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TREASURY DEPARTMENT
UNITED STATES COAST GUARD

HANDBOOK
ON
CARE AND OPERATION OF GASOLINE ENGINES

PREPARED UNDER DIRECTION OF
THE CAPTAIN COMMANDANT

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LETTER OF PROMULGATION.

TREASURY DEPARTMENT,
UNITED STATES COAST GUARD,
Washington, January 13, 1917.

The following "Handbook on Care and Operation of Gasoline Engines" has been prepared by Second Lieutenant of Engineers W. M. Prall, United States Coast Guard, and is issued to officers and enlisted men of the Coast Guard for the information and guidance of all concerned.

E. P. BERTHOLF,
Captain Commandant.

HANDBOOK ON CARE AND OPERATION OF GASOLINE ENGINES.

CHAPTER I.

PURPOSE FOR WHICH THIS PAMPHLET IS ISSUED.

No attempt has been made in the preparation of this pamphlet to cover all the phases of design, construction, and operation of gasoline engines. It is not expected that the contents will be of any material aid to the person who has had considerable experience in handling these engines. The sole object in view is to present the subject of gasoline engines in such a manner that persons without special education or practical training along mechanical lines can acquire a good general idea of how these engines work, how they should be cared for, and the special meanings of words and expressions when used in connection with engines of this type. In other words, these few chapters are intended as a sort of primer for the use of enlisted men intrusted with the care and operation of gasoline engines.

Manufacturers of gasoline engines and of gasoline motor vehicles often publish information and instructions concerning their products for the guidance of their patrons. Frequently, however, these articles make use of such technical terms and expressions that a reader, who has not made a study of the subject, soon becomes confused and discouraged. In some cases, too, these articles are written with the purpose of convincing the reader that the design, materials, and method of construction of the particular engine described are the only ones that can be used with success.

There is also available at present an abundance of literature on the subject of the gasoline engine, which, though thoroughly reliable, is written for the use of trained designers and engineers, but is of little value to others.

This pamphlet is prepared with the hope that it will enable the reader to gain sufficient knowledge of the subject to make possible the reading of more extensive works with understanding, and enable him to secure the most satisfactory service from an engine of which he has charge.

CHAPTER II.

GASOLINE.

What gasoline is.—In certain parts of the world large tracts of land have been found, underlying which are immense quantities of inflammable liquid commonly known as crude oil. In this country there are three principal oil regions: The Pennsylvania, which includes parts of West Virginia and Ohio; the Texas region, which extends into Oklahoma and Kansas; and the California region. To obtain the oil, wells are drilled to depths varying from an average of about 100 feet in the Pennsylvania region to 3,000 or 5,000 feet in California. Occasionally upon drilling a well the oil is forced violently to the surface of the earth, forming what is known as a "gusher," but more often the oil has to be removed from the wells by means of pumps.

This natural oil is usually thick, heavy, and dark brown or green in color. But crude oil is really a mixture of several kinds of oil, differing greatly in their nature, and quite easily separated one from the other by the process known as distillation.

To better understand the nature of crude oil let us consider a liquid, fresh water, for example, which is *not* a mixture of different kinds of liquids. When a vessel of pure fresh water is boiled, a gas known as steam is formed, which can be carried to a cooling chamber and condensed; that is, cooled until it again becomes liquid. No matter how much of the water from the vessel has boiled away, the condensed steam is always found to be water, the last drop condensed being exactly like the first drop, and all exactly like the water which was boiled.

When crude oil is slightly heated gases are given off which may be condensed to a liquid by cooling. This liquid is not at all like the original oil, but is quite colorless, light as compared with crude oil, and easily vaporized (changed to the form of gas) by slight heating. The crude oil, if further heated, continues to give off gases which, when condensed, form a liquid much like that first obtained, but slightly heavier and not quite so easily vaporized. This process can be continued and a whole series of liquids obtained, each slightly heavier and less easily vaporized than the one before it, until the product is no longer colorless, but yellow, green, or brown. The first liquids thus obtained are not of much use commercially. They vaporize so rapidly that explosive gas is generated at ordinary temperatures, making these oils too dangerous for ordinary use. After these, however, comes a series of oils which are of great value in modern life, known as gasoline, kerosene, and lubricating oils. Gasoline is the part of crude oil obtained after the lighter liquids referred to above have been distilled off and while the heating proceeds from about 230° F. to about 280° F.

Kerosene is obtained as the distillation continues between 280° and 500°. After that, lubricating oils are produced. The remainder, a thick, heavy, sticky oil, is suitable for use as fuel, and is used in some parts of the country for firing locomotives, making steam for factories and power plants, and as fuel on steam vessels.

It is with gasoline that we are interested, this short description of one process of refining crude oil being given to explain what gasoline is, where it is obtained, and how it may be produced. Several methods are used commercially to separate these products, but all depend upon the difference between the boiling temperature of the various liquids. Recently attempts which promise to be successful have been made to perfect processes by which the heavier oils can be converted into more valuable lighter oils. This can be done, but the commercial success of the undertaking depends upon the cost of the operations and the difference between the price obtainable for the oil before and after treatment.

How gasoline produces power.—Chemists tell us that gasoline is composed principally of carbon and hydrogen. Carbon we are familiar with in the form of charcoal and coke, which substances are practically pure carbon. Hydrogen is a gas. It is due to processes of nature, very little understood, even by the chemists, that these two elements have been so united that they form oil.

Air is a mixture of two gases, oxygen and nitrogen; these gases are not united with each other, but simply mixed together, as pepper might be mixed with salt.

When gasoline vapor is mixed with air in the proper proportions we have what is called an explosive mixture. As long as the mixture is kept cool no action will take place, but let the least part of the mixture be sufficiently heated and a change will occur, so violent that it is termed an explosion.

What happens to cause this violent action? In the first place, it may be said that the carbon and hydrogen are held together in gasoline by an attraction that is very weak. When mixed with air and heated, the carbon and hydrogen no longer stay united as gasoline, but each is strongly attracted to the oxygen. The carbon suddenly unites with part of the oxygen present and forms a gas known as carbon dioxide, and the hydrogen unites even more suddenly with the other part of the oxygen and forms water. This sudden action creates a large amount of heat, which causes the temperature of the carbon dioxide and water to rise very high, so high that the water is present only in the gaseous form of steam. Nitrogen present in the mixture does not change, though its temperature is raised by the heat of the other gases.

It is well known that a gas if highly heated expands to several times its original volume, or, if it is heated when confined in a closed vessel so that it can not expand, it creates a high pressure. It is because of these facts that gasoline can be used as a source of power in the gasoline engine, and it is evident that what is commonly regarded as the dangerous property of gasoline, the explosiveness of the gas generated therefrom, is also the very property that makes it so useful.

Precautions that must be taken in handling gasoline.—There are two chief sources of danger from gasoline if it is not properly handled—the danger of fire and the danger of explosion. As gasoline evaporates rapidly in the presence of air, it forms a rich mixture of inflammable gas near the surface of the liquid. If ignited this gas burns rapidly; the heat accelerates evaporation from the surface and causes the volume of flame to increase with great rapidity.

To avoid the danger of fire, gasoline should always be kept in strong, tight tanks, and whenever handled in the open air no flame or spark should be allowed in the vicinity.

Gasoline itself is not explosive. It is only the mixture of gasoline vapor and air that will explode, as before described. When gasoline is handled or left exposed to the air in a confined space, such as a closed garage or boathouse, evaporation, especially in warm weather, may cause the contained air to be so charged with vapor that the mixture would be exploded by a flame or spark.

It is therefore always expedient to have proper ventilation in rooms where gasoline is exposed to the air or where tanks containing gasoline are stored, the frequent change of air carrying away vapors and preventing the accumulation of a rich mixture. It should also be borne in mind that an explosive mixture of gasoline vapor and air usually occupies the space over gasoline in a partially filled tank, which makes it extremely dangerous to have a flame near when the tank is opened for filling or for measuring the contents.

Water should not be used in an attempt to put out a gasoline fire, for the gasoline will float on top of the water and continue to burn, the only result being a spreading of the flames. Sand or ashes thrown on the fire to reduce the exposed surface of gasoline, or, better yet, a good fire extinguisher, the contents of which will generate a smothering blanket of inert gas, are the most effective means of subduing the fire.

What determines the quality of gasoline?—In engineering the quality of fuel for producing power is usually determined by the amount of heat which 1 pound of that fuel will produce when burned. But with gasoline, as used in the modern gas engine, another quality is commonly placed foremost. The expressions "good gasoline" and "poor gasoline" are often heard, also "high-test" and "low-test" gasoline. By "good gasoline" and "high-test gasoline" is meant that which vaporizes readily, thus causing easy starting and smooth running of a motor. "Poor gasoline" and "low-test gasoline" lack this quality to a noticeable extent. It so happens that the ease with which gasoline is vaporized can be determined by comparing the weight of a given volume of the oil with an equal volume of pure water. If equal volumes of different grades of gasoline were carefully weighed, that found to be lightest would be best, as far as ease of vaporization is concerned; the heaviest would be poorest. In practice, the grade of oil is determined by means of an instrument called a "hydrometer," graduated to an arbitrary scale called the "Baumé scale." When the instrument is floated in a liquid the reading of the scale at the surface is a measure of the relative weight of the liquid as compared with water, the readings being higher for light liquids than for heavier ones. Gasoline that tests 66° Baumé is now commonly considered good. The lower grades test about 56° to 64°. The reason for this variation in the quality of different grades of gasoline lies in the fact that gasoline, like the crude oil from which it is obtained, is really a mixture of several oils.

The weight of a given volume (say, a gallon) of gasoline depends upon the weights per gallon and the proportions of these separate oils. Since during distillation the lighter oils are first separated from the crude product, the weight per gallon of the oils becoming greater as the temperature of distillation increases, it is evident that the lower the temperature and the narrower the range of temperatures over which the distillation is allowed to proceed during the production of gasoline the lower will be the weight per gallon of the final product. If the distillation is allowed to proceed over a wide range of temperatures, the heavier oils distilled at the higher temperatures increase the weight per gallon of the final product, with a result that the gasoline is heavier and less readily vaporized. Of course in the latter case the amount of "gasoline" produced from a given quantity of crude oil is much greater than in the former.

As kerosene oil is obtained from crude oil over the next higher range of temperature of distillation, oil producers have used this ready means of regulating their production of gasoline and kerosene to suit the demand. A few years ago, when the consumption of kerosene was enormous as compared with that of gasoline, distillation of the latter covered a narrow range of temperature, and the quality was high, as great in some cases as 84° Baumé. On the other hand, as the recovery of kerosene was commenced at a comparatively low temperature, its weight per gallon was consequently low, a very undesirable quality, which made the kerosene vaporize so easily that it was somewhat dangerous for domestic use. In more recent years consumption of gasoline, due to its use in motor vehicles, power boats, and the like, has so increased that oil producers, in order to meet the demand, have found it necessary to broaden more and more the range of temperature in the distillation of their crude oil, during which gasoline is produced, thus obtaining a greater quantity of heavier grade. One fortunate result, however, is the superior quality of the kerosene now produced, for, being distilled at a higher range of temperature, its dangerous qualities are greatly reduced without detracting from those that make it useful for light and heat. In fact, it may be truly said that the words "gasoline" and "kerosene" as ordinarily used to-day hardly mean more than "products from crude oil" suitable for the uses with which these names are associated, gasoline being the lighter of the two, but their exact qualities depending upon the relative consumption, the sagacity of the oil refiners, and just how exacting the public is in its demands.

CHAPTER III.

DEFINITIONS OF WORDS AND TERMS USED WITH REFERENCE TO GASOLINE ENGINES.

In many instances common words and phrases, when used in connection with gasoline engines, have a special meaning. This often confuses a reader and makes it advisable, before going further into the subject, to define or explain such of these words and expressions as are most often met with.

It must be kept in mind that the definitions given in each case refer only to the use of the word or phrase in its connection with a gasoline power plant.

For convenience, an alphabetical arrangement has been adopted:

Air cooling.—A system of cooling engine cylinders by means of a current of air.

Alignment.—A state of having the various parts of a machine in proper position—that is, "in line"—with relation to each other. When this proper relationship does not exist the parts are said to be "out of line" or "out of alignment." For example, the center line of a cylinder should lie in a plane perpendicular to the center line of the crank shaft in order to be "in alignment." Or, as another example, if the center of each crank shaft bearing is not in a single line drawn between the centers of the two end bearings, these bearings are "out of alignment."

Alternating current.—A current of electricity that flows through the circuit first in one direction, then in the opposite direction. the alternations occurring with great rapidity.

Automatic spark advance mechanism.—A device, usually built on the principle of a centrifugal governor, which automatically changes the timing of the spark and eliminates the necessity of hand regulation.

Baffle, or baffle plate.—A partition or projection fitted in a chamber or passage to check, distribute, or change the direction of a current of gas or liquid.

Battery.—A group of cells used as a source of electricity. When all positive terminals are connected together and all negative terminals are connected together, the cells are said to be connected in "parallel." When the positive terminal of a cell is connected to the negative terminal of the next cell, and so on, the cells are said to be connected in "series." When a combination of these two systems is used the cells are said to be connected in "multiple series." A primary battery is one that can not be recharged by passing a current through it, an example being a group of ordinary dry cells. A secondary or storage battery is one which can be recharged by causing a direct current from another source to flow through it in the opposite direction to that of the current generated by the battery itself. The current furnished by a battery is always a direct current.

Bearing.—Every part of a machine must have adequate support; moving parts must be so supported that excessive friction and wear will not be caused by their motion. Such a support is called a bearing. Thus a main shaft bearing consists of a frame, usually lined with antifriction metal, which is made to fit accurately, but not bind the shaft.

A ball bearing is one so arranged that the shaft or rotating part is supported by steel balls which in turn are held in a recess in the fixed frame, called the ball race (sometimes the shaft or spindle is stationary and the frame revolves around it). Roller bearings are similar in arrangement, but here steel rollers instead of balls are used. The principle involved in the use of balls or rollers is the same as that which makes it advisable to use rollers when moving any heavy weight, the force necessary to cause rolling generally being less than that required to cause sliding.

Binding post.—A threaded screw or "post" with nuts and lock nuts or other fastening device for attaching wires to electrical apparatus.

Bloc cylinders.—When all cylinders are cast in one piece the engine is said to have "bloc cylinders," or the cylinders are cast "en bloc." The same expression is used whenever groups of cylinders are cast in one piece, and the total number of cylinders is made up of two or more of these groups, but in this case the number of cylinders in a "bloc" is usually stated.

Break (as applied to electrical circuits).—The interruption of flow of an electric current by making a gap in the metallic circuit. Under proper conditions a hot spark or "arc" is produced at the point of break in the ignitor.

Breather.—A passage between the open air and the inside of a closed crank case on a four-cycle engine. Its purpose is to prevent either pressure or vacuum in the crank case.

Brush.—A device for making a good electrical contact between a stationary part and a moving part of a circuit. Examples are: The brushes of a dynamo which collect the current generated in a moving armature, or the brush of a commutator which revolves and comes in contact with stationary insulated terminals, thus completing an electrical circuit at certain times.

Bushing.—A sleeve or collar used as a lining for a bearing, usually made of antifriction metal.

Cam.—An accurately shaped projection on a shaft for imparting the necessary motion to a valve, ignitor, or other part at the proper times.

Cam shaft.—The shaft that carries the cams for operating valves or ignitors. A cam shaft receives its motion from the crank shaft by means of spur gear or silent chain connection.

Carbon.—A deposit of black scale or soot which forms on interior walls of the combustion chamber. It is caused both by the burning of the gas and by the burning of lubricating oil which finds access to the chamber. The rate of deposit is increased by the use of an overrich mixture of gas and by excessive piston lubrication. The carbon deposit is often rough and sometimes peels up in flakes. The high portions or flakes become red hot when the engine is running and ignite the charges of gas before the piston has reached the end of its compression stroke, causing a sharp thud termed the "carbon knock."

Carburetor.—A device for vaporizing gasoline (or other volatile liquid fuel) and mixing it with air to form an explosive mixture.

Cell.—A jar or case containing "electrodes" (one usually made of carbon, the other of zinc) and a solution of chemicals, which combination will generate an electric current. In other words, a unit of an electric battery.

Centrifugal force.—The tendency of a body revolving around an axle or shaft to fly away from the axle. It is used as the basic principle of most governors and automatic spark-advance mechanisms.

Check valve.—A valve which allows passage of gas or liquid through it in only one direction.

Circuit.—Electricity can flow as a current only when it has a loop or closed path of conducting material (usually metal) starting from the source of electricity and leading back to that source. Such a path is called a circuit. A "closed circuit" is one that is complete so that the current can flow. An "open circuit" is one having a break or gap (for example, an open switch), which prevents the flow of current. By a "short circuit" is meant a connection (either accidental or intentional) which allows the current to take a " short cut " from some part of the regular circuit back to the source.

Circulating pump.—When a water-cooling system is used some means must be employed to cause the water to circulate through the cooling jackets. A pump used for this purpose is called a circulating pump. Likewise, when forced-feed lubrication is used, a pump for forcing the oil through the system is called an oil-circulating pump.

Closed circuit.—(See Circuit.)

Clutch.—A coupling between two parts of a machine so arranged that when it is " thrown out " one part can operate independently of the other part (in other words, they are disconnected), when " thrown in " the parts are held together, one usually driving the other. In connection with gasoline engines, a clutch is often used to readily connect or disconnect the engine from its load without stopping the engine. It is always used on gasoline vehicles, for without it the engine could never be started without the vehicle starting at the same time.

Coil.—The induction coil used in ignition systems is usually spoken of simply as the " coil." (See " Induction coil.")

Combustion.—The burning of the gasoline mixture. This burning takes place with such rapidity that it is termed an explosion. (See Chapter II.)

Commutator.—A device forming part of the primary circuit of an ignition system, which " closes " and " opens " this circuit in such a manner that sparks are caused at the proper times in each cylinder.

Compression.—After a charge of mixture has been introduced into the cylinder its volume is reduced and its pressure is increased by the movement of the piston toward the cylinder head. This action is called " compression."

While the piston is moving toward the cylinder head, causing compression of the mixture, it is said to be making the " compression stroke."

When a leak from the combustion space (past a loose or poorly fitted piston, through a leaky valve or defective spark plug, or in any other way) allows such an escape of mixture that a proper compression of the mixture is not obtained, the cylinder is said to have "poor compression" or "has lost its compression."

Connecting rod.—The bar which connects the piston to the crank. It is fitted with a bearing at each end.

Contact points.—The points in vibrators or other forms of interrupters where the electric circuit is "made" and "broken." Ordinarily they are not actually points, but small, flat buttons made of platinum, platinum-iridium alloy, tungsten, or other material well adapted for resisting extreme heat and the destructive action of the electric spark.

Control.—The levers, links, switches, etc., by which the regulation of the engine is accomplished is called the "control."

Cooling fins or flanges.—The ribs or projections used on air-cooled cylinders and radiators for the purpose of increasing the surface from which heat may radiate.

Cooling jacket.—The chamber, surrounding the cylinder and valve recesses of a water-cooled engine, through which the cooling water is circulated.

Crank.—The offset part of the shaft where the connecting rod is attached by means of a bearing. (Also the handle by which an engine is started by hand.)

Crank case.—The casing which incloses the space around the crank. Various other parts are also located within this inclosure.

Cranking.—The act of turning an engine to accomplish starting.

Crank shaft.—The main shaft of the engine which carries the cranks.

Cup (grease or oil).—A small vessel or recess for holding a supply of lubricant. They are usually so arranged that the supply of oil or grease is fed gradually to the surface lubricated.

Current.—The flow of electricity around a circuit.

Cylinder.—That part of the engine (usually an iron casting) in which the piston moves to and fro.

Cylinder head.—The cover which closes that end of the cylinder which is farthest from the crank. Sometimes the head is part of the cylinder casting, but the present tendency is to make it a separate part, fastened to the cylinder by bolts. With a removable head cleaning of the combustion chamber and inspection of the interior of the cylinder are more easily accomplished than when the head is cast on the cylinder.

Cycle.—In general, the word "cycle" means a series of events occurring in regular order and ending with all conditions in the same state as that which existed at the beginning, whereupon another cycle begins. With particular reference to a gasoline engine, a cycle means that series of operations which takes place in producing one power impulse. The words "two-cycle" and "four-cycle" in themselves really have no meaning. They were unfortunately coined by early inventors to signify the number of strokes the piston of their engines made in producing one explosive impulse. Thus when the piston makes two strokes for each explosion (or to complete a cycle) the engine is said to be of the "two-cycle" type; when four strokes of the piston are required to produce one explosion, the engine is of the "four-cycle" type. From the above it is apparent that *a stroke is not a cycle,* as is often supposed and sometimes stated in books of instructions.

To avoid the confusion caused by these terms some authorities distinguish between the two types by calling them "two-stroke" and "four-stroke"; others call them "two-stroke cycle" and "four-stroke cycle" engines.

Displacement, piston.—By piston displacement is meant the difference between the volume of space within the cylinder when the piston is at the head end of its stroke and the volume of space when the piston is at the crank end. It is equal to the cross-sectional area of the cylinder measured in square inches, multiplied by the length of the stroke measured in inches.

Distributor.—An automatic electrical device for directing the igniting current to the various cylinder spark plugs at the proper times. It operates in much the same manner as a commutator, but is so designed that it will handle the high tension current.

Dowel or "dowel pin."—A pin for the purpose of holding two or more parts of a machine in an exact position while the permanent fastening is made by means of bolts or screws. Dowels are often so arranged as to make it impossible to assemble the parts except in their proper relative positions. One end of the pin is permanently fastened in one part of the machine, the other end fitting neatly into a hole in the other part.

Drain cock.—A faucet or valve fitted in the lower part of water chambers, radiators, carburetors, tanks, etc., for emptying or "draining" these chambers.

Dual ignition system.—Two systems of ignition, more or less independent, fitted to an engine so that either can be used for generating the sparks is called a dual system. As a general thing batteries and coil are used for starting, or in case of emergency, and a magneto used for regular running. When two sets of spark plugs are used, and the system so arranged that for regular running a spark is produced at both plugs of each cylinder for every explosion, the system is said to be "double," or "two-point." A combination of these two arrangements is a "double dual ignition system."

Dynamo.—An electric generator geared or belted to the engine and used to furnish current for ignition, charging batteries, lighting, etc.

Electrode.—The two "elements" or plates of a battery cell are the electrodes. The positive plate or terminal—that is, the one through which the current flows from the cell—is called the "anode." The one through which the current returns to the cell is called the "cathode."

Electrolyte.—The electrodes of a cell are immersed in a liquid called the "electrolyte." The chemical action between electrodes and electrolyte generates an electric current.

En bloc cylinders.—(See "bloc cylinders.")

Exhaust.—The discharge or escape of burnt gases from the cylinders.

Exhaust valve.—The valve through which the burnt gases escape from a cylinder.

Explosion.—The violent combustion or burning of the mixture of gasoline vapor and air.

Factor-of-safety.—The numerical ratio between the strength of any part of an engine and the force which this part is required to resist. When an engine is spoken of as having "a general factor of safety of 12," it is meant that the strain necessary to break any part is at least 12 times as great as the actual strain that the particular part sustains when in operation.

Fan.—The air propeller used to cause rapid passage of air through the radiator or, on an air-cooled engine, around the cylinders.

Firing order.—In a multiple-cylinder engine, after an explosive impulse is delivered in one cylinder, each of the other cylinders delivers an impulse before the next explosion takes place in the first cylinder, and these impulses occur in regular order, determined by the angles of the cranks on the shaft. The order in which the impulses follow one another in the various cylinders is usually spoken of as the firing order.

Float.—Carburetors of the "float-feed" type have a small reservoir in which a constant level of gasoline is maintained. The cork block or metal drum which floats in this gasoline and automatically controls the inlet needle valve is called the "float."

Flywheel.—The heavy wheel usually carried on one end of the crank shaft. By virtue of its weight, it causes steady operation of the engine.

Friction.—The resistance which must be overcome to cause motion between two parts in contact with each other. Oil reduces this resistance by forming a liquid coat on the surfaces and preventing close contact.

Gap.—The space between the points of a spark plug across which the current jumps in forming the spark. The "circuit" is "open" at this gap, there being no metallic conductor for the current. It is high voltage that enables the current to overcome the resistance encountered at the gap.

Gas.—The mixture of gasoline vapor and air is often spoken of simply as the "gas." This word is also sometimes used as a short term for gasoline in the liquid form.

Gasket.—A layer of comparatively soft elastic material used between metal parts to form a tight joint. A common form of gasket consists of a sheet of asbestos packing cut to proper shape to fit the joint and covered by a casing of very thin sheet copper or brass.

Gears.—Toothed wheels which, through the engagement of their teeth, transmit motion from one wheel to the other. When the motion is transmitted through several gears the combination is called a "train of gears" or a "gear train."

"Half-time gears" are those that transmit motion to the cam shaft in such a way that this shaft will make one revolution while the crank shaft makes two. When the axes about which a pair of gear wheels revolve do not lie parallel to each other the teeth have to be tapered and cut at an angle (one side of the wheel is smaller than the other). They are then called "bevel gears." The smaller of two or more gears of a set is called the "pinion."

Recently, for high-class work, it has become the practice to cut half-time gears so that their teeth are at an angle instead of straight. This causes the teeth to engage gradually and does away with much of the usual noise and vibration that attends the use of plain gears. When the teeth are cut in this manner the gears are said to be "helical." Sometimes bevel gears are made with helical teeth.

A "worm gear" consists of a pinion with teeth so cut that they wind around the axis in the form of a screw engaged with a wheel having teeth properly shaped to "mesh" with this screw.

Generator.—(See Dynamo.)

Governor.—A device which automatically operates the throttle when the engine is running and regulates or limits the speed.

Graphite.—A solid form of lubricant, usually mixed with grease or oil, for reducing the friction of gears.

Ground (electrical).—An electrical connection in any part of a circuit to the body or base of the engine. It may be intentional or accidental. Two "grounds" often produce a "short circuit."

Half-time shaft.—A cam shaft which makes one revolution while the crank shaft makes two. (Cam shaft of a four-cycle engine.)

High tension or high voltage.—As used in connection with gasoline-engine ignition this expression means "tension" or "voltage" sufficiently high to cause the current to jump across the gap in a spark plug.

Hot-air pipe.—A passage or pipe which conducts heated air to the carburetor. The heated air is usually drawn from a jacket around the exhaust pipe.

Hydrometer.—A graduated float used for measuring the weight of a liquid as compared to the weight of an equal volume of pure water. (See p. 11.)

Ignition.—The complete system which generates the sparks for exploding the charges of gas is often spoken of as the "ignition."

Induced current.—The electric current which flows through the secondary circuit of an induction coil. It is produced by the action of another current flowing through the primary circuit. The secondary circuit is high tension; the primary is low tension.

Induction coil.—The device in which a "low-voltage" current is transformed into a high-tension current. For jump-spark ignition a coil has two separate windings—the "primary" or low-voltage winding being a comparatively few turns of fairly coarse insulated wire, the "secondary" or high-tension winding having many turns of fine wire.

The current in the primary coil induces a high-tension current in the secondary coil, hence the name "induction coil."

Inlet valve.—The valve through which the charges of gas are admitted to the cylinder.

Insulation.—The nonconducting material used as a covering for electric wires or to separate any part of a circuit from contact with conducting material which is not a part of the circuit.

Interruptor.—A device which rapidly makes and breaks an electrical circuit. The magnetic vibrator is the most common form of interruptor.

Jump spark.—The common name for the spark generated by a high-tension current leaping across the gap. High-tension ignition is often called "jump-spark ignition."

Key.—A suitably shaped piece of metal, usually steel, fitted in a slot or recess, part in the shaft and part in the wheel, cam, sleeve, or other device carried on the shaft. Its purpose is to fasten these parts on the shaft. A sliding key or "feather" is one so fitted that the part carried on the shaft can move lengthwise but can not revolve except as the shaft revolves.

Knock.—The regularly repeated jar or thumping sound caused by a loose bearing, or other poorly fitted or loose working part. A "carbon knock" is one caused by preignition, due to excessive carbon deposit in the combustion chamber.

L-head engine.—An engine, the cylinder of which has inlet and exhaust valves located on one side of the combustion chamber.

Liner.—A thin layer of suitable material (usually metal) placed between the two halves of an adjustable bearing to prevent too close contact between the bearing metal and the pin or shaft. Liners are sometimes called "shims."

Low-tension (*low voltage*).—With reference to gasoline-engine ignition "low tension" means, suitable, as regards voltage, for use with a "make-and-break" ignition system.

Lubricant.—Any substance used to coat the surface of bearings for the purpose of reducing friction between parts that rub one upon the other.

Lubrication.—The act or process of furnishing lubricant to bearing surfaces.

Magneto.—An electric generator especially designed for gas-engine ignition. It differs from a dynamo in that the current is intermittent, being furnished only at the time a spark is required. For this reason a magneto has to be so connected to the engine that its armature will be driven at a speed proportionate to the engine speed, and so set that a current is generated at the proper instants for ignition. "Timing" a magneto means setting the armature so that the above conditions are achieved.

Because of the intermittent nature of the current produced by a magneto, these machines are not suitable for lighting electric lamps or charging storage batteries.

A high-tension magneto is one that produces current at sufficiently high voltage to cause it to jump the gap of a spark plug.

A low-tension magneto produces a current at comparatively low voltage. This low-tension current has to be transformed to high-tension current by use of an induction coil if the jump spark is used.

Low-tension magnetos are sometimes used to furnish current for "make-and-break" ignition.

Make-and-break ignition.—An ignition system using a low-tension current and generating a spark by breaking the circuit within the combustion chamber at the proper time for ignition of each charge.

Manifold.—A pipe or passage having two or more branches leading to like ports or chambers of the several cylinders on multiple-cylinder engines. The two principal manifolds on an engine are the inlet manifold for conducting mixture from the carburetor to the cylinders, and the exhaust manifold for leading the exhaust from the separate cylinders into a common exhaust pipe.

Missing.—When the proper impulses fail to take place regularly in one or more cylinders the engine is said to be "missing." To "find which cylinder is missing" means determining in which cylinder the explosions do not occur either with regularity or at all. A word commonly used by motorists is "hitting," meaning the opposite of missing. As an example: Suppose four cylinders of a six-cylinder engine are working properly, while the other two cylinders do not deliver their power impulses regularly, then the four cylinders are said to be hitting, the two cylinders are missing.

Mixture.—The mixture of gasoline vapor and air as furnished by a carburetor is usually called simply "mixture."

A "lean mixture" is one that has a comparatively large proportion of air as compared with the proportion of gasoline vapor. A mixture having a comparatively large proportion of gasoline is called a "rich mixture."

Muffler.—A device for silencing or reducing the noise of the exhaust.

Needle valve.—A valve capable of close adjustment so that a very small amount of gas or liquid can flow through.

Oil groove.—A channel cut in a bearing surface to aid in the distribution of lubricant.

Oil sump.—A reservoir usually formed in the lower part of the crank case or sub-base, from which lubricating oil is circulated to bearings and to which it returns for recirculation.

Open circuit.—(See Circuit.)

Piston.—The cylindrical casting, together with its packing rings, which slides to and fro in the cylinder.

Piston ring.—A spring or ring neatly fitted in a groove around the piston body to form a tight joint between the piston body and the cylinder.

Piston pin.—The pin, carried in the piston body for forming the movable joint between the piston and the connecting rod. This pin is also sometimes called a wrist pin, gudgeon pin, or crosshead pin.

Port.—An opening for passage of gases into or out of a cylinder.

Preignition.—Explosion of the charge before the proper time.

Primary circuit.—The low-tension circuit of a jump-spark ignition system.

Priming a cylinder.—Introducing liquid gasoline into a cylinder or inlet manifold to facilitate starting.

Priming cock.—A pet cock with a cup-shaped nozzle, so fitted to the combustion chamber that it can be used to introduce liquid gasoline directly into this space. They are also sometimes called "relief cocks" since they furnish a means of releasing part of the charge as it is compressed, thus reducing the force required to turn the engine in starting.

Pump.—A device for causing a flow of gas or liquid, usually through pipes or passages. The three types of pump most used in gasoline engines are:

(*a*) Plunger pumps, having a piston or "plunger" working in a cylinder and check valves properly arranged to direct the flow.

(*b*) Centrifugal pumps, having a bladed wheel, or "impeller," somewhat like a paddle wheel, which revolves in a chamber or casing.

(*c*) Gear pumps, in which the flow is induced by the action of the teeth of gear wheels working in a casing.

Push rod.—A rod or pin operated by a cam, which transmits the cam motion to another part of the engine.

Radiator.—The chamber or system of passages through which cylinder cooling water is circulated to reduce its temperature.

Retarding the spark.—Nearly all engines have the ignition mechanism so arranged that the time at which the spark occurs in the cylinder can be regulated while the engine is running. When the adjustment is such that the spark occurs just at the end of the compression stroke or a little thereafter it is said to be "retarded."

Scores.—Scratches or grooves worn in the bearing surfaces as a result of poor lubrication. The bearing surfaces of pistons and the cylinder bore are especially liable to score unless properly lubricated and kept free of carbon or other gritty matter.

Secondary circuit.—The high tension circuit of a jump-spark ignition system, fitted with induction coil.

Sediment trap.—A bulb or pocket in a pipe line so located that dirt and solid matter settle in this chamber instead of being carried on through the piping. It is usually equipped with a strainer and arranged to be readily cleaned.

Series connections.—A method of connecting the various parts of an electrical circuit end to end, forming a single path for the current.

Shaft.—Any cylindrical bar, which transmits motion from one part of a machine to another part by virtue of a rotary motion about its own center line, is called a "shaft." Various devices such as cranks, eccentrics, cams, etc., when fitted to a shaft are usually included by the term "shaft." In a gasoline engine the principal shafts are the crank shaft and the cam shaft.

Short circuit.—(See Circuit.)

Spark.—The hot, brilliant glow caused by the electric current when the points of a make-and-break ignition plug are separated, or when a high tension current jumps the gap of a spark plug.

Spark advance.—To obtain economical and satisfactory working of an engine it is necessary to so regulate the time at which the spark is made that it occurs earlier in the cycle when the engine is running at high speed than when at slow speed. This regulation is usually accomplished by hand through a system of links and levers (the " spark advance mechanism "). This same mechanism is used for " retarding the spark."

Spark plug.—By " spark plug " is usually meant the ordinary " high-tension " plug, consisting of a threaded metal shell incasing an insulated spindle. The gap is between this spindle and a pin fastened to the outer shell. The plug or plate which carries the movable latch and insulated pin for a " make-and-break " spark is sometimes called a spark plug, but more often an " ignitor plug," or simply " ignitor."

Springs, valve.—In four-cycle engines the valves are usually opened by cams which operate the push rods, these, in turn, pushing the valve stems and lifting the valves from their seats. The return motion, or closing of the valve, is accomplished by steel coiled springs, called " valve springs."

Starter.—The mechanism by which the working parts of the engine are set in motion to accomplish starting. A hand starter usually consists of a hand crank which engages, through a ratchet, with the crank shaft in such a way that the engine can be turned in the proper direction and the crank is pushed out of engagement when the engine begins to run under its own power. When the engine is started by other than manual effort, it is said to be self-starting, and the mechanism is called a self-starter.

Strainer.—A screen used as a trap for dirt and sediment in oil or gasoline pipes.

Stroke.—By the stroke of an engine is usually meant the linear distance the piston moves in one direction. This distance is equal to twice the " throw of the crank " and is expressed in inches. The term " stroke " is also used to denote the movement of the piston in one direction; thus, in a four-cycle engine, by suction " stroke " is meant the movement of the piston during which a charge of mixture is drawn into the cylinder; the compression " stroke " is that during which the charge is compressed; the expansion " stroke " that during which the charge burns and power is delivered; and the exhaust " stroke " that during which the burnt gases are discharged from the cylinder. (See " Cycle.")

Sump.—(See " Oil sump.")

Switch.—An electrical device used to open or close a circuit.

Tension.—Same as " Voltage."

T-*head.*—A four-cycle engine having inlet valves on one side of the combustion chamber and exhaust valves on the other side is called a " T-head engine."

Thermo-siphon cooling.—A water-cooling system so arranged that circulation is caused by the difference in the weight of equal volumes of water at different temperatures.

Three-port engine.—A two-cycle engine having three ports in the cylinder walls.

Timer.—For successful operation the igniting spark must always take place when the piston has reached a certain point in the cycle; this point varies somewhat, according to the speed of the engine. That part of the ignition apparatus which determines the time at which the spark occurs is often called the " timer."

Timing.—The act of so adjusting or setting a timer that proper ignition results is called " timing " the ignition. The adjustment of the cam-shaft gearing is called " timing " the cam shaft.

Transformer.—(See Induction coil.)

Two-port engine.—A two-cycle engine which has but two ports in the cylinder walls.

Vacuum.—A vacuum is said to exist in a chamber when the contained gases are rarefied; that is, reduced to a pressure below that of the atmosphere.

Valve.—A device for opening or closing a passage through which liquids or gases flow, or for regulating the flow of these substances through a passage.

"*Valve-in-head.*"—When the valves of a four-cycle engine are fitted directly in the head of the cylinder the engine is said to be of the "valve-in-head" type. This construction is used to reduce the wall surface of the combustion chamber.

Valve lifter.—A tool for removing valve springs. Valve "push rods" are sometimes called valve lifters.

Valve seat.—The finished surface against which the disk of a valve presses to form a tight joint and close the passage.

Valve stem.—The rod on which the valve disk is carried and by which it is lifted from and drawn to its seat. Usually the valve disk and stem are integral; that is, a single piece of metal.

V *arrangement of cylinders.*—With engines having more than six cylinders the customary practice is to install the cylinders in two sets of equal numbers, the two sets being inclined at a suitable angle in the form of a V. Two-cylinder motorcycle engines usually have cylinders arranged in this manner.

Vaporizer.—This word is sometimes used with the same meaning as the word carburetor, especially with reference to carburetors of the simpler type.

Voltage.—The electrical pressure which causes a current of electricity to flow through a conductor.

Water-cooling system.—A system for preventing too high temperature of cylinder walls by circulating water through chambers surrounding these walls.

Wiring.—The insulated conductors or wires used to connect the various parts of an ignition system and form the various circuits is, as a whole, called the wiring.

Wiring diagram.—A sketch or plan showing the electrical connections of the apparatus which comprises the ignition system.

Worm gear.—(See "Gear.")

CHAPTER IV.

HOW A GASOLINE ENGINE WORKS.

A gasoline engine is a machine in which the power of an explosive mixture of gasoline vapor and air is used to produce rotary motion of a shaft. From this shaft the power can be transmitted to the apparatus which is to do the useful work.

Without taking into account engines of unusual design and those working on the turbine principle, still in the experimental stage of development, there are in use to-day a vast number of makes of gasoline engines, some differing so much in appearance and details that it seems quite impossible that all operate on the same general principle. But in practically all gasoline engines now manufactured the following series of operations takes place. Gasoline from the supply tank is carried by piping to a vaporizing apparatus, usually called a carburetor. Here the gasoline is converted into vapor and mixed with a proper proportion of air, forming the explosive mixture. A charge of this mixture is compressed in the engine cylinder by motion of the piston toward the cylinder head. When the piston is at or near the end of its compression stroke the charge is ignited and burns, the resulting pressure driving the piston away from the cylinder head, and by means of a connecting rod and crank causing rotary motion of the crank shaft and flywheel. The weight of the flywheel keeps the shaft in motion until another charge is compressed and exploded, thus causing continuous operation.

Two distinct types of engines have been developed, both operating as explained above, but differing in the method used for introducing fresh charges of gas into the cylinder. These two types of engines are designated as two-cycle and four-cycle, because in the former a complete series of events (technically called a cycle) necessary to produce one power stroke takes place during two strokes of the piston, while in the latter four strokes of the piston are required for each power stroke.

From a mechanical standpoint the two-cycle engine is much less complicated than the four-cycle. From a theoretical point of view the four-cycle is somewhat the simpler, since in this type the gases, both before and after combustion, are handled only in the cylinder space, while the two-cycle principle necessitates the use of another closed space, usually the crank case on the opposite side of the piston. As regards the relative merits of two and four cycle engines, each has distinct advantages for certain classes of work, as will be made evident by a careful study of the characteristics of each type.

THE TWO-CYCLE ENGINE.

A two-cycle gasoline engine is one in which an explosion takes place in the cylinder every time the shaft makes one revolution.

Figure 1 represents in section a single cylinder engine of the ordinary two-cycle type. When the engine is running the following operations take place. As the crank rotates in the direction of the arrow the piston (A) approaches the head of the cylinder (B) and compresses an explosive charge of gasoline vapor and air. At the extreme end of the stroke the charge is ignited by means of an electric spark inside the cylinder. The charge burns almost instantly, as described in the first chapter, generating heat, and therefore pressure, which forces the piston away from the cylinder head and delivers power to the crank shaft (C). When the piston uncovers the opening in the cylinder wall (D), called the exhaust port, the burnt gases escape to the open air, usually being led through a sound muffler and piping to a convenient place for discharge; but while the piston is moving away from the cylinder head a

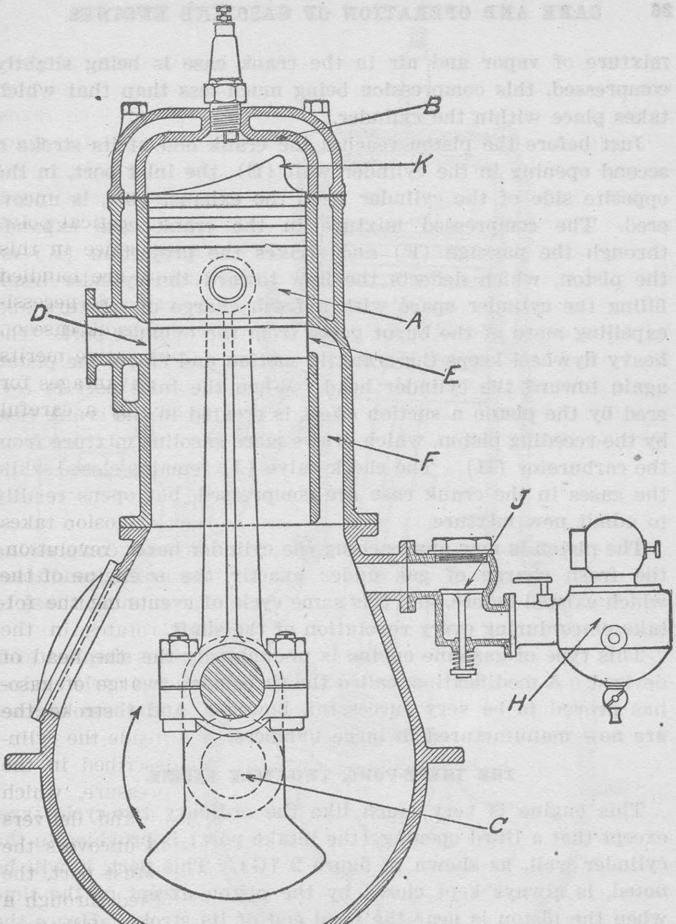

Figure 1.—Two-port, two-cycle engine.

mixture of vapor and air in the crank case is being slightly compressed, this compression being much less than that which takes place within the cylinder.

Just before the piston reaches the crank end of its stroke a second opening in the cylinder wall (E), the inlet port, in the opposite side of the cylinder from the exhaust port, is uncovered. The compressed mixture in the crank case expands through the passage (F) and strikes the projection (K) on the piston, which deflects the flow toward the cylinder head, filling the cylinder space with a fresh charge of mixture and expelling more of the burnt gases from the exhaust port. The heavy flywheel keeps the crank in motion and starts the piston again toward the cylinder head. When the inlet port is covered by the piston a suction effect is created in the crank case by the receding piston, which draws more gasoline mixture from the carburetor (H). The check valve (J) remains closed while the gases in the crank case are compressed, but opens readily to admit new mixture.

The piston is now approaching the cylinder head, compressing the fresh charge of gas under exactly the same conditions which existed before, and this same cycle of events continues to take place during every revolution of the shaft.

This type of gasoline engine is undoubtedly the simplest ever devised. A modification, called the three-port, two-cycle engine, has proved to be very successful, however, and these engines are now manufactured in large numbers.

THE THREE-PORT, TWO-CYCLE ENGINE.

This engine is very much like the ordinary two-cycle type, except that a third opening (the intake port) is provided in the cylinder wall, as shown in figure 2 (G). This port, it will be noted, is always kept closed by the piston except at the time when the piston is near the head end of its stroke. Hence the crank-case space is tightly closed as the piston recedes and

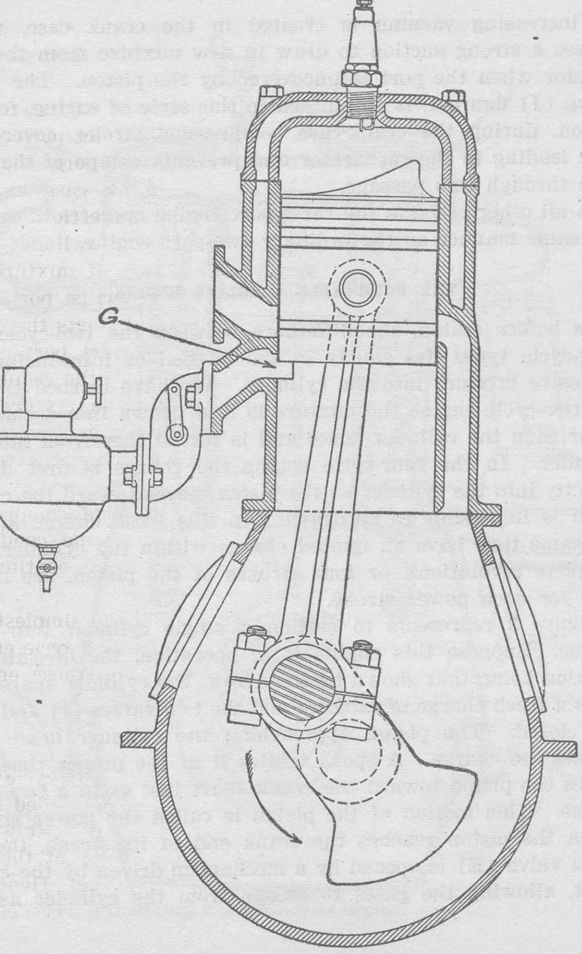

Figure 2.—Three-port, two-cycle engine.

an increasing vacuum is created in the crank case, which causes a strong suction to draw in new mixture from the carburetor when the port is uncovered by the piston. The check valve (J) figure 1, is eliminated in this style of engine, for the piston, during the crank-case compression stroke, covers the port leading to the carburetor and prevents escape of the mixture through this passage.

In all other respects the three-port engine operates in exactly the same manner as the ordinary two-port engine.

THE FOUR-CYCLE GASOLINE ENGINE.

As before stated, the difference between the two-cycle and four-cycle types lies chiefly in the method of introducing the explosive mixture into the cylinder. We have learned that in the two-cycle engine the mixture is first drawn into a chamber other than the cylinder space and is forced therefrom into the cylinder. In the four-cycle engine the charge is first drawn directly into the cylinder as the piston moves toward the crank. As it is impossible to be drawing in this fresh charge and at the same time have an ignited charge within the cylinder, two complete revolutions, or four strokes of the piston, are necessary for each power stroke.

Figure 3 represents in section a single cylinder four-cycle engine. Suppose this engine is in operation, the direction of rotation being that shown by the arrow, the cylinder space contains a fresh charge of mixture and the two valves (I) and (E) are closed. The piston approaching the cylinder head compresses the charge. A spark ignites it at the proper time and drives the piston toward the crank shaft just as in a two-cycle engine. This motion of the piston is called the power stroke. When the piston reaches the crank end of its stroke, the exhaust valve (E) is opened by a mechanism driven by the crank shaft, allowing the gases to escape from the cylinder as the

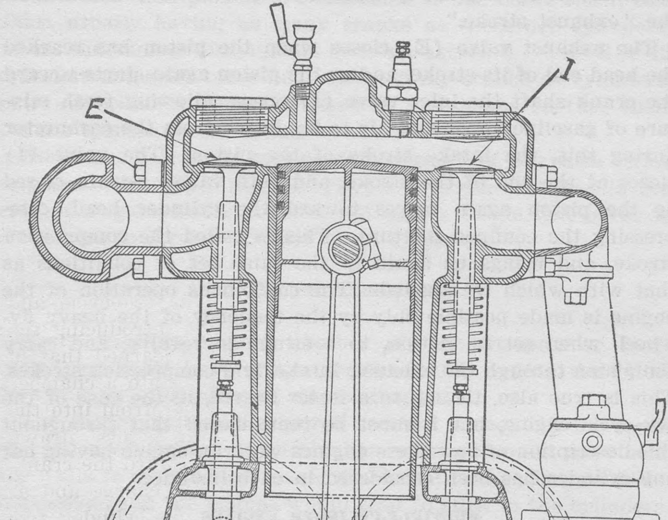

FIGURE 3.—Four-cycle engine.

piston moves toward the cylinder head, or makes what is termed the "exhaust stroke."

The exhaust valve (E) closes when the piston has reached the head end of its stroke, and as the piston again starts toward the crank shaft the inlet valve (I) opens, allowing fresh mixture of gasoline vapor and air to be drawn from the carburetor during this, the intake stroke of the piston. The valve (I) closes at the end of the stroke, and both valves remain closed as the piston again moves toward the cylinder head, compressing the confined mixture. This is called the compression stroke, and brings us again to the same set of conditions as that with which we started. The continuous operation of the engine is made possible only by the tendency of the heavy flywheel, when set in motion, to continue to revolve, and carry the piston through the exhaust, intake, and compression strokes. This is true also, though to a lesser degree, in the case of the two-cycle engine, but it must be remembered that throughout this description of how these engines work an engine having but one cylinder has been considered in each instance.

MULTIPLE-CYLINDER ENGINES.

It is evident that if two two-cycle engines had their shafts coupled together, two power strokes would be obtained during each revolution of the shafts, and if the connection was so made that the cranks were opposite each other, one engine would be furnishing a power stroke while the other engine was compressing a new charge of mixture. A much lighter flywheel would therefore be required for a pair of engines coupled as above than would be necessary for a single engine, the delivery of power to the shaft would be much more uniform, and vibration would be much less than that of a single engine of the same power.

In practice, instead of coupling two or more engines together to gain these advantages, two or more cylinders are so arranged that their pistons are connected to one crank shaft, this shaft usually having as many cranks as there are cylinders, where the number of cylinders does not exceed 6. With 8 or 12 cylinders there are often but half as many cranks as cylinders, pairs of cylinders being arranged in a V shape so that their pistons operate on one crank.

No matter how many cylinders an engine has, the same series of events takes place in each cylinder as those described in the case of single-cylinder engines, although a single carburetor is often used to furnish mixture to all cylinders.

COOLING AND LUBRICATION.

Every gasoline engine, whether of the two-cycle or four-cycle type, must have proper provisions for cooling the cylinders and for lubrication of all working parts.

The cooling system is required because, without it, the rapid succession of explosions within the cylinders would soon heat the walls to such a high temperature that lubrication would be impossible, and the pistons would tend to stick in the cylinders. Even though it were possible to accomplish lubrication at this high temperature, the heat would soon become so great that the material of which cylinders and pistons are made would be damaged, and the charge of mixture would be ignited before the proper time, causing what is termed "preignition."

The lubricating (oiling) system is necessary to prevent excessive friction and wear on moving parts of the machine. In some respects the lubricating system is the most important part of an engine. Derangement of the gasoline or ignition systems may cause great annoyance and make an engine run badly or refuse to run at all, but such troubles seldom cause real damage, whereas failure of the lubricating system is almost sure to cause very serious damage, such as burned-out bearings or scored pistons and cylinders.

CHAPTER V.

DESCRIPTION OF THE VARIOUS PARTS AND SYSTEMS OF A GASOLINE ENGINE.

We have now learned what operations must take place when a gasoline engine is running. The various parts and systems which are essential to make possible these operations will now be described.

A complete practical gasoline engine may be considered as an assembly of the following parts and systems:

(*a*) The main engine body, made up by cylinders, crank case or cylinder supports, pistons, connecting rods, crank shaft, flywheels, valves and valve-operating mechanism, bearings, and bedplate.

(*b*) The gasoline system, including storage tank, piping, carburetor, and passages for conducting the mixture of air and vapor to the engine.

(*c*) The ignition system, which includes the battery, dynamo, or magneto, supplying the electric current, induction coils, vibrators, timing devices, wiring, switches, and spark plugs.

(*d*) The cooling system, embracing water jackets, piping, pumps, radiators, fans, air conduits, etc., as the case may be.

(*e*) The lubricating system, consisting of oil reservoirs, grease cups, pumps, regulating devices, indicators, piping, and passages.

Mufflers, governors, self-starters, and various other equipment not absolutely essential to make the engine run are quite necessary in some cases for convenience or to adapt the engine to certain uses.

THE MAIN BODY OF THE ENGINE.

Cylinders are ordinarily made of cast iron on account of its cheapness, the comparative ease with which this material can be cast into intricate shapes and machined to accurate dimensions, and the fact that this material has properties which make it very efficient in resisting the wearing effect of the reciprocating piston. As the cylinders constitute the largest part of an engine their form and arrangement determines the general arrangement of the complete machine. Most engines now manufactured have vertical cylinders, the head, or closed end, being uppermost. This type occupies somewhat less floor space than is required for an engine of equal power having horizontal cylinders. But as floor space in some instances is not of primary importance many stationary engines are built with horizontal cylinders.

The vertical arrangement of cylinders is especially adapted for marine and automobile use, as here only a restricted amount of space is available, and the low position of the crank shaft is required to allow direct connection to a propeller shaft or drive shaft. A few years ago, when the automobile industry was in its infancy, designers seemed to attempt to hide the propelling apparatus beneath the seat or body of the vehicle. Engines having horizontal cylinders were therefore used. Experience, however, showed the desirability of setting aside a special place for the engine where it would be readily accessible for inspection, cleaning, and repair. The location which best fulfills these conditions is at the front of the vehicle, the engine being set with shaft lengthwise, and covered only by a light sheet-metal hood. This arrangement is now universally used.

Recently several automobile manufacturers have brought out machines with engines having 8 or 12 cylinders. If all these cylinders were arranged vertically in a single row, the complete engine would be so long that the body of the car would have to be very short, or the length of the car would be too great for practical use in street traffic. Automobile engines having 8 or 12 cylinders are therefore arranged with two sets of 4 or 6 cylinders, these two sets being inclined at an angle of 45° from the vertical if the number of cylinders is 8, and 30° if there are 12 cylinders, and so arranged that the pistons of the forward cylinder of each set are both connected to the forward crank of the shaft, the pistons of the next two cylinders are connected with the second crank, and so on.

Eight and twelve cylinder aeroplane engines usually have the cylinders arranged in this manner, though some makers place the two sets of cylinders horizontally. An engine thus arranged is said to have "opposed" cylinders. Four and six cylinder aeroplane engines are usually of the vertical type, this engine being much like that of a four or six cylinder automobile.

In the design of cylinders a vast variety of arrangements of minor parts has been devised. In some cases the cylinder and cylinder head are cast together; in others the heads are separate and held in place by bolts. The first arrangement eliminates the joint between the cylinder and head and reduces the number of separate parts, the second makes it much easier to open the cylinder, as by simply removing the head the interior of the cylinder and combustion space is exposed for inspection and cleaning.

Some two-cycle engines have a single casting for the cylinder and crank case, removable plates being fitted to the crank case for access to the working parts and for installing the crank shaft. Other engines have the cylinders bolted to the crank case. The cylinder of a two-cycle engine must be carefully designed and accurately made as regards the location of the exhaust and inlet ports, because the economical operation of the engine depends largely on the time and duration of inlet and exhaust. In a similar way the design of combustion chamber and valve arrangement of four-cycle engines is of extreme importance from the standpoint of economy. Four-cycle engines having inlet valve chamber on one side and exhaust valve chamber on the opposite side of the combustion chamber are called T head engines because of the likness of the shape of the cylinder casting to the letter T. Where both valves are on one side of the cylinder the engine is an L head, the casting having a general shape like an inverted L. A "valve-in-head" engine has its valves fitted directly in the cylinder head.

In multiple-cylinder engines each cylinder may be a separate casting, or two or more cylinders may be cast together; that is, "en bloc." This point is determined by practical considerations, such as the use for which the engine is built, the number of a single size to be manufactured, cost of construction, etc.

As to the relative merits of these various arrangements, although manufacturers of certain types devote considerable space in catalogues and pamphlets to arguments "proving" their design is superior to others, the fact remains that engines of almost every conceivable design have been successful. Proper proportion of parts, high quality of material, and good workmanship apparently have more to do with the ultimate success or failure of an engine than type and general arrangements.

CRANK CASE.

The ordinary type of two-cycle engine must have a separate air-tight crank case for each cylinder, because, as we have learned, these engines utilize the crank case as a sort of pump chamber for introducing the mixture into the cylinder. With engines working on the four-cycle principle there is no absolute necessity for any crank-case at all, many engines, especially in the larger sizes, being constructed with the cylinders mounted on columns, leaving the crank shaft, connecting rods, etc., entirely exposed. This arrangement is not practicable in small engines, and the usual practice is to inclose the crank shaft and bearings in a case common to all cylinders, which prevents dirt from reaching the working surfaces and facilitates lubrication. The upper part of this case is usually made of cast iron and provided with webs to support the crank-shaft bearings. The lower part may be of cast iron, pressed steel, or aluminum alloy, and is often arranged to form an oil reservoir.

CRANK SHAFT.

Crank shafts are made of forged steel. In high-grade engines and those built for service requiring a minimum weight of engine per horsepower developed, steel containing a small proportion of other elements, such as vanadium and nickel, which give the metal greater strength, is used. Shafts are made by forging the rough bar (or billet) into the approximate shape required in the finished shaft, then surplus metal is removed by machine tools and the bearing surfaces turned to exact dimensions. For high-class engines, after being finished in this manner, the shaft is given a heat treatment to improve the quality of the metal, then all bearing surfaces are carefully ground to a smooth, glassy finish.

The crank shaft revolves in the main bearings. In large engines these bearings are carried by a foundation frame or bedplate; in small four-cycle engines, by webs of metal cast in the crank case; in small two-cycle engines by plates on the sides of, or between, the separate crank cases.

The position of the cranks with relation to each other in multiple-cylinder engines is so fixed that equal intervals will elapse between explosions in the various cylinders, insuring as nearly as possible a constant delivery of power.

CONNECTING RODS.

Connecting rods are usually made of forged steel, though cast bronze is sometimes used in small engines. The shape of cross section of the rod is often made similar to an I, H, or +, as with the same weight of metal a rod having one of these shapes has greater strength to resist bending than would be obtained in a plain round one. The crank end of the rod is enlarged to form a bearing for connection to the crank pin. This bearing ordinarily is in halves, one half being on the solid end of the connecting rod, the other half being a cap held in place by the connecting-rod bolts. The other end of the rod is fitted with a bearing to allow it to swing on the wrist pin, or, in some engines, this pin is fastened solidly in the connecting rod and works in bearings in the walls of the piston.

PISTONS.

Pistons are made of cast iron or, for light high-speed engines, of aluminum alloy. As it is impossible to make a piston that will fit a cylinder closely enough to prevent leakage and at the same time not be so tight as to cause excessive friction between the surface of the piston and the cylinder wall, special provision is made to prevent leakage by turning recesses in the body of the piston and accurately fitting split metal rings of such shape and dimensions that elasticity causes them to press tightly against the cylinder wall.

Two-cycle engines are often spoken of as being valveless. In a certain sense this statement is true, for no special parts are necessary to regulate the admission of mixture and the discharge of burnt gases from the cylinder, these operations being entirely controlled by the piston as it reciprocates. To properly regulate these events a two-cycle engine piston has a projection, as shown in figure 1 (K), to prevent the fresh charge passing directly across the cylinder and escaping through the exhaust passage. In some three-port engines an opening is provided in the side of the piston for the admission of mixture from the carbureter to the crank case.

VALVES.

With four-cycle engines, admission and exhaust valves before referred to (fig. 3) (I and E) are installed. These valves are almost invariably operated by cams on a shaft which is geared to the crank shaft in such a manner that it makes one revolution while the crank shaft makes two. On account of this fact cam shafts are sometimes called "half-time shafts."

CAM SHAFTS.

The location and arrangement of cam shafts and their driving gear varies greatly in different makes of engines. With T-head, multiple-cylinder, four-cycle engines, all cylinders have exhaust valves on one side and inlet valves on the other side. These engines often have two cam shafts, one carrying the cams that operate the exhaust valves, the other for the inlet-valve cams. Some T-head engines, however, have a single cam shaft located over the cylinder heads, from which all the valves are operated by levers. When two cam shafts are used, and in L-head engines, which have but one cam shaft, a location as shown in figure 3 is usually chosen, though in some engines outside of the crank case.

In large engines the cams are separate steel forgings fastened in their proper places on a plain shaft; in the smaller engines the cams and shaft are usually one solid forging. While it is cheaper to make the cams and shaft separate, and assemble the parts to form the complete cam shaft, there is always danger with a small shaft built up in this way that the fastenings will work loose and allow the cams to slip out of position and operate the valves at other than the proper time. In fact great care has to be exercised in making cam shafts, for accuracy with which the valves of a four-cycle engine open and close at the proper times is absolutely necessary for smooth running.

FLYWHEELS.

Flywheels are made of cast iron because this metal is heavy, cheap, and easily cast and machined. Aside from its purpose of keeping the engine in motion during intervals when power is not being delivered by the explosions, the flywheel exercises a steadying effect on the machine by its tendency to eliminate sudden changes in the speed of rotation of the shaft. One-cylinder stationary engines often have two flywheels of comparatively large diameter, for in this case there is no objection to the considerable weight, and full advantage can be taken of the steadying effect. With a two-cylinder engine, the flywheel may be much lighter than that required for a single-cylinder engine of the same type and power. This is true to a greater degree with engines having more than two cylinders, until with 8 or 12 cylinders the necessity for a flywheel is almost eliminated, power being delivered by one or more of the several pistons at all times. This is one of the advantages of multiple-cylinder engines, especially where a light-weight engine is required, as in an aeroplane.

THE GASOLINE SYSTEM.

The form and construction of gasoline supply tanks depend almost wholly upon the class of work the engine is to perform. For automobiles, the tanks must have sufficient strength to resist strains due to vibration and the jar caused by rough roads; for aeroplanes, made as light as possible without too great a sacrifice of strength; and for vessels, usually so shaped that they will fit conveniently the form of the hull. Partitions or swash plates, dividing the tanks into several chambers, are fitted in tanks that are not stationary, thus preventing the whole body of liquid from shifting about suddenly and straining the tank. Small openings at the top and bottom of these partitions prevent air pockets and allow the liquid to flow slowly from one chamber to another. Stationary tanks may be of almost any form or size to suit the local conditions. When the engine is installed inside of a building, it is advisable, if possible, to locate the tank outside the building. Large supply tanks are often placed underground, and the gasoline forced up through a pipe to the engine by air pressure, this method of feeding the gasoline to the engine being commonly used whenever the tank outlet is below the level of the carbureter. The hole for filling the tank should be conveniently located so that a common funnel of large size may be used when replenishing the supply.

Where the gravity-feed system is used—that is, when the tank is higher than the carburetor and the fuel simply flows through a pipe by gravity—a small hole in the top of the tank (usually in the filling plug) must be provided to allow air to enter the tank as the fuel is used. Where the tank is lower than the level of the carburetor the tank must be air-tight and strong enough to withstand sufficient air pressure to force the gasoline up to the carburetor. This pressure is maintained by a small air pump attached to the engine, by a hand pump, or by the pressure of the exhaust gases. Recently some carburetor manufacturers have adopted the system of using partial vacuum for drawing fuel from the tank. Several advantages are claimed for this arrangement, such as less danger from leaks and elimination of any possibility of the tank bursting from too great air pressure.

The pipe for conducting gasoline to the carburetor should have its suction end as low in the tank as possible. A stop cock or valve should always be fitted next to the tank, and a suitable strainer, so arranged as to be easily cleaned, located next to this valve is a great advantage. The pipe line should have as few joints as possible and must be securely supported so that there will be no chance of breakage from vibration or other cause.

The mixing device or carburetor is located near the cylinder, often being fastened to a support provided for this purpose on the engine body. When the industry was in its infancy the scheme usually adopted to vaporize the gasoline was to pass air over the surface of a body of the liquid. This involved at best a large and cumbersome device, sometimes ingeniously arranged to secure a sufficient surface of liquid to make an explosive mixture. Although these surface carburetors worked fairly well with high-grade gasoline, they have been entirely supplanted by a much smaller and more efficient apparatus, in which the liquid is vaporized by being sprayed into a current of air. About the simplest device of this sort, and one that works well for small engines running at nearly constant speed, is shown in figure 4. It consists of a sort of check valve (A) fitted with an adjustable stop (S) for regulating the amount this valve may open, and a needle valve (B) for regulating the gasoline feed through a small hole in the seat of valve (A). This type of carburetor is called a "gasoline generator valve" or "vaporizer." The manner in which it works is as follows: The suction effect of the engine is communicated to the valve (A) through the connection (M) and the chamber (N), lifting the valve and drawing in air through the opening (O). As long as the valve (A) is closed no gasoline can flow through the small hole (C), for it is covered by the valve, but the instant the valve is lifted off its seat a fine stream of gasoline sprays into the passage, becoming vapor and mixing with the air current. The purpose of the needle valve (B) is to regulate the amount of liquid that can enter, and thus make the mixture richer or leaner as desired. A coiled spring on the guide stem holds the check valve snugly to its seat when the engine is not exerting the suction effect or when stopped. This type of carburetor is undoubtedly less economical than the more complicated forms hereafter described, but this disadvantage is quite offset in many cases by its ex-

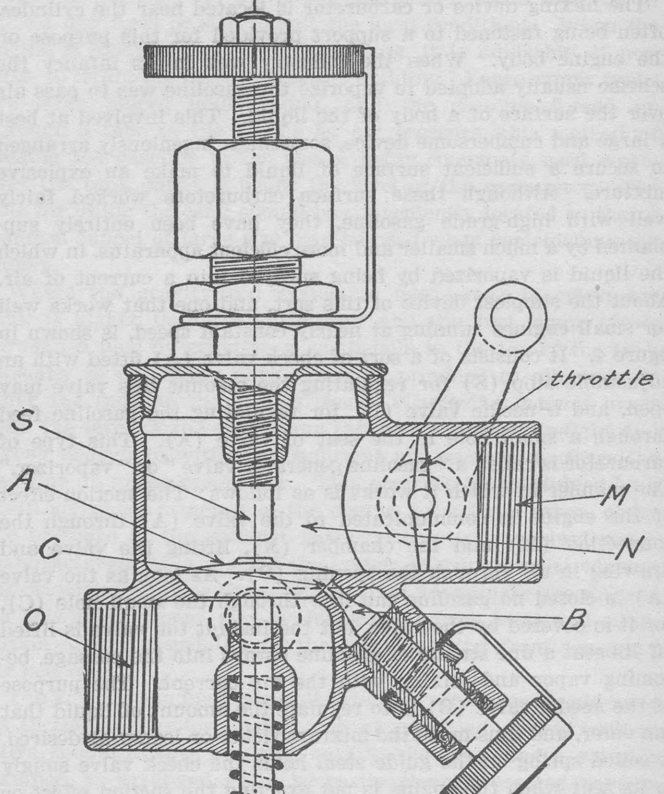

FIGURE 4.—Vaporizer.

treme simplicity and durability, especially when used on small-powered two-cycle engines.

The form of carburetor now used to a greater extent than any other, and which seems destined to be universally adopted, is that known as the "float-feed" type. Figure 5 represents a typical form of float-feed carburetor and illustrates the general principle on which nearly all of these carburetors operate. Gasoline enters the bowl from the pipe line through the needle valve (A). As the depth of gasoline in the bowl increases, the float (F), usually made of cork, rises, and through its connection to the needle valve (A) by the lever (L), shuts off the flow. A level of gasoline in the bowl is thus maintained, which is just below the opening of the spray nozzle (N), but when the engine exerts its suction on the carburetor the liquid is drawn up through this nozzle and sprays into the current of air flowing throught the passage (P). A needle valve (K) is fitted in the spray nozzle to regulate by hand the size of the opening, and a gate or valve (X) is placed in the discharge passage to act as a throttle and control the flow of mixture to the engine. A similar gate or valve (Y) is usually fitted in the air intake.

The distinguishing feature of this type of carburetor, and the one that makes it so popular, is the automatic regulation of the flow of gasoline by the float, since when once properly adjusted the apparatus needs no attention, and changes in the depth of fuel in the tank or in the height of tank above the carburetor cause no variation in the rate of feed, this rate being affected only by the setting of the throttle and the strength of suction of the engine. Furthermore, when the engine is stopped, the flow of gasoline is automatically shut off. Of course, the size of the carburetor is determined by the size of the engine cylinder, the number of cylinders, and the rate at which the engine runs, or, in other words, by the horsepower.

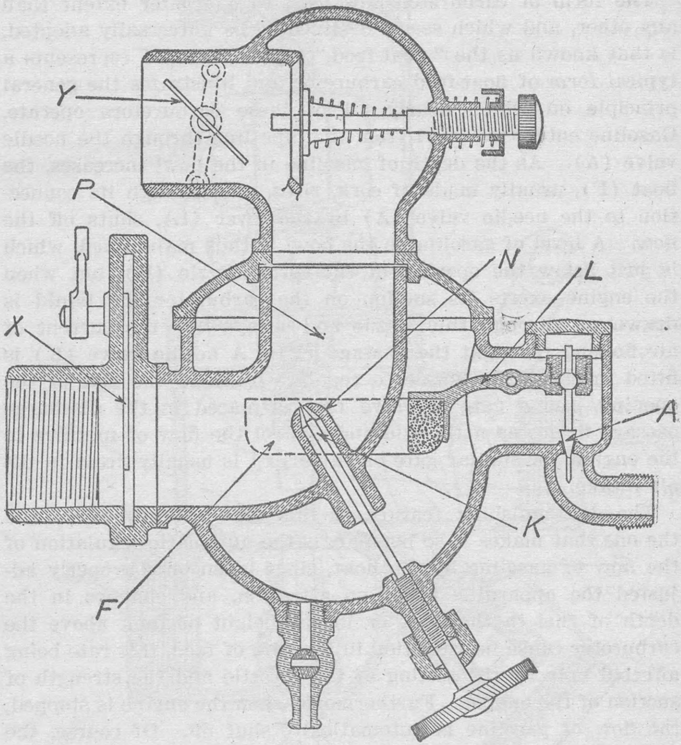

FIGURE 5.—Float-feed carburetor.

In the various makes of float-feed carburetors can be found almost every conceivable shape, arrangement, and proportion of parts. Some have two or more spray nozzles which are arranged to open successively as the speed and power of the engine increases or as the throttle is opened. Others have elaborate arrangements for the operator to admit heated or cooled air, either before it reaches the gasoline spray, or in the passage between this point and the engine. But, in general, it is true that, unless an engine is to be operated by a man so expert that he can take advantage of these refinements and thus keep the carburetor adjusted so as to obtain the maximum economy of fuel, it is much more satisfactory to have an engine equipped with a simpler type which is less liable to disarrangement, even though some slight sacrifice is made from an economical standpoint.

The passage for conducting the mixture from the carburetor to the engine is usually a plain piece of pipe when there is but one cylinder. Where the carburetor furnishes mixture for two or more cylinders the connection is usually a single casting or brazed tubing with separate outlets to the several cylinders, and is called the intake manifold.

IGNITION.

In most gasoline engines now manufactured ignition, as before stated, is accomplished by an electric spark. Two distinct systems have been invented for producing a spark within the cylinders at the proper time for igniting the charges of gas.

One system is that known as the "make-and-break" or low-tension system; the other is the "jump-spark" or high-tension system.

"Make-and-break" ignition is possible owing to the fact that when a metallic circuit in which a current of electricity is flowing is broken a spark is generated at the point where the break occurs. This spark is caused by the fact that air, vapors, and gases are poor conductors of electricity. Now, in breaking a metallic circuit the break necessarily begins with a very slight separation of the terminal points (no matter how sudden may be the break). The current of electricity, however weak, has power to leap across this very slight break, and in so doing heats the intervening medium of air, vapor, or gas to such a degree that it glows and forms a spark or "electric arc."

This spark is greatly increased in magnitude if a choke coil (commonly called a "make-and-break" coil) is connected in the circuit. This type of coil is a very simple affair, consisting only of an iron core upon which is wound fairly coarse insulated wire, just as thread is wound on a spool. In practice it has been found that a battery, dynamo, or low-tension magneto furnishing a 6 or 8 volt current will generate a spark of sufficient intensity to fire a charge of gasoline vapor and air when compressed in the engine cylinder, provided a suitable coil is connected in the circuit and the break within the cylinder is sufficiently sudden.

The device used to make and break the current within the cylinder and thus generate a spark usually consists of a stationary metal pin which projects into the combustion chamber and a movable latch with a stem extending through the walls of the combustion chamber. The stationary pin is kept from metallic contact with the surrounding metal by an insulating medium (usually mica) to prevent the current from flowing directly from the pin to the body of the engine. One of the terminals of the battery or dynamo is connected by insulated wire to one terminal of the coil and from the other coil terminal to this pin. The movable latch is so located with relation to the stationary pin that when the stem is slightly rotated the arm within the cylinder is brought into contact with the pin. The current can then flow across this point of contact to the latch, thence into the body of the engine, and back to the other terminal of the battery or dynamo through an insulated wire connecting the body of the engine to this terminal.

A mechanical timing device operated from the crank shaft, or (in four-cycle engines) from the half-time shaft, is connected to the latch in such a manner that the arm is rotated into contact with the pin just before the end of the compression stroke of the engine piston, thus establishing a current, and then suddenly jerked away from the insulated pin, breaking the current and causing a spark at the proper instant for ignition of the compressed charge. This operation is repeated for each working stroke of the piston.

For comparatively slow-speed engines, especially those of the two-cycle type, the make-and-break system works very well if the operating mechanism is well designed and carefully made.

The advantages of this system of ignition are:

(*a*) *Simplicity.*—The electrical connections and the mechanical operating device being so simple that they are readily understood.

(*b*) *Possibility of easy repair.*—On account of its simplicity repairs can usually be made to any part of this system with the facilities to be found in small repair shops.

(*c*) *Freedom from trouble caused by electrical leakage.*—With the low voltage required by this system there is seldom any trouble experienced due to breaking of insulation. This is especially advantageous in marine work, where damp air and water often cause leakage from high-tension wires.

The disadvantages of make-and-break ignition are:

(*a*) *Burning away of contact points.*—The action of the spark burns the insulated pin and latch at the point where the break occurs, causing these surfaces to become rough and dirty and preventing a good contact to "make" the current. To avoid this trouble the pin and latch have to be fitted with small platinum or platinum-irridum contact points, which metals best resist the action of the spark. However, as these metals are costly, the expense of renewal is high.

(*b*) *Noise and excessive wear.*—The mechanical timing device usually has reciprocating parts that are noisy and require frequent repair.

(*c*) *Leakage of compression around latch pin.*—Loss of compression is often caused by leakage around the movable latch pin where it passes through the walls of the combustion chamber.

JUMP-SPARK OR "HIGH-TENSION" IGNITION.

The jump-spark system of ignition depends upon the fact that, if the "electrical tension" or voltage is sufficiently high, the current will leap across a small permanent break or gap between the two ends of the metallic circuit and cause a spark at this point.

To produce this high voltage either a low-tension current is used and a high-voltage current obtained therefrom by means of an induction coil, or the high-tension current is produced direct by a high-tension magneto, which instrument both generates a low-tension current and transforms it to high tension.

A jump-spark ignition system using batteries, dynamo, or low-tension magneto is made up of the following parts:

(*a*) The source of the low-tension current (battery, dynamo, or low-tension magneto) furnishing a current of from six to eight volts.

(*b*) A timing device or commutator for making and breaking the low-tension circuit (called the primary circuit).

(*c*) Transforming induction coil with magnetic vibrator, which, through the action of the primary current, generates a high-tension or secondary current.

(*d*) A distributor for directing the secondary current to the spark plug of the proper cylinder (not necessary with a single-cylinder engine).

(*e*) Spark plugs, which are fitted in the combustion chambers and furnish the gap across which the high-tension current jumps and forms the spark.

(*f*) Wiring and switches for connecting the above apparatus in the proper manner. Wires for the high-tension circuit differ from that which is suitable for the low-tension circuit, in that the insulation has to be much heavier to prevent the high-electrical pressure breaking the insulation and allowing the current to leak out into neighboring metal parts of the engine.

Let us consider how these various parts are connected and operate on, say, a four-cylinder, four-cycle engine, a battery being used as the source of current.

The battery stands ready to cause a current to flow around the primary circuit whenever this circuit is "closed"; that is, complete with no breaks or gaps. One terminal of the battery is connected to a binding post on the commutator. This commutator is a sort of switch so arranged on a four-cylinder, four-cycle engine that it will "make and break" the primary circuit four times while the crank shaft makes two revolutions, causing a current to flow for a short interval at the times when the spark is required for each cylinder. When the circuit is thus closed by the commutator, current flows from the battery through the commutator contacts and through a wire connection to the proper binding post on the induction coil. Here the current flows around the primary winding of the induction coil and through the vibrator, magnetizing the iron core and causing the vibrator to rapidly interrupt the current. From the coil the current flows back to the other battery terminal. (In practice it is usual to have the rotating part of the commutator in metallic contact with the body of the engine. The battery terminal first mentioned is then connected to the body of the engine and is said to "grounded." The current flows through the connection, through the body of the engine and into the stationary contact point or points of the commutator, which, like all other parts of the circuit, are insulated from the engine body.)

Thus far we have considered only the primary circuit. When the circuit is closed by the commutator and is being rapidly interrupted by the vibrator, a high-tension current is "generated" or "induced" in the secondary winding of the coil. The binding post at one end of the winding is connected to the central connection of the distributor, this device being a rotary switch much like the commutator, but suitable for handling the high-tension current, and so arranged that it leads the current through four connections to the spark plugs. The commutator in the primary circuit and the distributor in the secondary circuit have to be so timed that contacts are made simultaneously.

From the distributor the high-tension current flows to the binding post on the insulated spindle of the proper spark plug, jumps the gap causing a spark, and returns through the body of the engine and wiring to the other end of the secondary winding on the coil.

The distributor sends the high-tension current successively to each spark plug at the proper time for ignition in the various cylinders.

There are several variations of the above arrangement, one being the use of a separate coil and vibrator for each cylinder. This eliminates the use of a distributor, but has a disadvantage in that four vibrators instead of one have to be kept in adjustment.

When an engine has but one cylinder the commutator is arranged to make and break the circuit once each revolution of the engine, if the engine is two-cycle, and once for each two revolutions if four-cycle. In this case no distributor is necessary, as the secondary coil has to send its current to only one spark plug.

In any case the commutator and distributor have to be designed especially for the particular number of cylinders and the type of engine with which it is to be used.

As before mentioned, the high-tension magneto is a form of electric generator which produces directly a high-tension current without the use of a separate coil. Some of the instruments of this type are splendid examples of the instrument maker's art and are so arranged that they not only produce the high-tension current, but also distribute it to the proper spark-plug connections. The magneto has to be so driven from the crank shaft or half-time shaft that its speed of rotation will bear a definite relation to the engine speed, determined usually by the number of cylinders, and the armature must be so set or "timed" that sparks will be produced at the proper instants for igniting each charge.

The instruments are very complicated, and no person other than an expert should attempt to repair or make other than the simpler adjustments to the mechanism. This statement is also true with regard to induction coils, the only adjustment permissible in this case being that of the vibrator.

It is common practice to equip high-class engines with two independent ignition systems, one employing batteries and induction coils, used only when starting the engine and in case of emergency, the other being a magneto for regular running.

A few engines are built which use both "make-and-break" and "jump-spark" ignition.

Where two separate systems are used, it is, in most cases, for the sake of reliability, though in engines required to deliver a maximum of power there is a distinct advantage in running the two systems in unison, as this insures more instantaneous ignition and therefore higher power.

THE COOLING SYSTEM.

Two methods are used for cooling cylinders of gasoline engines, one using air, the other water as the cooling agent.

Probably the simpler system is that which employs air, but this system is satisfactory only on engines having comparatively small cylinders. It is used on engines of motor cycles, on several makes of aeroplane engines, and in one instance very successfully for an automobile engine.

In order to furnish sufficient surface from which the heat can pass (radiate) to the air, cylinders of air-cooled engines have metal projections, either cast as part of the cylinder body itself or fitted as separate pieces around the cylinder casting.

Moving air at atmospheric temperatures cools a heated surface much more rapidly than quiet air. This fact is used to advantage in the case of air-cooled engines. On motorcycles air circulates rapidly past the cooling projections or fins on account of the motion of the vehicle itself. On an aeroplane both the velocity through the air and the blast from the driving propeller accomplishes this circulation. Successful air cooling of an automobile engine has only been accomplished through the use of an ingenious arrangement of air passages and fans.

For water cooling the cylinder has to be surrounded by a chamber (water jacket) or passages through which the water is circulated. In most instances the cylinder castings are made with two walls, the outer one surrounding the combustion chamber and valve recesses to form the water passage. Where extreme lightness is essential, a thin metal case is fitted to the cylinder casting with water-tight joints to form the jacket.

If an unlimited supply of water is available, as is the case with marine engines, a water circulating pump, driven by the engine itself, draws water from the source of supply (in marine practice from the water in which the vessel floats) and forces it through piping to the cylinder jackets. On passing through the jackets, the water cools the cylinders and itself becomes heated. From the jackets, the heated water is led by piping to a convenient place for discharge (overboard in marine practice).

For vehicles, and where the supply of water is limited, a radiator is used and the heated water after leaving the cylinders passes through this radiator where it is cooled and thus made ready to be pumped again through the cylinder jackets. The radiator used for this purpose is made of narrow sheet metal passages so arranged that air can circulate between them and reduce the temperature of the water. Through the use of a radiator, a comparatively small quantity of water is required, this supply being circulated round and round through the cylinders and radiator; being alternately heated in abstracting heat from the cylinders, and cooled while passing through the radiators. The cooling effect is increased by inducing a rapid passage of air through the radiator. An air fan is therefore used in most cases to accomplish this purpose. Practically all automobile engines and those of aeroplanes using water as the cooling agent are cooled by this method.

Circulation of the water through the jackets and radiator is accomplished in some cases without the use of a water pump. This is possible because water expands when heated, hence, if the radiator is at about the same level as the cylinders, the heating and cooling action of the cylinders and the radiator, respectively, will cause the water to circulate through the system. The term "thermo syphon" is used to designate this form of circulation.

THE LUBRICATION SYSTEM.

Proper lubrication (or oiling) of all parts that rub upon each other is an absolute necessity in all gasoline engines. This lubrication serves two purposes; it reduces the amount of power required to move the working parts, thereby preserving this power for doing useful work, and it reduces the amount of wear on the bearing surfaces.

Every properly designed engine has suitable arrangements and devices for accomplishing efficient lubrication by distributing oil to bearing surfaces automatically. The old-fashioned method of having the operator go over the engine with an oil can, giving it a squirt here and there at more or less irregular intervals, is entirely inadequate for such a machine as a gasoline engine with its many close-fitting bearings, high speed, and high temperatures.

Several methods are used for automatic lubrication of gasoline engines, the three most common being "splash," "forced feed," and "independent lubricator feed."

Splash lubrication involves the use of the bottom of the crank case as an oil reservoir. Sufficient oil is supplied to this case to keep the level of the surface at such a height that the lower ends of the connecting rods, or projections on the connecting-rod caps, dip slightly and splash oil to all parts of the case. The oil thus finds access to oil pockets and grooves that lead it to the bearings. Indicators to show the level of the oil surface are provided, as well as suitable means of introducing fresh oil to the case (usually the vent or "breather pipe" on four-cycle engines). The bottom of the crank case has a drain plug for removing old, worn-out oil.

This method of lubrication is quite satisfactory if ordinary care is taken to keep the oil at the proper level. It supplies all internal bearings with a copious supply of lubricant and has the virtue of freedom from any chance of mechanical derangement. Its only bad features lie in the fact that the oil is splashed up into the body of the piston, where contact with highly heated parts of the engine tends to carbonize the oil and lower its lubricating efficiency, and, if the piston and rings are much worn, too much oil is carried past these parts into the combustion chamber, where it forms excessive amounts of carbon deposit.

All working parts not located within the crank case must have other provisions for lubrication on engines using the splash system. These parts are usually few in number and such that grease is suitable for their lubrication. This form of lubricant is fed to the bearing surfaces by separate grease cups, often so arranged that a spring and plunger keep a constant pressure on the grease and feed it as required.

For forced feed lubrication an oil pump and system of pipes and passages is installed as a permanent part of the engine. The lower part of the crank case is used as an oil well, but in this system the level is kept low enough to prevent dipping of the connecting rods, the oil well or "sump" often being partially separated from the crank-case space by a light perforated metal plate or screen strainer. A pump, driven from some rotating part of the engine, draws oil from this well and forces it through a system of pipes and holes leading to each bearing. A supply of oil is furnished in this manner to all working parts, and, having passed through the bearings, drains back to the well, where it cools and is again available to be pumped to the bearings. In this manner the oil is used over and over again, loss being made up by occasional additions to the supply, introduced through the filling pipe (usually the "breather"). When forced feed oiling is employed, extreme care must be exercised to use only clean oil, and keep it clean by an efficient strainer, so placed that it will collect all dirt before it enters the distributing pipes, where it might plug up the passages or work into the bearings and cut or score them.

Where an independent lubricator is used for oil distribution the crank case is not necessarily used as an oil reservoir, though this space is often utilized to collect the waste oil. In the simpler form the lubricator consists of a tank of suitable size attached at some convenient place to the upper part of the engine. For each bearing a needle valve and sight glass is fitted at the tank, with pipes leading to the separate bearings, and the oil flows by gravity through these pipes at a rate determined by the amount the needle valves are opened. This rate is regulated by hand to the requirements of each bearing and should be just sufficient to properly lubricate the surfaces. With this system the oil is used but once. To avoid the necessity of hand regulation, this type of lubricator is sometimes fitted with a system of mechanical dippers operated by gearing or belt from some rotating part of the engine in such a way that they cause oil to enter the pipes at a rate proportional to the speed of the engine.

Independent force-feed lubricators are much like those described above, except that each oil pipe has a small mechanically operated pump which causes the oil to be delivered under pressure.

Many engines are arranged to use a combination of some of these three systems. With two-cycle engines, lubricating oil is sometimes mixed with the gasoline in the supply tank and fed through the carburetor to the crank case. This is a very convenient way of introducing oil to the engine and insures a supply that is proportional to the speed and power developed.

MUFFLERS.

Exhaust gases leave the cylinders with such violence as to cause loud reports much like that of a gun when fired. To eliminate this disagreeable feature, the exhaust gases are led through a silencing chamber, or muffler. This chamber furnishes a space in which the velocity of the gases is reduced and partially equalized, so that they escape to the air more as a steady flow and with practically no noise.

The ordinary type of muffler is cylindrical and has an interior arrangement of perforated baffle plates for changing the direction of flow of the gases several times, thus reducing the violence of the separate exhaust impulses. On marine engines it is common practice to use water-jacketed mufflers, the cooling effect of the water reducing the volume of the exhaust gases, which materially aids in elimination of noise.

At best, the muffler increases the back pressure which the exhaust must overcome in leaving the cylinders. The work necessary to rid the cylinders of burnt gases is therefore increased and the useful work obtainable from the engine is less than would be the case were no muffler fitted. For this reason a muffler cut-out which, when opened, allows the gases to escape from the exhaust pipe direct to the atmosphere without passing through the muffler, is often fitted on motor cars to increase the available power when climbing steep grades. However, in many localities the use of these cut-outs is prohibited by law on account of the noise which their use involves.

GOVERNORS.

The function of a governor is to automatically control the speed at which the engine runs. For some kinds of work, such as driving an electric dynamo, a constant, unvarying number of revolutions per minute is necessary for satisfactory service, even though sudden and large variations of load occur.

Gasoline-engine governors, like those of most other engines, usually depend upon centrifugal force for their operation. Weights and springs are so arranged with a system of links and levers that, when the mechanism is rotated by a positive driving gear from some rotating part of the engine, the weights change position against the tension of the springs, the change of position becoming greater as the speed of rotation increases. This movement is transmitted by suitable connections to the throttle valve of the engine in such a manner that the throttle gradually closes as the displacement of the governor weights increases.

Governors are not often fitted to engines of pleasure vehicles, small motor boats, or aeroplanes, for in each of these cases hand control of the engine speed is sufficient. They are used in the following cases for the reasons given:

On engines used for driving shop machinery, dynamos, etc., where a constant speed is essential.

On medium and large power marine engines, to limit the maximum speed at which the engine can run and prevent excessive engine speed when the propeller leaves the water in rough seas or when the clutch is suddenly thrown out.

And on motor trucks and traction engines to limit the speed at which the vehicle can be driven, such regulation being necessary because, while the engine must have sufficient power to haul heavy loads up steep grades, if this power is used to obtain high speed on level roads, the wear and tear on the running gear becomes excessive. The ordinary driver can not be trusted to properly limit his speed, and automatic regulation is therefore resorted to.

SELF-STARTERS.

One of the worst features of the gasoline engine lies in the fact that it can not be made to start itself. Of course, if the engine is stopped with a compressed charge of gas in one or more of the cylinders, and there are suitable arrangements in the igniting apparatus for closing the circuit and causing a spark in this cylinder, the engine may start, provided the compression of the charge has not been too much reduced by leakage past the piston. This method of starting is uncertain and can not be depended upon. Until quite recently nearly all gasoline engines had to be started by hand. This in many cases requires considerable muscular effort and is always more or less dangerous, to say nothing of the inconvenience which it involves under many circumstances.

The advantage of being able to start the engine of a motor vehicle from the driver's seat is self-evident, and now that fairly satisfactory starters have been invented all up-to-date pleasure cars are so equipped. For stationary engines, commercial vehicles, and in marine practice (unless the power is great) hand starting is still usually depended upon because of the additional weight and initial expense which self-starters involve.

Compressed air or electric power is used to operate these starters.

The compressed-air system is adapted for use only on multiple-cylinder engines. It consists of a pump attached to the engine, which forces air into a tank, where it is stored at high pressure. Pipes and valves are so connected between this tank and the engine cylinders that the compressed air can be admitted to the proper cylinders and through pressure on the tops of the pistons cause the crank shaft to turn.

Electric self-starters consist of a storage battery for furnishing electric current, wired through a switch to an electric motor which is geared to the shaft. Some starters are so designed that the gears are disengaged as soon as the engine starts. To start the engine the switch is closed and current from the battery runs the motor which in turn runs the engine. As soon as the engine begins to run under its own power the disengaging mechanism throws the starting motor out of gear and breaks the electric circuit. The use of this system usually necessitates the attachment of an electric generator to the engine for use in replenishing the battery charge.

CHAPTER VI.

ADVANTAGES OF GASOLINE ENGINES OVER OTHER FORMS OF POWER.

A few pages will now be devoted to discussion of the advantages which gasoline engines possess over other forms of power, where circumstances are favorable, and what distinguishing features are possessed by engines for various classes of work.

First of all, it must be understood that the power of gasoline engines is limited to from one-half to 300 horsepower. This statement does not mean that it is impossible to build engines for powers smaller or greater than the limits given, but that in most cases the use of very small or large gasoline engines is inadvisable.

Following are the chief merits of gasoline engines, where the amount of power required lies within the above limits:

(*a*) The entire power plant can be made to occupy comparatively small space and to depend in no way upon outside apparatus, wherein it differs from an electric motor, which must necessarily be connected by wires to the central station or other source of current.

(*b*) The weight per horsepower of a gasoline power plant can be made less than that of any other known power producer.

(*c*) Danger of destructive explosions, such as sometimes occur in steam-power plants, is almost entirely eliminated where gasoline power is used.

(*d*) The average person can learn in a very short time to properly operate and take care of these engines—for steam plants, in most localities, a licensed engineer must be employed.

(*e*) As now designed, gasoline engines can be kept clean and made to present at all times a neat, tidy appearance without undue effort on the part of the attendant, their operation is not accompanied by the disagreeable tasks of handling dirty fuel and ashes as with most steam plants, and, if properly adjusted, no smoke and very little heat is produced as compared with that incident to the use of steam.

As regards cost of operation, a general comparison between gasoline and other forms of power is difficult to make. Up to about 50 horsepower the gasoline plants are invariably as economical as any other kind, excepting water power. Where more than 50 horsepower is required for a stationary outfit, circumstances may be such that steam can be used to good advantage. The whole question of cost of operation necessarily depends, to a large extent, upon the cost of various kinds of fuel in the locality where the power is to be used. For example, in regions where natural gas is abundant, gas engines have the advantage, or where water power is easily obtained, electric current is usually very cheap and motors are largely used. At the same time cost of maintenance and wages of the operator (if one has to be employed) often have more to do with the total cost of operation than the price of fuel.

These considerations make it extremely advisable, whenever the low cost of operation is of primary importance, to submit the question to a mechanical engineer for careful calculation, off-hand decisions under such circumstances usually being failures.

However, for automobiles, small work vessels, pleasure and speed launches, farm tractors, aeroplanes, small isolated electric lighting and pumping stations, for machinery on the farm requiring driving power, and numerous other uses, the advantages of gasoline engines as outlined above fully justify their adoption to even a greater extent than that which obtains at present.

To many people the question probably occurs: "Why so many different types of engines; why isn't one successful style of engine suitable for use under all conditions?"

Probably you have seen a young athlete run a hundred-yard dash in 10 seconds. He appeared to be a perfect specimen of the human family. If this same young man were put to work in a ditch, he could probably shovel out about as much earth as the ordinary laborer for the first few hours, then his hands would begin to blister and his back begin to ache, though the laborer beside him would be showing no signs of distress. At the end of the day it would probably be found that the laborer had performed more work than the athlete; in other words, the laborer proved to be the better power plant as far as ditch digging is concerned.

This is exactly the way it is with gasoline engines. For high speed, needed for comparatively short periods, the engine must be built for this particular kind of work, while for heavy, constant duty a more rugged type of engine is required.

The characteristics of gasoline engines as designed for various classes of work will now be briefly discussed.

Plenty of space is usually available for stationary power plants, and there seldom exists any reason to limit the weight of such plants. Hence, with the engines for this class of work, the designer is free to choose any arrangement of cylinders and other parts that he may deem advisable. Compactness in this case is of secondary importance, and the various parts should be so placed with relation to each other that all are readily accessible for cleaning, inspection, and repairs. In these engines the use of expensive materials which possess great strength, combined with little weight, may be dispensed with, equally good results being obtained by making the parts of greater proportions from materials of a cheaper grade. The first cost of the engine is thus reduced, while at the same time a very high "factor of safety" (that is, great strength of parts for the work they have to do) can be obtained.

These remarks also apply to traction engines. In fact, weight in the engine here is a distinct advantage, for the pulling power of such a machine depends in a large measure upon sufficient weight being placed on the wheels to insure against slipping.

In marine practice, where the vessel is of heavy build and high speed is not required, the statements above regarding stationary plants hold true for engines used for propulsion. In this case, however, it is essential that the crank shaft be kept quite low so that it can be installed in line with the propeller shaft. This requirement somewhat determines the general arrangement of the plant.

For pleasure launches and passenger-carrying boats weight and space occupied by the engine are of more importance, while in racing power boats and very high-speed pleasure craft every possible measure is taken to reduce the engine weight to the minimum. To this end such expensive materials as aluminum alloy, vanadium and tungsten steels, bronze, etc., are used wherever possible, but care is taken to make all parts of sufficient strength to guard against breakage and prevent the necessity for frequent overhauling.

Engines for self-propelled vehicles have to be fairly light for the power which they will develop and must also be very compact so as to occupy as little space as possible. It is very difficult to so design an engine that it will be compact and also have its various parts accessible. This is a fault in automobile engines that can not be entirely overcome.

It may be well to mention here the fact that automobile engines, especially those for pleasure cars, occupy a unique position in the gasoline-engine family. It is only during a very small portion of their whole existence that they are called upon to deliver their maximum power. Most of the time they are running at a very small per cent of their total capacity; often they simply idle while the car is coasting down hill. These conditions make possible the successful use of smaller bearing surfaces and lower factors of safety than are advisable in marine or other engines which have to deliver power constantly at rates near their maximum.

In aeroplane engines we reach the extreme as regards light weight per horsepower developed. Here every possible measure is taken to make the engine light. Only the very highest-grade materials are used, and the parts are very carefully balanced to reduce vibration to the minimum. This necessarily makes the aeroplane engine an expensive affair. The work these engines are required to perform might be compared to that of the young athlete mentioned before, in running his 100-yard dash; while they *do* work, they have to develop almost constantly all the power of which they are capable, but this is at the expense of frequent lay-ups for thorough overhauling and repair.

CHAPTER VII.

INSTRUCTIONS FOR RUNNING GASOLINE ENGINES.

Because of the great variation of design used by builders of gasoline engines and the multitude of arrangements possible in ignition devices, lubrication methods, cooling systems, and other details, it is difficult to give any but the most general instructions for running, which will apply in all cases.

First of all, it must be remembered that a gasoline engine must be supplied with gasoline in order to run. Many a thoughtless person has cranked an engine, perspiring, and sometimes cursing, when no other fault existed than exhaustion of the gasoline supply. An engine certainly can not be blamed for failure under such circumstances; but this is one simple illustration of many conditions that can arise which will make it impossible for the engine to do its duty and against which there is, and always will be but one defense—the display of plain common sense on the part of the operator. With nearly all gasoline power-plant installations the procedure in starting up the engine should be as follows:

(1) Turn on the gasoline supply, making sure that every valve or cock between tank and carburetor is open and noting at the time if any leaks are apparent. Do this first of all, for then, should there be confined air in the line it can be driven out and the gasoline will find access to the carburetor before you are ready to turn the engine.

(2) See that the cooling system, whatever the type, is in order and ready to do its work, that fan belt is in place and tight enough to prevent slipping, that radiator is filled with water, or that valves in the circulating system are open, as the case may require.

(3) Note whether a sufficient amount of oil is in the lubricating system and that this system is ready to perform its function the instant the engine is started.

(4) See that the needle valve of the carburetor is open the proper distance and that the throttle is opened just enough to allow the engine to run at moderate speed with no load. *Never start an engine with throttle wide open.*

(5) Now make sure that gasoline is present in the carburetor by opening the pet cock or drain valve in the bottom to see if *gasoline* drips out. (Smell it.) As soon as you are satisfied, close the cock.

(6) See that the clutch is "out" (if one is fitted) or that there will be no load or minimum load on the engine.

(7) Throw the ignition switch into the battery position, if batteries are installed; if not, to the dynamo or magneto as circumstances require.

(8) See that the spark control lever is set for a retarded (late) spark. This is most important, for with the spark advanced the engine is almost sure to "kick back"—that is, start in the wrong direction. If hand starting is resorted to, this kick back may seriously injure the operator.

Always note the position of the spark-control lever just before cranking the engine.

(9) Now turn the engine by whatever means is employed; if by hand, do it in such a way that injury will not be sustained should the engine, for any reason, "kick back." With an engine in proper adjustment it should start after three or four turns at the most.

(10) When the engine has started and is running regularly, advance the spark gradually, meanwhile opening the throttle to obtain the desired speed.

In cold weather gasoline engines are often difficult to start. Do not blame the engine for this; it is just as natural as it is for a steam engine to fail to start when the water in the boiler is cold. Gasoline does not vaporize readily at low temperature, hence an explosive mixture is difficult to obtain.

Under such conditions a little heat applied to the carburetor by placing cloths soaked with hot water around it, or even by pouring hot water on the intake manifold and carburetor, will usually make starting easy. Another scheme is to inject a little warm gasoline into each cylinder through the priming cocks, one teaspoonful to each cylinder.

TO STOP THE ENGINE.

(1) Slow the engine and throw off load or reduce it to minimum.

(2) Move the spark-control lever to the position which gives a retarded spark.

(3) Throw the switch to the "off" position (the engine now stops).

(4) Shut off lubricator feeds.

(5) Close such cocks or valves in the gasoline line as may be advisable to prevent possibility of leakage.

Caution.—In freezing weather do not fail to drain all water from radiator, cooling jackets, piping, and pumps, unless a nonfreezing cooling mixture is used or the engine is to be started again within a short time. Otherwise, the water may freeze and do serious damage because of its tendency to expand and burst the container.

When an operator becomes accustomed to running a particular engine, he will find many ways of relieving the machine of undue strain. Sudden changes of load should be avoided, the throttle should be opened gradually in speeding up, and the engine should never be allowed to "race"; that is, run at excessive speed with no load. Any engine of this kind will give better and more constant service if it is not forced to develop its maximum power continually. For this reason it is always best to have an engine installed in the first place that is somewhat more powerful than might be considered actually necessary; this will prove to be an economical measure. Likewise, where the engine is used for pleasure service, as in a launch or automobile, while an occasional "brush" with a rival is probably harmless, a practice of continually driving the engine to its utmost will surely result, in the long run, in annoyance and trouble out of all proportion to the possible pleasure derived from such practice. Be moderate—then the engine will be moderate in its demands for repairs and its cost of upkeep.

CHAPTER VIII.

CARE AND MAINTENANCE OF GASOLINE POWER PLANT.

The problem of proper care of an engine is one that should receive more attention from those who operate these machines than it usually does. It may not be out of place to state here that this question of care and maintenance should be studied even before the engine is purchased, and extreme caution exercised to secure a plant that is suitable in all respects for rendering the service desired. Many a good gasoline engine has been installed and proved a failure solely because it was never intended for the kind of service to which it was applied.

To guard against an initial mistake of this kind, the person about to purchase an engine should, unless well informed on the subject, seek the advice of a competent gasoline engine expert, preferably one who is not financially interested in any particular make or type of engine. By so doing an outfit can be secured that will cause a minimum amount of trouble and render good service without undue attention.

Assuming that the power plant is adapted to its work, is properly installed, and found to render satisfactory service, then care and maintenance should be such that this happy state of affairs may continue to exist.

Cleanliness, proper lubrication at all times, and prompt repair or adjustment whenever the necessity for same becomes apparent, prolong the life of any engine, while the satisfactory service thus obtained repays an owner many fold for the little time and attention required by their accomplishment.

By cleanliness, as applied to a gasoline engine, means not only a neat and clean external appearance, but also strict care that foreign matter be kept from all internal parts. The gasoline supply should always be strained through chamois when it is introduced into the supply tank. This removes all water as well as dust and dirt, and eliminates the possibility of stopping up the small passages through pipes and carburetors. Likewise, only clean oil should enter the lubricating system, whether it be of the splash, partial forced feed, separate forced feed, or other type, for grit or dirt introduced to bearing surfaces will surely cause scoring, and sooner or later make adjustment or renewal necessary. Whenever there is indication that the interiors of combustion chambers are foul with carbon or soot deposit steps should be taken to remove same as soon as circumstances permit.

When any internal part of the machine has been opened for inspection or repair, special care must be exercised to see that no loose articles, such as bits of waste or rags, or anything else not belonging there, are left within when the space is again closed. It is best to use only cheesecloth or other woven fabric around a gasoline engine whenever work is being done on internal parts, for when waste is used threads and strings which are bound to become detached are liable to get into and stop up oil passages.

To accomplish external cleanliness, a regular time for wiping down the engine should be fixed upon. Circumstances determine how frequently such periodical cleaning is necessary. When the engine is used intermittently it should always be wiped immediately after being shut down, for the oil and grease which often finds its way to external surfaces of the engine collects dust and dirt even when the engine is idle and makes the cleaning more tedious the longer it is delayed.

With reference to proper lubrication, every person operating gasoline engines should understand that lack of lubrication can cause more damage in 10 minutes than a year of constant service under proper conditions. Designers and manufacturers have surely done all that is possible to accomplish constant and sufficient lubrication of their engines, but no measures on their part can forestall the disastrous results of carelessness or neglect on the part of the operator. If any doubt exists as to the kind of oil to use, consult a competent person or refer the matter to the manufacturers of the engine. They will be glad to furnish such information. Closely allied with lubrication is the matter of cooling the cylinders. If the cooling system fails, the first indication other than excessive heat will be increased friction of the pistons in the cylinders. Often the pistons stick so tight that the engine can not be moved, and sometimes serious damage results. Where a radiator is fitted for water cooling, it should always be kept well filled and invariably examined before the engine is started, to see that such a condition exists. In boats, as soon as the engine is started, the operator should see that water is being circulated through the jackets, and should the least sign of overheating become apparent the cooling system should receive attention to find the cause, and remedy it.

After a person has become accustomed to the rhythmical sounds made by an engine, he should be prompt to take notice whenever a change takes place in these sounds and try at once to find the cause. Lack of lubrication in any large bearing, overheating of one or more cylinders, and a multitude of other troubles will often make their presence known in this manner before any material damage is sustained and long before actual performance of the engine in delivering power will indicate their presence. After a reasonable period of service it is advisable to give the engine a thorough inspection and overhauling. Too often they are allowed to run until wear or maladjustment causes

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breakage of some part, this often doing serious damage to other parts and greatly increasing the cost and labor of placing the engine in good order.

Overhauling should be carried out in such a manner that, when the machine is assembled, it is to all intents and purposes in as good condition as when it was installed. This requires the substitution of new parts for such as are badly worn, renewal of springs that have become weak, scraping of bearing surfaces that are rough, and readjustment of those that are worn. Whenever a part is found to be cracked, bent, or broken, a duplicate part, secured preferably from the manufacturers of the engine, should be fitted rather than repairs being made to the old parts. This may cost a little more at the time, but in the long run will prove to be sound economy.

To sum up the question of care and maintenance it is only well to repeat: if your power plant is satisfactory in the first place, take care to keep it constantly in just as near that same condition as possible, let good enough alone, avoid makeshift temporary repairs, and when the least thing goes wrong remember that "a stitch in time saves nine."

CHAPTER IX.

ADJUSTMENTS, REPAIRS, AND OVERHAULING.

No person should attempt to make even minor adjustments or repairs to a gasoline engine unless he has a fair general understanding of the construction and mode of operation of the machine. When something goes wrong, haphazard attempts to find the trouble and remedy it are sure to result in further derangement. These facts are fully realized by manufacturers and, almost without exception, they furnish with each engine complete printed descriptions of their products and carefully prepared directions for properly adjusting the various parts. This information should always be carefully studied and thoroughly understood by the person who has charge of an engine. He should examine all parts of the machine itself, both while it is running and when at rest. A good way to become acquainted with the action of the various parts is to turn an engine slowly by hand and see just how they perform their functions. For this kind of study, the internal working parts should be exposed to view by the removal, if possible, of cylinder heads, valve covers, crank-case plates, etc. The motion of each part, the relation of the motion to that of other parts, and the position of the piston at the time each operation takes place can then be observed. The whole mechanism should be studied in this way until the reason for every action is fully understood. Several hours can profitably be devoted to this practice. Then, when trouble arises, the operator is better prepared to determine what part is out of order and what is necessary to restore its former good condition.

Of course engines differ so radically in general design and details that no definite directions can be given for finding the cause of trouble and applying corrections. However, a few general hints will be offered, the following tabulated statement showing the troubles most often encountered, their usual causes, and remedies. In each case, the troubles mentioned are to be considered as having developed while the engine has been running satisfactorily.

To locate the seat of trouble in an engine which fails to start is a far more difficult task than finding what is wrong when the engine runs but does not act properly. In the former case a systematic search must be conducted until the fault is located. Those parts of the engine most likely to get out of adjustment should first be investigated. When a part is apparently in good order care must be taken to leave it in just that condition in which it was found, lest other trouble than that which first existed be created.

Trouble.	Causes.	Remedies.
(1) Explosions cease suddenly and engine stops in the same manner that it does when the ignition switch is opened.	(1) Usually a break or complete short circuit in the primary circuit; in general, any derangement of the ignition which will suddenly prevent sparking in all cylinders.	(1) Test ignition system to see if sparks are generated. If none can be obtained, examine switch, wire connections, vibrators, etc. Find what prevents proper flow of current and correct same.
(2) Explosions gradually grow weaker and engine finally stops, sometimes back-firing through carburetor (crank case if two-cycle engine) just before it stops.	(2) Gasoline supply exhausted; fuel supply piping, strainer, or passages through carburetor stopped up; admission of too much air to carburetor; in general, any derangement of gasoline system that causes weakening of gas mixture.	(2) Examine carburetor and see that gasoline is being properly supplied to same, and that passages are clear of dirt; also that adjustment of air admission register has not changed; if necessary, clean strainer and piping or readjust carburetor to give a proper mixture.
3) Explosions in one or more cylinders do not occur regularly; in other words, misfiring takes place.	(3) Fouled or worn-out points on spark plugs; dirt in commutator, which prevents good contacts; broken or leaky wire in secondary system (where high tension is used); weak current from battery or generator; vibrator poorly adjusted; or contact points rough or dirty.	(3) Determine first in which cylinder the trouble occurs, then examine parts of ignition system which serve this cylinder, and clean, readjust, or renew, as necessary.
(4) Explosions in one cylinder cease entirely.	(4) Failure of ignition apparatus of this particular cylinder, usually the spark plug or (with make-and-break) the tripping mechanism	(4) Locate trouble and correct same without disturbing, if possible, any part of ignition system that serves other cylinders.

Trouble.	Causes.	Remedies.
(5) Engine runs, but with lack of power.	(5) Carburetor poorly adjusted so that mixture is either too rich or too weak; muffler or exhaust pipe choked up; cylinder too cold or excessively hot; spark too much retarded or advanced.	(5) Try to determine from the general aspects of the case what is the most likely cause. Remember that when the engine will run at all it is much easier to locate the trouble by keeping the engine in motion under its own power and slightly altering adjustments of carburetor, etc., carefully noting effect.
(6) Engine gradually slows down as if greatly overloaded.	(6) Lack of lubrication of bearing or piston, or general lack of lubrication due to insufficient supply of oil or failure of feeding apparatus; possibly actual overloading of the engine, overheating of cylinders, or, in some cases, excessively rich gas mixture.	(6) First quickly determine whether or not an actual overload exists. If not, look for signs of overheating of bearings or cylinders. If they are hot due to lack of lubrication, remove load from engine, slow same, and apply oil as quickly as possible. After a bearing or cylinder has been overheated it should be examined at the first opportunity to see if damage was sustained.
(7) Explosions take place in crank case (only with two-cycle engines).	(7) A weak gas mixture that burns so slowly that combustion is not complete when the inlet opens. The entering charge is ignited by this burning gas and the flame flares back into the crank case. Another cause is greatly retarded spark.	(7) Adjust carburetor to give a richer gas mixture, or advance the spark.

(8) Explosions back-fire to carburetor (only with four-cycle engines).	(8) Same as 7. In this case the gas mixture in the manifold is ignited. A very weak gas mixture may burn so slowly that there is flame in the cylinder when the inlet valve opens. This ignites the entering charge and causes an explosion of the gas in the inlet manifold. Or a leaky inlet valve may cause these flarebacks.	(8) Same as 7.
(9) Explosions occur in muffler.......	(9) Very rich gas mixture, unburned portions of which enter muffler, or misfires, allowing charges of gas to pass into muffler. An accumulated charge of this unconsumed gas in the muffler is ignited by the hot exhaust gases.	(9) Make such readjustment of carburetor as necessary to produce a leaner mixture. Eliminate the cause of misfiring.
(10) Black smoke issues from exhaust..	(10) Gas mixture too rich............	(10) Adjust carburetor to give leaner mixture. Under proper conditions the exhaust should be practically invisible.
(11) Blue smoke issues from exhaust..	(11) Too much lubricating oil is finding access to the cylinder space. This may be caused by too great supply of oil, by use of too light a grade of oil, or, in old engines, by loose piston or worn out rings.	(11) With splash system reduce depth of oil in crank case; in any case make sure that too much oil is not being supplied. If necessary, use heavier grade of oil. This condition should not be allowed to continue, for fouling of combustion spaces with carbon and soot, which deposits cause preignition, and failure of ignition plugs is sure to result. Of course, if cylinder pistons or rings are greatly worn, the trouble must be endured until these parts are renewed.

Trouble.	Causes.	Remedies.
12) Each explosion is accompanied by a dull thud.	(12) Spark is probably too far advanced. A loose main bearing may sometimes be the cause of this trouble.	(12) See if retarding spark somewhat will eliminate trouble; if not, see that all main bearings are in proper adjustment.
(13) A sharp knock occurs with each explosion, especially when load is heavy or when throttle is suddenly opened.	(13) Excessive deposits of carbon and soot on walls of combustion chamber.	(13) Remove carbon, either by scraping it out mechanically or having it burned out by means of oxygen.
(14) A knock, comparatively light, occurs at each end of the stroke in one or more cylinders, especially noticeable when engine is suddenly slowed down.	(14) The connecting-rod connection is loose at either wrist-pin or crank-pin bearing, possibly both.	(14) Take up slack and properly adjust these bearings.
(15) The engine stops with considerable noise or rattle, or this condition suddenly arises, though the engine continues to run.	(15) Probably some working part broken or worked loose. If the damage is confined to but one cylinder of a multiple-cylinder engine, the machine may continue to run on power from the other cylinders.	(15) Unless engine stops itself, throw off ignition switch immediately. Do not attempt to run the engine until cause of trouble is found, for a broken or loose part may do serious damage to other parts.

After a little experience with gasoline engines some people seem to have very little difficulty in quickly finding the cause of trouble; others seem never to acquire this knack. The reason for this lies in the ability of some minds to grasp the relationship between causes and effects. Extraordinary mental development or unusual intelligence on the part of the operator is not essential, but it can safely be said that the person who uses his head and reasoning powers when running a gasoline engine will find less necessity for using his hands than the person who depends solely on printed directions and his mechanical skill in repairing broken machinery.

When mechanical troubles develop, repairs should only be made by someone who knows how to perform such work. Reading matter, explaining how valves should be ground, bearings fitted and adjusted, cam shafts timed, and similar repairs accomplished, will aid a person in learning how to do this work, but in addition to this it is absolutely essential that a person should see such work actually done by a competent mechanic before he attempts to do it himself. If no damage could result from failure to make such repairs in a proper manner, then the case would be different, but unfortunately, poor workmanship often causes damage, and many a good engine has practically been destroyed by attempts of a novice to accomplish repairs that would test the skill of a trained machinist.

A general overhauling should only be necessary after the machine has been in service for a considerable length of time. If possible, it should be done where the facilities of a well-equipped machine shop or garage are available, for very often special tools or the use of machine tools such as a lathe, shaper, or drill press will be required. A thorough overhauling should involve the dismantling of the whole machine and putting each part in good condition; then, in reassembling, the parts are carefully adjusted with relation to each other, bearings are set so that the effect of former wear is eliminated, parts worn badly are renewed; in fact, all possible steps taken to restore the machine to a condition approximating that which existed when it was new.

While, as before stated, it is most difficult to explain just how repairs should be accomplished, a few cautions as to certain things that should never be attempted by the average operator will not be amiss.

Never take apart a magneto, except to remove the cover and adjust contact points. Neither the magnets nor the armature should ever be removed from the body of the instrument except by an expert. When the machine fails to work take it or send it to a service station or to a competent repair man. These remarks also apply to induction coils. Adjustment of vibrators is easily accomplished and often necessary, but no attempt should ever be made to examine the interior or repair it. This again is work for a skilled man.

Never change the shape or size of needle valves, floats, or other parts of a carburetor. They were carefully designed by men who understood the principles of carburetion. Proper adjustment by means of the facilities provided is all that is necessary to make a carbureter do its duty. If not, send it back to the maker.

Alterations of the engine or any part of it with the view to improvement should never be attempted unless you are absolutely sure that it will be for the best. Such attempts are usually failures, often cause serious damage, and are likely to be expensive.

CHAPTER X.

CONCLUSION.

In concluding this pamphlet it is only fair to the gasoline engine to state that it is now a well-perfected invention. Its development has been remarkably rapid during the twenty-odd years that it has been in practical use. To be sure, in its early days this type of power fell into ill repute when a bucking or entirely inert launch engine or gasoline automobile was the target for ridicule from bystanders and an inexhaustible source of ideas for the cartoonist. But this period of disgrace was largely due to overenthusiasm on the part of the manufacturers themselves, who advertised their engines with such expressions as "Simple as A B C's," "Any child can run it," and so on, which statements, while they may have sold a few engines to the unsuspecting public, only caused resentment on the part of owners when they discovered that a gasoline engine, like any other mechanism, required at least a small degree of mechanical ability on the part of the operator and would stand but a limited amount of abuse. In spite of all this the merits and possibilities of gasoline power for small units was so apparent that engines of this type continued to be installed and used in spite of their defects. In the meantime manufacturers, through improvement of design, use of better materials, and superior workmanship, constantly improved and continue to improve their products.

Present-day engines are far from "fool proof," though many have been so perfected that a person with no mechanical knowledge can run them successfully for limited periods, and the actual care can be left to others. Thousands of automobiles are now run in this manner, the driver knowing nothing whatever of the care and operation of the engine further than how to start and stop it, while garage mechanics look after its adjustment, lubrication, cleanliness, and general condition.

It is to be expected that this idea will be carried still further, and that the gasoline engine of the future will be one which produces practically no noise or vibration, which has absolutely no working part exposed, except the shaft where power is delivered, and which has its parts so nicely designed and proportioned that no one part will show excessive wear while other working parts are apparently as good as new. Such an engine, if properly supplied with fuel, water, and lubricants, would continue to give service throughout its natural life, the same as a horse or mule if properly fed, until finally a general breakdown like that of the "one-hoss shay" ends its career and sends it to the scrap heap.