up.

Function of the Muffler. — The function of the muffler is to provide a comparatively large space into which the exhaust may pass and expand, thereby reducing the pressure and deadening the sharp impulses. The gas under the much reduced pressure then passes out into the air with little disturbance. No particular shape is essential, the volume being the only requirement. Mufflers for small engines are usually made of cast iron, while for the larger sizes they are of sheet metal riveted together. In some cases the exhaust pipe itself may be enlarged to serve as a muffler.

Many special forms of muffler have been devised, in which, by a suitable arrangement of plates and orifices, a suction effect is obtained, which tends to draw the exhaust gases toward the muffler and thus lessen the back pressure. In other forms the same effect is obtained by introducing the cooling water into the muffler in such a way as to quickly cool the exhaust gases and greatly reduce the pressure.

Under Water Exhaust. — It is often possible to carry the exhaust directly outboard just below the surface of the water, thus saving nearly all exhaust piping and completely deadening the noise of the exhaust. While this is a very convenient way of disposing of the exhaust, and is many times satisfactory, great care must be taken in fitting it, or poor results will be obtained. When the exhaust is led directly outboard a certain pressure is required to displace the water; this pressure is furnished by the exhaust and is a back pressure, acting to retard the piston, reducing the power of the engine. Some form of shield must be fitted over the opening of the exhaust pipe to direct the stream of the exhaust aft and thus reduce the back pressure. Several devices of this kind are on the market, most of which consist of a brass casting bolting on the outside of the hull, and having a threaded stem projecting inside the boat, to which the exhaust pipe is connected. It is often possible to use a right-angle elbow for this purpose, screwing it on so that the outlet leads aft; and fitting a washer and packing between it and the planking. Some form of expansion chamber or small muffler must be provided between the engine and the outlet to break up the violent pulsations and make the outward flow fairly constant. A pet-cock, or other opening, should be provided in the exhaust pipe, which may be opened when the engine is at rest, to prevent the water being drawn up by any partial vacuum which might arise. As there is sometimes difficulty in starting an engine with the under-water exhaust, it is well to fit a cock or valve some size, so that it may be used as an outlet while starting the engine.

Cooling Water Piping. — This system of piping should next be fitted; it should be of brass and of the same size as the fittings on pump and engine. The suction to the pump is connected to a pipe extending through the bottom of the boat at some convenient point. The joint at the planking must of course be water-tight; special fittings should be used for this purpose, having some provision for fitting packing water-tight at the plank, and an inside stem for the attachment of the piping. This is one of the fittings which are provided with every engine outfit. This pipe may be made up solid if desired, but it is considered good practice to fit a short length of stout rubber hose at some convenient point to take up any vibration and prevent the starting of the joint at the plank. The outer end of the pipe must be covered with some kind of strainer to prevent the entrance of weeds or other material which would clog the pump. If desired, a branch suction pipe may be run to the lowest point inside the boat, allowing the boat to be drained by the pump while the engine is running. When this is done a valve should be placed in each branch so that the pump may draw from either as desired. Both valves should be closed when the boat is put up, to prevent the water from backing up through the two suctions and flooding the boat. It is considered by some not to be good practice to run the water from the bilge through the jackets on account of the liability of depositing slime and oil in the passages of the jackets. If, however, a strainer is fitted on the end of the suction, and care is taken to use it only at the beginning of a run, no objection can be made to this method of piping.

The piping from the pump discharge to the cylinders is usually fitted up when the engine is assembled, or in many cases the pump discharges directly into the cylinder as in Fig. 11.

The overflow from the cylinders is piped directly overboard in a convenient place. It is good practice to branch this overflow pipe, leading the second branch to an opening in the exhaust pipe, so that a part of the cooling water passes directly into the exhaust pipe and mingles with the exhaust gases. The presence of the cooling water in the exhaust cools the latter very materially, reducing the noise of the exhaust and rendering the pipe itself cooler. All of the cooling water can hardly be run into the exhaust as the cooling effect might be too great; for this reason a valve should be fitted in each branch so that any desired amount may be run into the exhaust. The point where the cooling water pipe enters the exhaust pipe should, if possible, be at a level lower than the exhaust from the engine, to avoid any possibility of water being drawn back into the cylinders. The cooling water should not be run into the exhaust until the pipe has become well heated, as otherwise the water might not be carried out, but might collect at some point and cause trouble. A pet- or drain-cock should be placed at the lowest point of the exhaust pipe to drain off any collection of water which may condense.

Joints in the water piping should be smeared with white or red lead before setting up.

Carbureter and Fuel Piping. — The piping of the carbureter to the engine should be fitted when the engine is assembled. The inlet to the carbureter or vaporizer should be screened so that any spray or rainwater cannot be sucked in with the air, thus spoiling the mixture. When possible, warm air should be delivered to the carbureter, by running a pipe from the air inlet to a point between the cylinders, or to a perforated jacket around the exhaust pipe. Many carbureters, and vaporizers are provided with a threaded air inlet, making this piping an easy matter. Where the end is plain, it can many times be tapped out, or the pipe may be clamped on. For this air pipe, a sheet metal pipe is amply strong. The furnishing of warm air to the carbureter is much to be recommended, as, since the temperature of the incoming air is always nearly the same, the mixture is less affected by atmospheric changes and the engine runs more regularly. When the drawing of warm air is not provided for, the proportions of the mixture will change with each change of atmospheric conditions, requiring slight adjustments of the air and fuel supplies from time to time.

Even if it is not feasible to supply warm air to the vaporizer, it is advisable to so pipe the air supply as to draw it from a dry place, as from a locker. Care must, however, be taken to fit a screen over the end of the pipe and otherwise prevent light articles like cotton waste from being sucked into the pipe to cause trouble.

The fuel tank and piping must be made and fitted with the greatest care, as any leak may have fatal consequences. Too much stress can hardly be laid on this point, as nearly all accidents can be traced to a leak in the fuel tank or piping, combined with more or less carelessness.

The tank should be of strong construction, of either copper or galvanized iron, well riveted and then soldered, with suitable swash plates if the tank is of large size. When convenient to use, the round, cylindrical form of tank is best as it has the fewest joints and is the strongest shape. The filling pipe should extend from the tank to above the deck with no break, so that any overflow while filling the tank will run overboard instead of into the boat. A screw cap should be fitted to the filling pipe above the deck. A small vent hole should be fitted at some convenient point to admit the air as the fuel is drained out.

Some builders and designers favor the fitting of pans or other arrangements under the fuel tank to catch and carry off any possible leakage, but in the writer's opinion it is as well to make sure that all joints are absolutely tight at the start and by constant observation assure that they stay so.

The fuel piping should be either of copper, brass, or lead, and should have as few joints as possible, and these, except a union at each end, should be soldered. A stop-cock should be fitted to the fuel tank and another where the piping joins the engine; this allows the overhauling of either the carbureter or the pipe without draining the tank. Some form of strainer should be fitted in the fuel pipe near the carbureter to catch any sediment or other foreign matter which would clog the carbureter. A device of this kind is shown in Fig. 109, it consists of a fitting containing a screen *G* of wire gauze through which the fuel must pass. The bottom can be unscrewed and any collection removed. The same effect can be had by the fitting shown in Fig. 110.

FIGS. 109–110.—Fuel Strainers.

The fuel pipe is joined to the carbureter by a Tee fitting, one branch of which points downwards; into this branch is screwed a piece of pipe a few inches long, and one or two sizes larger than the fuel pipe. Sediment or water, being heavier than the fuel, will settle down into the vertical pipe and may be removed by unscrewing the cap.

The fuel tank may be placed wherever most convenient, provided that the outlet is always a few inches above the carbureter to assure a flow. A common place is at the bow, as the space there is usually the least valuable. Under the seats in the standing room is also a convenient position. If a water-tight standing room is fitted any possible leakage will thus drain overboard. The tank should, of course, be kept as far as possible from hot pipes or the muffler.

This completes the usual piping; additional piping may be fitted in some cases to carry out some particular idea, or for some special make of engine. Many engine builders furnish piping plans to accompany the engine, and many others will furnish them if requested.

In all piping and wiring care should be taken to make all connections as simple and direct as possible, so that in the case of trouble or repairs it can be easily and quickly gotten at. Unions should be used in such positions that piping may be removed without breaking any threaded joints. When piping runs through lockers or other woodwork it should be so arranged that it can be taken down without disturbing the woodwork.

Batteries, Coils, and Wiring. — All parts of the ignition outfit should be placed in a dry place, as moisture greatly interferes with their action or may in time ruin them entirely. Dry batteries especially should be kept with great care, as moisture will run them down very quickly. In a cabin boat the batteries should be placed in a locker well above any moisture from the bilge water. In an open boat, the batteries should be packed into a box with paper stuffed in around them and the whole kept as dry as possible. For small boat work a very satisfactory arrangement is to fit batteries and jump-spark coil into one box with a cover. Connections are made inside the box to binding posts on the outside so that connections can be readily made. This box may be kept on shore when not in use so that all may be kept dry and in good order. In this way the life of the batteries may be greatly prolonged and the reliability much increased. It is often advised to seal up the batteries in a box or cover them completely with tar or pitch, with the object of rendering them waterproof. This is not always to be advised, as a single poor cell in a set will spoil the action of all and it is best to have them accessible so that in case of trouble they can be tested and the poor ones replaced.

From four to six batteries should be used in a set. If too few batteries are used the current and the resulting spark will be weak; on the other hand, if too many are used, the contact points on the coil are apt to suffer. As a rule six batteries may be used in a set without fear of damage, and these will give sufficient current to make the ignition fairly sure and allow of some deterioration in the batteries without replacing.

If a magneto is fitted, it may be placed on the floor and run by a friction wheel against the flywheel, or by a belt. When it can be done, it is preferable to arrange brackets from the engine frame to support the magneto; as it may then be placed clear of the floor where it is less liable to damage.

A convenient tool and supply locker, with a lock, should be arranged. Too often small tools or parts are thrown loosely into a locker, to be lost or ruined by water. The locker should be convenient of access and in such a position as to prevent the access of water. This locker is a point to which too little attention is usually given.

It is, of course, impossible to enumerate all points in connection with the installation of all the varied types of engines under the varying conditions, but the general principles remain the same with only the differing details of each individual installation.

CHAPTER XIII

Operation and Care of Engines

Starting. — Before attempting to start an engine one should acquaint himself with the operation of all parts of the engine, and the water, oiling, and ignition systems.

If the engine has been standing some time, the ignition system should be tested to make sure that it is in good order. The make-and-break system may be tested by first closing the switch in the circuit, then turning the flywheel until, by observing the action of the mechanism, the points inside the cylinder are known to be in contact, closing the circuit. The wire is then removed from the insulated terminal of the igniter and brushed across it; if the circuit is complete a brilliant spark will result. If no spark is obtained all connections must be examined and, if necessary, the sparking points removed from the cylinder and cleaned. After a spark has been obtained through one cylinder the other cylinders should be tested.

The jump-spark system is tested by removing the plug from the cylinder and resting it upon any of the bright metal parts of the engine with the secondary wire still in contact. With the primary circuit closed the engine is then turned until contact is made by the timer, which should be indicated by the buzz of the vibrator. The sparks should pass across the points of the plug at the same time. If no buzz of the vibrator occurs it shows a defect in the primary circuit. If the vibrator buzzes, but no spark passes the sparking points, it shows a fault in the secondary circuit. This may often be remedied by removing any deposit of carbon or oil which may have collected on the points of the plug, or by fitting another plug. After a rain, or in damp weather, the most common sources of ignition troubles are weak batteries or a "ground." The former can be found by testing the batteries with an ammeter; the latter is caused by the current, especially the secondary, jumping across from the wire to some adjacent pipe or other part. It may be found by carefully examining the wires, or, in the case of the secondary current, the sparks may be seen to pass where the current jumps. The wiring of each cylinder should be tested in turn. At the same time that the ignition is tested, the point of ignition should be noted in reference to some point on the flywheel, and its variation with the different positions of the timer handle noted. The gear or timer should be so set that the spark occurs when the piston is at the top of its stroke.

Oil- and grease-cups should now be filled and a small amount fed from each.

The fuel supply should now be turned on, both at the tank and at the carbureter. The needle valve on the carbureter or vaporizer should be opened slightly and the carbureter primed somewhat to make sure of a good flow of fuel. The engine may now be turned over by hand in the direction in which it is to run, using the crank, lever, or flywheel rim, as the case may be. After a few trials the engine should explode a charge and turn a few turns and possibly continue to run. If it does continue to run, the fuel and air supplies should be adjusted gradually until the engine turns at its highest speed. Oil-cups should then be opened to allow the oil to feed.

If, in the case of a four-cycle engine, it does not start at once, all that is necessary is to turn it under varying conditions of fuel and air supplies, after making sure that the ignition system is operating and that fuel is flowing to the carbureter. In the case of a two-cycle engine the fuel should be shut off and the compression cock opened. It is probable that several charges of gasoline have been taken into the base and not exploded; making the mixture far too rich and "flooding" the engine, as it is termed. The flywheel is now turned several times and the mixture diluted and partially expelled. An explosion will finally take place and the engine run until the supply in the base has been used up.

Another trial can now be made, with a reduced fuel supply, and continued under the varying conditions until the engine starts, always making sure that the ignition occurs properly, and taking care not to flood the base.

Starting is often made easier by priming the engine, that is, by inserting a small amount of gasoline directly into the cylinder through the compression cock, or through a special priming cock which on some engines is provided for that purpose.

When turning the engine over by hand care must be taken to have the sparking gear so set that the spark cannot occur until the piston has reached the top of its stroke. If this is not done and ignition takes place before the piston has reached the top of its stroke, it will be driven violently downward in the wrong direction, giving a "back kick," which is liable to cause damage.

After the engine has run a short time it will often gradually slow down and finally stop, with a muffled explosion in the base. This is a sign of a weak mixture, and the fuel supply should be slightly increased. On the other hand, if the engine labors, slows down, and finally stops, with black smoke issuing from the exhaust, it shows a too rich mixture and the fuel supply should be cut down.

The best fuel mixture can be found only by experiment, and will even then vary somewhat, according to atmospheric conditions. The proper regulation of the air supply to the fuel supply has a marked influence upon the fuel economy.

Two-cycle engines of the two-port type are easily and readily started as follows: The spark is advanced to a point somewhat below the usual running point so that the ignition will take place on the up stroke when the engine is turned in the opposite direction to which it runs. The flywheel is then turned until the piston is at the bottom of its stroke, and is then rocked backwards and forwards a few times; the piston thus acts as a pump, drawing a few small charges into the base and charging the cylinder. The flywheel is then turned quickly in the reverse direction to which it runs, bringing the piston up against the charge, which finally ignites and forces the piston down again, but in the right direction. The flywheel is then released and the engine starts. The spark is then restored to the running position.

This method cannot be used on a three-port engine, which must be started by turning it over the center.

Some engines will start with the compression cocks fully or partly open, which lessens the labor; others must be pulled over against the full compression.

In starting the engine with a crank or lever it should be held loosely in the hand, so as to be quickly released in the event of a back kick. Frequent accidents happen from the disregard of this precaution.

Oiling. — When the engine is well started the fuel and air supplies should be regulated until the engine is running on the least possible amount of fuel. The oil supply should be regulated to a point just below that at which smoke would issue from the muffler. Blue smoke coming from the muffler usually shows that too much oil is being fed, which instead of being of use in the engine is burned or carried away by the exhaust, and wasted.

The cylinder oil-cups should be adjusted to feed from three to six drops per minute, according to the size of the engine. Where splash lubrication is used, oil must be fed into the crank case or base at intervals. Exterior parts, such as thrust bearing, igniter gear, and pump journals, are, of course, oiled from an oil can when necessary. In running a new engine oil should be used rather freely at first while the bearings are wearing down into place. The cylinder surface may be greatly improved by feeding in some powdered graphite mixed in oil, which fills up the pores and helps to form a sort of scale on the bore of the cylinder. While too much oil should not be fed, as it is not only wasted, but makes the engine dirty, a sufficient lubrication should be made certain at all times, as much damage may be done in a short time if bearings are allowed to go dry.

Under some circumstances good results can be obtained by mixing the lubricating oil with the gasoline in the tank and feeding both together. No difficulty is experienced with the vaporization and the lubrication is simplified. Although the relative amounts will vary considerably, a fair proportion seems to be about one pint of oil for every five gallons of gasoline.

Spark Advance. — While running the engine it will soon be noted that the time of ignition has a great effect on the speed. It will be found that the engine runs best when the ignition takes place just before the piston reaches the top of its stroke. This is due to the fact that the burning of the charge is not instantaneous, but requires an appreciable time. If the charge is fired at the moment when the piston is at the top of the stroke, the time taken by the charge to thoroughly ignite allows the piston to descend through a part of the down stroke, so that some of the effect of the impulse is lost. If the spark is so timed in advance that the charge is completely ignited at the time when the piston is just ready to descend, the full effect of the impulse is received and absorbed.

This advance of the spark is called the "spark advance" or "lead." It will of course vary somewhat according to the speed. The speed of the engine can be varied by shifting the point of ignition, and this is advocated by many. Starting with the spark occurring as the piston is at the top, it will be found that up to a certain point the speed will increase as the spark is advanced. Beyond this point the engine will pound and act irregularly. If the spark is retarded until after the piston has begun to descend, the speed will decrease. The speed of the engine may thus be regulated by changing the spark advance, but this practice is not to be recommended, as nearly the same amount of fuel is passed through the engine per stroke at all speeds. At low speeds the charge ignites so slowly that all the heat generated cannot be absorbed, but is passed along into the exhaust pipe and muffler, heating them beyond their usual temperature. The speed of the engine should be regulated by the throttle which is usually provided for that purpose; in this way the amount of the mixture is cut down in proportion with the speed. The speed should be regulated by the throttle and then the spark advanced to the best point by trial. In this way the greatest economy in the use of fuel may be obtained. Extremely slow speed must, however, be obtained by retarding the spark, in connection with the throttle.

Care of the Engine. — The degree of care which the engine receives, not only when running, but when laid up as well, has a great effect upon its life and also its satisfactory operation. Many engines which are well taken care of while in operation are allowed to suffer from exposure during the time when they are not in use. If the engine is in a cabin boat it is very easily kept in good shape, but if in an open boat, constant care is required to prevent it from being damaged by rust. A cover should be made from waterproof canvas, which will fit snugly over the engine and shed all rain. A water-tight pan under the flywheel will prevent the bilge water from rising around it and causing it to rust. Before leaving the engine for a few days all bright parts of iron or steel should be smeared lightly with grease, which may be readily removed with cotton waste. This precaution will save a large amount of scouring and polishing later.

One should become thoroughly familiar with the construction of his engine as soon as possible. It is not meant by this that the engine should be pulled down just to see how it is constructed, but quite the contrary. As long as the engine is running, particular pains should be taken not to disturb it. The construction should, however, be studied so that in case of necessity it could be taken down. Much expense can often be saved by this knowledge, as there are many small repairs which can easily be made by the amateur owner.

Before starting on a run all nuts and bolts should be examined, and any which may be loose should be tightened.

Engine Troubles. — The presence of trouble in the engine is usually indicated by a peculiar hammering noise, known as a "knock." It may be caused by excessive friction on some part and the oiling system should be at once examined and perhaps an additional amount fed for a few moments. A similar knock may be caused by the failure of the water-circulating pump, which may be told by the unusual amount of heat radiated from the cylinders. The lack of cooling water causes the cylinders to become much too hot for use, increasing the friction and eventually causing damage to cylinders and pistons. If the knock cannot be found in this way, the engine should at once be stopped, as damage may be caused. The knock is probably caused by some part which has become loosened, and all parts should be thoroughly examined. A loose flywheel is a common cause of knocking. Where the flywheel is fastened with a key as in Fig. 10, the keyway may become worn so as to leave a small space between it and the sides of the key, allowing the flywheel to "play" slightly around the shaft. If this is the case the key should be withdrawn and a slightly wider one fitted, or a thin "shim" of steel may be carefully fitted into the keyway and the key driven in alongside of it.

A bearing which has become overheated and ground out will cause a knock; this is a more difficult cause to remedy, and is likely to require the services of a machinist to reset the bearing.

Sometimes the engine will run with apparently no trouble, and yet will show less than the usual power. This may be due to loss of compression, or in other words, a leakage from the compression space. This may be due to a loose plug or screw at some point, or in the case where the cylinder head is fastened on with studs, it may mean that the gasket under the head has become broken at some point and it may be remedied by fitting a new gasket. If the cylinder has been flooded too freely with oil, the excess may carbonize and collect around the piston rings, cementing them to the piston and allowing the gas to escape by the piston. This may often be remedied by flushing the cylinder with kerosene oil. It may often be necessary to remove the cylinder and separate the rings from the piston. In removing the rings from the piston great care is necessary as they are of cast iron and very brittle. Before attempting to remove them they should be well washed with kerosene, to loosen them as far as possible. In removing a ring, one corner should first be raised with a screw-driver or other tool, and a narrow strip of tin placed across the groove under it to keep it from springing back; this is followed up all around the ring, tapping it lightly and adding more strips until the ring is entirely supported clear of the groove. It may then be slid from the piston. Rings and grooves should be thoroughly cleaned with the help of kerosene. In replacing the rings the reverse operation is followed.

In the four-cycle engine it is necessary to "grind in" the valves at intervals when the seats and surfaces become pitted or worn. When the valves are arranged as in Fig. 24, the inlet valve may be removed to allow access to the exhaust valve. The springs are removed from the stems, the valve is raised and the bevelled edge smeared with a paste of oil and emery. The grinding is done by rotating the valve in its seat by means of a screw-driver or brace; and the process continued until the surfaces are left smooth and polished, with no sign of corrosion. This paste is then removed and the finish put on with a mixture of water and pumice. During the grinding the entrance to the cylinder should be carefully stopped with a wad of waste to exclude the emery from the cylinder, where it would do great damage. If the inlet valve is removable it may be ground while held in the hand.

In replacing the valves it may often be found difficult to compress the springs sufficiently to allow them to be replaced. If no other means is at hand the spring may be compressed in a vise and bound with a few turns of strong cord. It may then be slipped on the stem and the key and washer put on. The string may then be cut and the spring let out.

Care of Spark Coil and Ignition Outfit.—The entire ignition outfit is somewhat delicate and requires its share of attention. It should be examined at intervals to make sure that all binding screws are tight and all contacts good. The insulation should be examined and any places where it becomes worn should be taped. Two parallel wires should never be fastened by a single staple, as the insulation is likely to chafe through, causing a short circuit. Each wire should have its separate staples.

The most common place for a wire to break is at some place where it is bent back and forth, as where the wires are connected to the timer; a short coil at such points will greatly increase the life of the wire.

The entire system, including the plugs and sparking points, should be kept clean and free from oil. Oil on the outside of the plug will cause a short circuit, as does the collection of soot around the points.

The spark coil should be looked over and if necessary readjusted slightly. Many operators set the vibrator adjusting spring too tight, with the idea that the very rapid motion gives a stronger spark. This may seem true when tested in the atmosphere, but on a quick running engine it may give trouble by skipping. A more reliable spark is given with a moderately rapid vibration of the buzzer, with considerably less battery consumption. A satisfactory adjustment of the vibrator may be obtained as follows: The vibrator adjusting screw is drawn back until it is clear of the spring; the spring is then set so that the iron button is from $\frac{1}{16}$ to $\frac{1}{8}$ inch from the end of the core. The adjusting screw is then screwed in until it touches the spring lightly. The engine is then started and the screw turned in slightly until the engine runs steadily; the spring should be left as weak as possible and still have the engine run steadily. The spring must bear against the screw when the engine is not running, as otherwise no current will pass and the engine will not start. In testing the spark in the secondary circuit, the spark should not be drawn out to the limit, as this strains the coil and is almost sure to cause trouble if there is any weakness in the coil.

The magneto requires only a small amount of attention. It should be kept oiled and dry. The breaker points should be cleaned when necessary and adjusted to separate on the break to about the thickness of a worn ten-cent piece. They should also be faced off when pitted, with a thin fine file. In the case of serious trouble with the magneto it should not be taken apart, but should be entrusted to some one making a business of such repairs.

Dry Cells. — Dry cells also should be examined occasionally. Weak cells may be located by testing with an ammeter. When new, dry batteries of the usual size should test from 18 to 25 amperes, and as a rule they should not be used after they have fallen below about 8 amperes. A single weak cell will spoil the action of an entire set; even if no new ones are at hand the action will be improved by cutting out the weak one. In testing a battery the ammeter should be held across the terminals only long enough to get the reading, as if held there even for a short time the battery is quickly run down.

Batteries which have been run out may be temporarily revived by punching a hole in the top and pouring in some water.

Storage Battery. — The storage battery should be disposed in a dry place and securely chocked against the motion of the boat. It should be kept fully charged as far as possible, as in this condition the deterioration is least. The battery should be examined at intervals and the specific gravity tested with a hydrometer, directions for doing which usually accompany the instrument. By unscrewing the caps the height of the liquid inside can be observed, and if the plates are not covered, distilled water should be added. When removed from the boat for any reason it should first be fully charged, and when replaced great care should be taken to connect it up as before, as a wrong connection will quickly ruin the battery. During the season when the boat is laid up the battery should be sent to some station making a business of caring for batteries, as it must be charged periodically and cared for, as otherwise it would probably be spoiled during the long laid up season.

CHAPTER XIV

Power of Engines

The term "horse-power," when applied to the ordinary small engine, is a somewhat elastic and in many cases an abused one. Few boat owners are aware of the real meaning of the term and are even less well informed as to the actual power which they should expect to get from their engines. Manufacturers, even, are not always informed as to the power of their engines, as great differences may be observed in the rating of the same size of engine by the different manufacturers.

The term horse-power is an arbitrary one, and signifies the ability to do 33,000 foot pounds of work in one minute; in other words, a force which can overcome a resistance of 33,000 pounds at the rate of 1 foot per minute will generate a horse-power. The same will be done by a force of 1 pound acting at the rate of 33,000 feet per minute, or a force of 1000 pounds acting at the rate of 33 feet per minute. It may be expressed thus:

$$\text{Work} = \text{force in pounds} \times \text{distance in feet.}$$

$$\text{Horse-power} = \frac{\text{force in pounds} \times \text{distance in feet}}{33{,}000}$$

The horse-power of the engine may be considered under the following heads:

1. Indicated horse-power or I.H.P.
2. Actual developed or brake horse-power — B.H.P.
3. Effective horse-power or E.H.P.

Indicated Horse-power. — Although this method of measuring the power of the engine is used mostly in the case of steam engines, it can be used on gas engines, and is so used in measuring the power of large engines. This method of calculation is dependent upon the use of the indicator; details of this instrument, which is very simple, can be found in any book on steam engineering. All that need be noted here is that by means of a moving strip of paper and a pencil which is controlled by the pressure in the cylinder, the pressure is recorded at all points of the stroke. This will be made plain by referring to Fig. 111. The length *A–B* of the diagram represents the stroke of the piston. Vertical distances above the line of no pressure, *A–B*, represent pressures; at any point in the stroke, then, the pressure in the cylinder will be shown by the distance from the base or zero line *A–B* to the diagram outline. The upper line is the diagram for the power stroke, while the lower line is that for the return stroke. The point *C*, where the pressure is highest, is just after ignition, when the maximum pressure is reached. The pressure falls as the piston descends, until the point *D* is reached, where the exhaust opens, after which it falls rapidly to the end of the stroke and becomes equal to the atmospheric pressure. At the point *E* the exhaust closes and the contents of the cylinder are compressed until the point *F* is reached, where ignition takes place and the pressure rises rapidly until the point *C* is reached again. This is the diagram for a two-cycle engine; that for a four-cycle engine is very similar As the lines of the exhaust and suction strokes are under practically atmospheric conditions, the exhaust stroke will be continued from *B* to *A* in a line coincident with the zero line, and the inlet stroke will also lie in this line from *A* to *B;* the compression line *B, E, F* is the same as before.

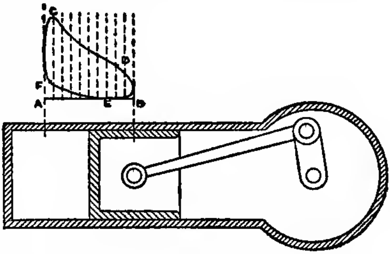


FIG. 111.— Pressure Diagram.

The expansion line *C, D, B* represents pressure acting upon the piston, forcing it ahead, while the line *B, E, F* represents pressure tending to retard the piston, or back pressure. Thus the width of the diagram at any point shows the net pressure acting on the piston, and the average width shows the average pressure throughout the stroke. This average pressure, or, as it is called, the "mean effective pressure" or M.E.P., is the force acting on the piston to produce the power. If we call the M.E.P. simply "*P*," and the area of the piston in square inches "*A*," the force acting on the piston is $P \times A$. If now this force is multiplied by the length of the stroke in feet, "L," $P \times A \times L$ equals the work done per stroke, and it is only necessary to multiply this by the number of power strokes per minute and divide by 33,000 to obtain the I.H.P.

In the case of the ordinary steam engine, which is double acting, there are two working strokes for each revolution. If the number of turns per minute equals "N," $2 \times N$ will be the number of power strokes per minute. Then the

$$\text{I.H.P.} = \frac{P \times A \times L \times 2N}{33{,}000}$$

or, as it is usually written for ease in remembering it,

$$\text{I.H.P.} = \frac{2 \cdot P \cdot L \cdot A \cdot N}{33{,}000}$$

It must be remembered that in this work the pressure is measured in pounds per square inch and the length of the stroke in feet.

The quantity $2 \times L \times N$ is termed the "piston speed" and is the distance travelled by the piston in one minute.

In the case of the gas engines the method is similar. In the single-acting two-cycle type, having one impulse for each revolution, the

$$\text{I.H.P.} = \frac{P \cdot L \cdot A \cdot N}{33{,}000}$$

For the four-cycle engine having an impulse on alternate strokes the number of power strokes per minute is $\frac{1}{2} N$, so that the

$$\text{I.H.P.} = \frac{P \cdot L \cdot A \cdot N}{2 \times 33{,}000}$$

These formulas are for the power of one cylinder and must be multiplied by the number of cylinders in the case of a multiple-cylinder engine.

The I.H.P. is a measure of the work done in the cylinder, rather than the power delivered by the engine. It will be plain that a certain amount of power is necessary to overcome the friction of the several working parts of the engine itself, or, as it is termed, the "engine friction." The remainder, which is delivered to the shaft, is the developed or brake horse-power. The proportion which the brake horse-power bears to the I.H.P. is called the "mechanical efficiency"; it might be further defined as the percentage of the I.H.P. which is available at the shaft. This proportion for gas engines is about 85 per cent for large engines and 80 per cent for small ones.

The indicator card, besides giving the power, also shows much regarding the general proportions and operations of the engine.

Brake Horse-power Formula. — There are several ways of arriving at the probable B.H.P. with sufficient accuracy for many purposes. The following formulas are found to give it quite closely for engines of usual design:

$$\text{For four-cycle engines B.H.P.} = \frac{A \times L \times N \times C}{1000}$$

$$\text{For two-cycle engines B.H.P.} = \frac{A \times L \times N \times C}{750}$$

where A = area of cylinder in square inches.
L = stroke of piston in feet.
N = turns per minute.
C = number of cylinders.

It should be noted that the area is in square inches and the stroke is in feet.

Results similar to the above will be obtained by calculation by the I.H.P. formulas just given, using a *net* M.E.P. of 66 pounds per square inch for four-cycle engines and 44 pounds for two-cycle. This net M.E.P. takes account of the losses and approximates to the B.H.P.

Brake Test. — Where it is possible to apply it, the brake test gives a very satisfactory and easily applied means of determining the power. This method gives directly the actual power which is available for use at the shaft.

The simplest form of brake is the rope brake shown in Fig. 112. It consists of several turns of rope around the flywheel, the ends of the rope being connected to the spring scales P and P_1. Some means of varying the tension in the rope is provided, such as the pulley S. The flywheel turns in the direction of the arrow.

The tension in the rope is adjusted until the engine runs at the desired rate; the pull on both scales is then read off, that on P_1 being found to be the larger. As these two scales oppose each other the difference between their readings will represent a net pull, which we may call F. It is this pull F which, acting at the rim of the flywheel, absorbs the power, and it may then be considered that the power is generated by a force equal and opposite to F, acting around the rim of the flywheel. Calling the diameter of the wheel D, the circumference will be

$$D \times \frac{22}{7}$$

and the work done during one revolution of the wheel will be

$$F \times D \times \frac{22}{7}$$

If the wheel turns N times per minute, the work done per minute will be

$$F \times D \times \frac{22}{7} \times N,$$

and if this result is divided by 33,000 the result

$$\frac{F \times D \times 22 \times N}{33{,}000 \times 7}$$

will be the horse-power developed.

Small chock pieces B, B may be fitted to prevent the rope slipping over the edge of the rim, but for small powers this is not necessary. The face of the wheel is lubricated and the number of turns of rope so adjusted as to absorb the power without undue tension. This form of brake cannot be used for a long test on account of there being no way of getting rid of the heat generated by the friction. For occasional testing, however, it will answer very well.

Where the power to be measured is greater, the "Prony" brake shown in Fig. 113 is used. It consists of a metal band B encircling the wheel, and carrying the series of wooden blocks which rest on the face of the wheel. The grip of the friction band is varied by the screw and hand wheel W. A frame F is connected to the band *B*, to the end of which the spring scale *S* is attached. With the wheel turning in the direction of the arrow the hand wheel *H* is tightened gradually until it runs at the desired rate. The band is prevented from turning by the tension on the scale *S*, which can be read off. The figuring of the power is the same as in the previous case, the horse-power equaling

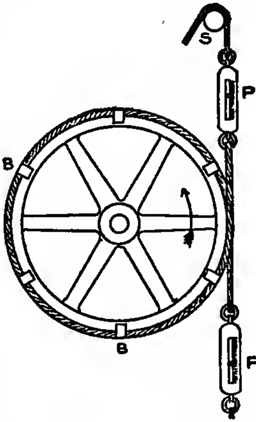


FIG. 112. — Rope Brake.

$$\frac{F \times 22 \times 2 \times R \times N}{7 \times 33{,}000}$$

F being the pull on the scale, *R* the distance from the center of the wheel to where the scale is fastened, and *N* the revolutions per minute.

This style of brake may be applied to any flywheel, although with the usual flywheel only short tests can be run on account of the heat generated. Special brakes are often made, to which the engine may be coupled; in this case a flywheel having a deep trough-like rim is used. Water may be fed into this rim, to be distributed over it by centrifugal force; the heat generated by the friction is used up in evaporating the water, which is replenished when necessary. This brake may then be used almost continuously. Where much testing is to be done, as in an engine factory, a brake of this description may be made, with wheel and bearings complete, independent of the engine. By means of a coupling the engine to be tested may be quickly attached. For large brakes the pressure of the arm *F* may be taken on a platform scale. By making the brake of sufficient size, large powers can be measured.

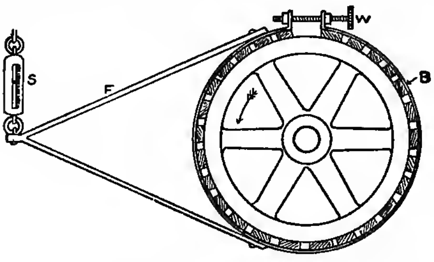


FIG. 113.— Friction Brake.

A very convenient method is by electrical measurement, in which the power developed is converted into electrical energy, measured and absorbed. The engine is coupled to the dynamo and the power developed is measured by volt and ammeters and absorbed by some electrical resistance, either lamps or water resistance. Fig. 114 shows the general arrangement for a test; the engine is coupled to the dynamo *D* and run at the proper speed, the load is adjusted by varying the resistance *R*, and the current generated is measured for voltage by the voltmeter *V* and for amperage by the ammeter *A*. The product of the amperes multiplied by the volts gives the number of "watts," which is the electrical measure of power. A horse-power equals 746 watts, so that if the number of watts developed is divided by 746, the result will be the horse-power developed by the dynamo. As the dynamo will not give out as much power as is put into it, the power developed by the engine must have been greater according to the efficiency of the dynamo. Thus the

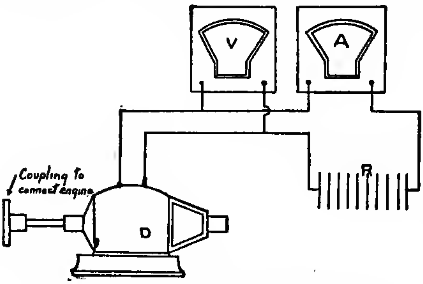


FIG. 114.—Wiring for Electrical Test.

$$\text{B.H.P.} = \frac{\text{amperes} \times \text{volts}}{746 \times \% \text{ efficiency}}$$

This is a very good method for general use as the efficiency of the dynamo is readily determined.

The revolutions of the engine do not enter into the final calculation of the power, but should be recorded so that the power may be known for each rate of speed.

Effective Horse-power—or Horse-power Used in Propulsion.—As stated in the chapter on propellers, the propeller does not use in actual propulsion all the D.H.P. delivered to it. The effective horse-power is thus less than the D.H.P. by the amount wasted by the propeller in friction and resistance. Taking the efficiencies there given it will be seen that for a large engine having a mechanical efficiency of say .85, turning a well-designed propeller whose efficiency may be perhaps .65, there will be a proportion $.85 \times .65 = .55$ of the I.H.P. actually used as E.H.P. in propelling the boat. For a small engine whose mechanical efficiency would be about .80, with a small propeller whose efficiency is likely to be not above .50, the E.H.P. is $.80 \times .50 = .40$ of the I.H.P. There are undoubtedly many boats in successful operation which would show an efficiency much less than the latter figure.

CHAPTER XV

Selecting an Engine

Type. — In selecting an engine for any particular purpose, several conditions must be considered. The most important of these is the use to which the engine is to be put. An engine for use in a heavy working or fishing boat should be of the heavy, slow-speed type. Under these conditions the engine is subjected to severe usage and only the heavy engine, with strong parts, will give the required service with the minimum amount of repairs. It is not advisable to fit a light, high-speed engine in a heavy boat, as the high rotative speed of the engine is not well suited to the slow speed of advance of the boat. For boats of this type large single-cylinder engines may be used to advantage, as they are less costly than those of more cylinders, and the vibration is not noticeable in the heavy boat.

For launches of the usual proportions which are used for pleasure only, engines of moderate weight and rotative speed should be used. A two or more cylinder engine should be used when possible to decrease the vibration and render the riding more pleasurable. Although the multiple-cylinder engine is more expensive, it is far more satisfactory in long runs where the vibration of a single-cylinder engine becomes objectionable.

For high-speed launches the light-weight high-speed engine may be used, as these launches are customarily used on short runs only, where the high-speed engine will be found satisfactory. For extreme high speed the maximum amount of power must be obtained on the lightest possible weight, which can, of course, only be done with a light, quick-running engine. This type of engine must be used with the greatest care and cannot be recommended for general use.

For use as an auxiliary a rather light engine should be selected; as for this purpose the engine is used only occasionally and the duty is not as severe as in a launch. The horizontal, double-opposed engine is in many cases well suited to this use, as it can be stowed away under the standing-room floor where the space is otherwise of little importance.

As to whether a two- or four-cycle engine should be selected is largely a question of personal preference, as either type will give good service. For small engines there is no reason why the two-cycle engine should not be entirely satisfactory, as it requires less care and has the added advantage of much less cost than the four-cycle. For medium and large engines, where the economy of fuel and extreme reliability are of importance, the four-cycle engine has its advantages.

Size of Engine. — The proper size of engine for any boat is largely a matter of judgment. While there are numerous ways of figuring for the required power for any desired speed, some are not suited to launches and others are too complicated for the present work. For launches of ordinary form a guide to the proper power may be obtained as follows: Divide the length by two and subtract seven, or $\frac{\text{length}}{2} - 7 = \text{H.P.}$ If the launch is narrower than usual the speed will be greater; on the other hand, an unusually wide or heavy boat will require more power than given by the above. It will, however, do as a starting point. This formula is not, of course, suited to a speed launch, as in this case as much power should be installed as is possible without adding an excessive amount of weight.

It must be remembered that the speed of the boat does not increase in direct proportion to the increase of power. Starting with a given power, doubling the power will by no means double the speed. The power required really increases as the cube of the speed, so that to double the speed of the boat an amount of power equal to $2 \times 2 \times 2 = 8$ times the original power must be installed. Doubling the power only increases the speed by an amount equal to $\sqrt[3]{2} = 1.25$ so that the speed is only a quarter greater. This illustrates the futility of trying to drive a bulky, heavy boat at a more than moderate speed. A small or moderate power will drive the boat practically as fast as a greater power, and much more economically, as so much of the greater power is used up in piling up waves at and near the bow.

Quality of Engine and Cost. — As to the quality of the engine, as good an engine should be bought as the money at hand will allow. A cheap engine, while low in first cost, has a short life and is likely to break down in service and cause vexation if nothing more. It should be borne in mind that it costs a certain amount to build an engine, and although a saving may be made by economy of production, the very cheap engine must be lacking either in size or quality.

The ratings of the engines of the different makers vary greatly, the ratings of similar engines varying sometimes as much as 50 per cent. It will be found that the extreme low priced engines are rated at a very high rotative speed, in many cases much in excess of what can be actually obtained in practice. The prospective buyer should consider the bore and stroke of the engine and form his own estimate of the probable power. By doing this he will often find that to obtain his required power a size larger than the rated size will be required, which brings the cost almost or quite up to that of the more conservatively rated medium priced engine.

Another point to be considered is the question of "outfit"; some makers list the engine alone, with the outfit as extra items, while others list the complete installation, including everything necessary to install and run the engine. The latter is much the better way, as the purchaser knows just what his outfit is to cost him.

For use on salt water, the engine must have "salt water fittings." This means that all parts coming in contact with the water must be of composition; including propeller, shaft, stern gland, and all screws and nuts. No steel and composition should be allowed to be in contact when in salt water, as the steel is rapidly eaten away by galvanic action. In fresh water these parts may be made of iron or steel without great detriment, but even here the bronze is better.

The general construction of the engine should be carefully examined; although the amateur can tell little as to the quality of material and workmanship, there are some points which can be looked into. As to the quality of the material the word of the builder must be taken.

One of the most important points is that the various parts be readily accessible, for examination or adjustment. While it is not of course intended that the engine shall be pulled down except in case of accident or overhauling, it is at the same time very desirable that the parts be so arranged and fastened that they may easily be taken down and examined or, in the case of accident, repaired. An engine which is easily accessible is likely to have better care and last longer than one which is not.

The bearing surfaces should be liberal, especially that of the crank-pin bearing which is under a severe pressure. Some means also should be provided for taking up the wear of all bearings which are under heavy pressure. The main bearings should be either of babbitt or bronze, and on four-cycle engines are usually made so that any wear can be taken up.

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