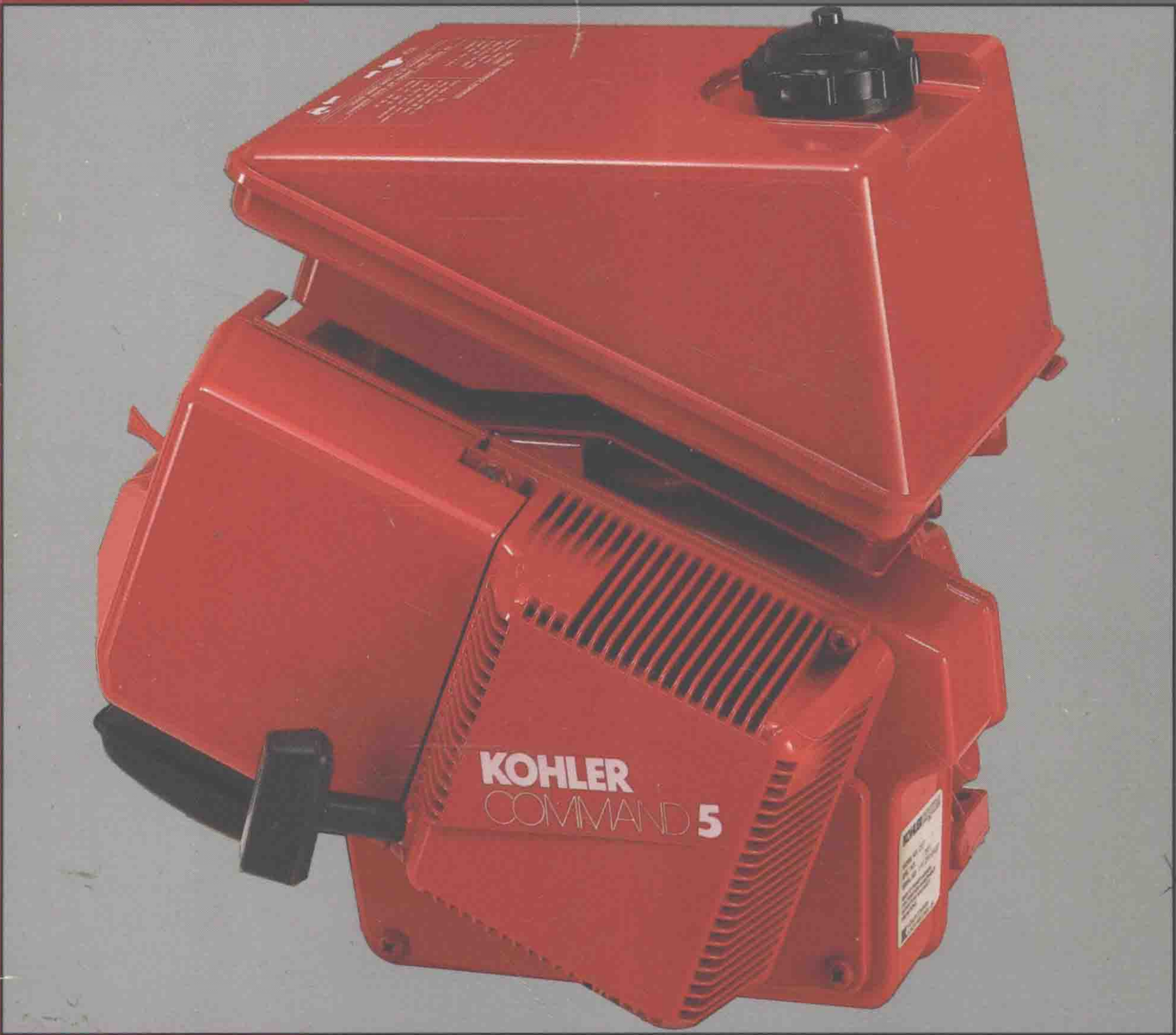
Small Air-Cooled Engine

SERVICE MANUAL ■ 17TH EDITION



Includes maintenance and repair information for small air-cooled engines with less than 15 cubic inch displacement and covers more than 30 different manufacturers.

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Small Air-Cooled Engine

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GENERAL

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DUAL DIMENSIONS

This service manual provides specifications in both the Metric (SI) and U.S. Customary systems of measurement. The first specification is given in the measuring system used during manufacture, while the second specification (given in parenthesis) is the converted measurement. For instance, a specification of "0.28 mm (0.011 inch)" would indicate that the equipment was manufactured using the metric system of measurement and U.S. equivalent of 0.28 mm is 0.011 inch.

FUNDAMENTALS SECTION

ENGINE FUNDAMENTALS

OPERATING PRINCIPLES

The small engines used to power lawn mowers, garden tractors and many other items of power equipment in use today are basically similar. All are technically known as "Internal Combustion Reciprocating Engines."

The source of power is heat formed by the burning of a combustible mixture of petroleum products and air. In a reciprocating engine, this burning takes place in a closed cylinder containing a piston. Expansion resulting from the heat of combustion applies pressure on the piston to turn a shaft by means of a crank and connecting rod.

The fuel-air mixture may be ignited by means of an electric spark (Otto Cycle Engine) or by heat formed from compression of air in the engine cylinder (Diesel Cycle Engine). The complete series of events which must take place in order for the engine to run may occur in one revolution of the crankshaft (two strokes of the piston in cylinder) which is referred to as a "Two Stroke Cycle Engine," or in two revolutions of the crankshaft (four strokes of the piston in cylinder) which is referred to as a "Four-Stroke Cycle Engine."

OTTO CYCLE. In a spark ignited engine, a series of five events is required in order for the engine to provide power. This series of events is called the "Cycle" (or "Work Cycle") and is repeated in each cylinder of the engine as long as work is being done. This series of events which comprise the "Cycle" are as follows:

1. The mixture of fuel and air is pushed into the cylinder by atmospheric pressure when the pressure within the engine cylinder is reduced by the piston moving downward in the cylinder (or by applying pressure to the fuel-air mixture as by crankcase compression in the crankcase of a "Two-Stroke Cycle Engine" which is described in a later paragraph).
2. The mixture of fuel and air is compressed by the piston moving upward in the cylinder.
3. The compressed fuel-air mixture is ignited by a timed electric spark.
4. The burning fuel-air mixture expands, forcing the piston downward in the cylinder thus converting the chemical energy generated by combustion into mechanical power.
5. The gaseous products formed by the burned fuel-air mixture are exhausted from the cylinder so that a new "Cycle" can begin.

The above described five events which comprise the work cycle of an engine are commonly referred to as (1), INTAKE; (2), COMPRESSION; (3), IGNITION; (4), EXPANSION (POWER); and (5), EXHAUST.

DIESEL CYCLE. The Diesel Cycle differs from the Otto Cycle in that air alone is drawn into the cylinder during the intake period. The air is heated from being compressed by the piston moving upward in the cylinder, then a finely atomized charge of fuel is injected into the cylinder where it mixes with the air and is ignited by the heat of the compressed air. In order to create sufficient heat to ignite the injected fuel, an engine operating on the Diesel Cycle must compress the air to a much greater degree than an engine operating on the Otto Cycle where the fuel-air mixture is ignited by an electric spark. The power and exhaust events of the Diesel Cycle are similar to the power and exhaust events of the Otto Cycle.

TWO-STROKE CYCLE ENGINES. Two stroke cycle engines may be of the Otto Cycle (spark ignition) or Diesel Cycle (compression ignition) type. However, since the two-stroke cycle engines listed in the repair section of this manual are all of the Otto Cycle type, operation of two-stroke Diesel Cycle engines will not be discussed in this section.

In two-stroke cycle engines, the piston is used as a sliding valve for the cylinder intake and exhaust ports. The intake and exhaust ports are both open when the piston is at the bottom of its downward stroke (bottom dead center or "BDC"). The exhaust port is open to atmospheric pressure; therefore, the fuel-air mixture must be elevated to a higher than atmospheric pressure in order for the mixture to enter the cylinder. As the crankshaft is turned from BDC and the piston starts on its upward stroke, the intake and exhaust ports are closed and the fuel-air mixture in the cylinder is compressed. When piston is at or near the top of its upward stroke (top dead center or "TDC"), an electric spark across the electrode gap of the spark plug ignites the fuel-air mixture. As the crankshaft turns past TDC and the piston starts on its downward stroke, the rapidly burning fuel-air mixture expands and forces the piston downward. As the piston nears bottom of its downward stroke, the cylinder exhaust port is opened and the burned gaseous products from combustion of the fuel-air mixture flows out the open port. Slightly further downward travel of the piston opens the cylinder intake port and a fresh charge of fuel-air mixture is forced into the cylinder. Since the exhaust port remains open, the incoming flow of fuel-air mixture helps clean (scavenge) any remaining burned gaseous products from the cylinder. As the crankshaft turns past BDC and the piston starts on its upward stroke, the cylinder intake and exhaust ports are closed and a new cycle begins.

Since the fuel-air mixture must be elevated to a higher than atmospheric pressure to enter the cylinder of a two-stroke cycle engine, a compressor pump must be used. Coincidentally, downward movement of the piston decreases the volume of the engine crankcase. Thus, a compressor pump is made available by sealing the engine crankcase and connecting the carburetor to a port in the crankcase. When the piston moves upward, volume of the crankcase is increased which lowers pressure within the crankcase to below atmospheric. Air will then be forced through the carburetor, where fuel is mixed with the air, and on into the engine crankcase. In order for downward movement of the piston to compress the fuel-air mixture in the crankcase, a valve must be provided to close the carburetor to crankcase port. Three different types of valves are used. In Fig. 1-1, a reed type inlet valve is shown in the schematic diagram of the two-stroke cycle engine. Spring steel reeds (R) are forced open by atmospheric pressure as shown in view "B" when the piston is on its upward stroke and pressure in the crankcase is below atmospheric. When piston reaches TDC, the reeds close as shown in view "A" and fuel-air mixture is trapped in the crankcase to be compressed by downward movement of the piston. In Fig 1-2, a schematic diagram of a two-stroke cycle engine is shown in which the piston is utilized as a sliding carburetor-crankcase port (third port) valve. In Fig. 1-3, a schematic diagram of a two-stroke cycle engine is shown in which a slotted disc (rotary valve) attached to the engine crankshaft opens the carburetor-crankcase port when the piston is on its upward stroke. In each of the three basic designs shown, a transfer port (TP—Fig. 1-2) connects the crankcase compression chamber to the cylinder; the transfer port is the cylinder intake port through which the compressed fuel-air mixture in the crankcase is transferred to the cylinder when the piston is at bottom of stroke as shown in view "A."

Due to rapid movement of the fuel-air mixture through the crankcase, the crankcase cannot be used as a lubricating oil sump because the oil would be carried into the cylinder. Lubrication is accomplished by mixing a small amount of oil with the fuel; thus, lubricating oil for the engine moving parts is carried into the crankcase with the fuel-air mixture. Normal lubricating oil to fuel mixture ratios vary from one part of oil mixed with 16 to 20 parts of fuel by volume. In all instances, manufacturer's recommendations for fuel-oil mixture ratio should be observed.

FOUR-STROKE CYCLE. In a four-stroke engine operating on the Otto Cycle (spark ignition), the five events of the cycle take place in four strokes of the piston, or in two revolutions of the engine crankshaft. Thus, a power stroke occurs only on alternate downward strokes of the piston.

In view "A" of Fig. 1-4, the piston is on the first downward stroke of the cycle. The mechanically operated intake valve has opened the intake port and, as the downward movement of the piston has reduced the air pressure in the cylinder to below atmospheric pressure, air is forced through the carburetor, where fuel is mixed with the air, and into the cylinder through the open intake port. The intake valve remains open and the fuel-air mixture continues to flow into the cylinder until the piston reaches the bottom of its downward stroke. As the piston starts on its first upward stroke, the mechanically operated intake valve closes and, since the exhaust valve is closed, the fuel-air mixture is compressed as in view "B."

Just before the piston reaches the top of its first upward stroke, a spark at the spark plug electrodes ignites the compressed fuel-air mixture. As the engine crankshaft turns past top center, the burning fuel-air mixture expands rapidly and forces the piston downward on its power stroke as shown in view "C." As the piston reaches the bottom of the power stroke, the mechanically operated exhaust valve starts to open and as the pressure of the burned fuel-air mixture is higher than atmospheric pressure, it starts to flow out the open exhaust port. As the engine crankshaft

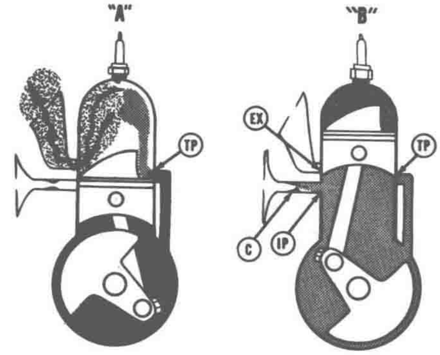

Fig. 1-2—Schematic diagram of two-stroke cycle engine operating on Otto Cycle. Engine differs from that shown in Fig. 1-1 in that piston is utilized as a sliding valve to open and close intake (carburetor to crankcase) port (IP) instead of using reed valve (R—Fig. 1-1).

C. Carburetor
EX. Exhaust port
IP. Intake port (carburetor to crankcase)
TP. Transfer port (crankcase to cylinder)

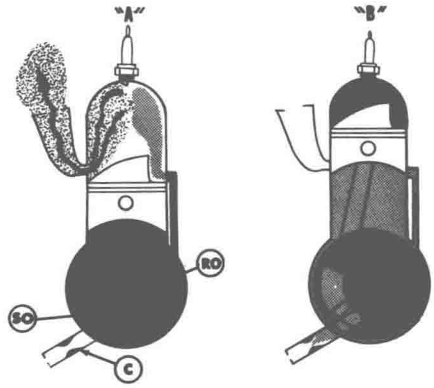

Fig. 1-3—Schematic diagram of two-stroke cycle engine similar to those shown in Figs. 1-1 and 1-2 except that a rotary carburetor to crankcase port valve is used. Disc driven by crankshaft has rotating opening (RO) which uncovers stationary opening (SO) in crankcase when piston is on upward stroke. Carburetor is (C).

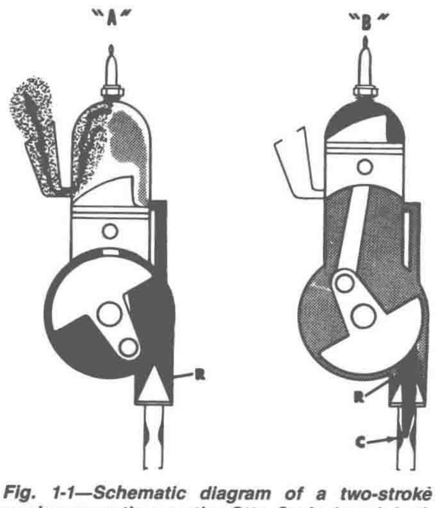

Fig. 1-1—Schematic diagram of a two-stroke engine operating on the Otto Cycle (spark ignition). View "B" shows piston near top of upward stroke and atmospheric pressure is forcing air through carburetor (C), where fuel is mixed with the air, and the fuel-air mixture enters crankcase through open reed valve (R). In view "A", piston is near bottom of downward stroke and has opened the cylinder exhaust and intake ports; fuel-air mixture in crankcase has been compressed by downward stroke of engine and flows into cylinder through open port. Incoming mixture helps clean burned exhaust gases from cylinder.

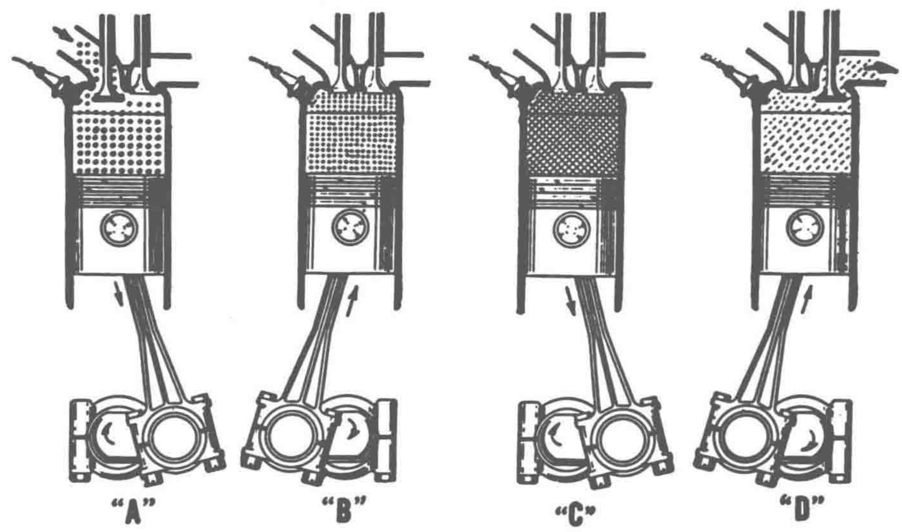

Fig. 1-4—Schematic diagram of four-stroke cycle engine operating on the Otto (spark ignition) cycle. In view "A", piston is on first downward (intake) stroke and atmospheric pressure is forcing fuel-air mixture from carburetor into cylinder through the open intake valve. In view "B", both valves are closed and piston is on its first upward stroke compressing the fuel-air mixture in cylinder. In view "C", spark across electrodes of spark plug has ignited fuel-air mixture and heat of combustion rapidly expands the burning gaseous mixture forcing the piston on its second downard (expansion or power) stroke. In view "D", exhaust valve is open and piston on its second upward (exhaust) stroke forces the burned mixture from cylinder. A new cycle then starts as in view "A."

turns past bottom center, the exhaust valve is almost completely open and remains open during the upward stroke of the piston as shown in view "D." Upward movement of the piston pushes the remaining burned fuel-air mixture out of the exhaust port. Just before the piston reaches the top of its second upward or exhaust stroke, the intake valve opens and the exhaust valve closes. The cycle is completed as the crankshaft turns past top center and a new cycle begins as the piston starts downward as shown in view "A."

In a four-stroke cycle engine operating on the Diesel Cycle, the sequence of events of the cycle is similar to that described for operation on the Otto Cycle, but with the following exceptions: On the intake stroke, air only is taken into the cylinder. On the compression stroke, the air is highly compressed which raises the temperature of the air. Just before the piston reaches top dead center, fuel is injected into the cylinder and is ignited by the heated, compressed air. The remainder of the cycle is similar to that of the Otto Cycle.

CARBURETOR FUNDAMENTALS

OPERATING PRINCIPLES

Function of the carburetor on a spark-ignition engine is to atomize the fuel and mix the atomized fuel in proper proportions with air flowing to the engine intake port or intake manifold. Carburetors used on engines that are to be operated at constant speeds and under even loads are of simple design since they only have to mix fuel and air in a relatively constant ratio. On engines operating at varying speeds and loads, the carburetors must be more complex because different fuel-air mixtures are required to meet the varying demands of the engine.

FUEL-AIR MIXTURE RATIO REQUIREMENTS. To meet the demands of an engine being operated at varying speeds and loads, the carburetor must mix fuel and air at different mixture ratios. Fuel-air mixture ratios required for different operating conditions are approximately as follows:

	Fuel	Air
Starting, cold weather	1 lb.	7 lbs.
Accelerating	1 lb.	9 lbs.
Idling (no load)	1 lb.	11 lbs.
Part open throttle	1 lb.	15 lbs.
Full load, open throttle	1 lb.	13 lbs.

BASIC DESIGN. Carburetor design is based on the venturi principle, which simply means that a gas or liquid flowing through a necked-down section (venturi) in a passage undergoes an increase velocity (speed) and a decrease in pressure as compared to the velocity and pressure in full size sections of the passage. The principle is illustrated in Fig. 2-1, which shows air passing through carburetor venturi. The figures given for air speeds and vacuum are approximate for a typical wide-open throttle operating condition. Due to low pressure (high vacuum) in the venturi, fuel is forced out through the fuel nozzle by the atmospheric pressure (0 vacuum) on the fuel; as fuel is emitted from the nozzle, it is atomized by the high velocity air flow and mixes with the air.

In Fig. 2-2, the carburetor choke plate and throttle plate are shown in relation in the venturi. Downward pointing arrows indicate air flow through carburetor.

At cranking speeds, air flows through the carburetor venturi at a slow speed; thus, the pressure in the venturi does not usually decrease to the extent that atmospheric pressure on the fuel will force fuel from the nozzle. If the choke plate is closed as shown by dotted line in Fig. 2-2, air cannot enter into the carburetor and pressure in the carburetor decreases greatly as the engine is turned at cranking speed. Fuel can then flow from the fuel nozzle. In manufacturing the carburetor choke plate or disc, a small hole or notch is cut in the plate so that some air can flow through the plate when it is in closed position to provide air for the starting fuel-air mixture. In some instances after starting a cold engine, it is advantageous to leave the choke plate in a partly closed position as the restriction of air flow will decrease the air pressure in carburetor venturi, thus causing more flow fuel to flow from the nozzle, resulting in a richer fuel-air mixture. The choke plate or disc should be in full open position for normal engine operation.

If, after the engine has been started the throttle plate is in the wide-open position as shown by the solid line in Fig. 2-2, the engine can obtain enough fuel and air to run at dangerously high speeds. Thus, the throttle plate or disc must be partly closed as shown by the dotted lines to control engine speed. At no load, the engine requires very little air and fuel to run at its rated speed and the throttle must be moved on toward the closed position as shown by the dash lines. As more load is placed on the engine, more fuel and air are required for the engine to operate at its rated speed and the throttle must by moved

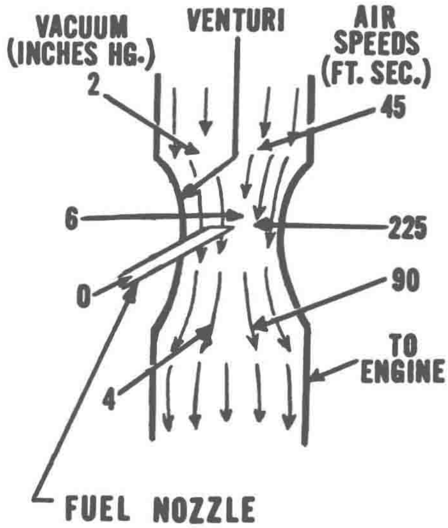

Fig. 2-1—Drawing illustrating the venturi principle upon which carburetor design is based. Figures at left are inches of mercury vacuum and those at right are air speeds in feet per second that are typical of conditions found in a carburetor operating at wide open throttle. Zero vacuum in fuel nozzle corresponds to atmospheric pressure.

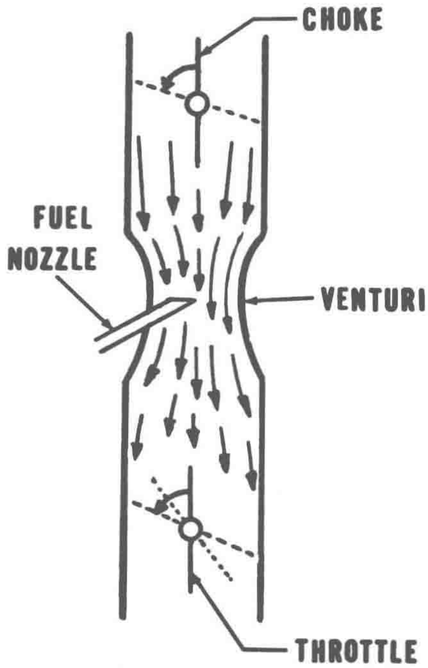

Fig. 2-2—Drawing showing basic carburetor design. Text explains operation of the choke and throttle valves. In some carburetors, a primer pump may be used instead of the choke valve to provide fuel for the starting fuel-air mixture.

closer to the wide open position as shown by the solid line. When the engine is required to develop maximum power or speed, the throttle must be in the wide open position.

Although some carburetors may be as simple as the basic design just described, most engines require more complex design features to provide variable fuel-air mixture ratios for different operating conditions. These design features will be described in the following paragraphs which outline the different carburetor types.

CARBURETOR TYPES

Carburetors used on small engines are usually classified by types as to method of delivery of fuel to the carburetor fuel nozzle. The following paragraphs describe the features and operating principles of the different type carburetors from the most simple suction lift type to the more complex float and diaphragm types.

SUCTION LIFT CARBURETOR. A cross-sectional drawing of a typical suction lift carburetor is shown in Fig. 2-4. Due to the low pressure at the orifice (O) of the fuel nozzle and to atmospheric pressure on the fuel in fuel supply tank, fuel is forced up through the fuel pipe and out of the nozzle into the carburetor venturi where it is mixed with the air flowing through the venturi. A check ball is located in the lower end of the fuel pipe to prevent pulsations of air pressure in the venturi from forcing fuel back down through the fuel pipe. The lower end of the fuel pipe has a fine mesh screen to prevent foreign material or dirt in fuel from entering the fuel nozzle. Fuel-air ratio can be adjusted by opening or closing the adjusting needle (N) slightly; turning the needle in will decrease flow of fuel out of nozzle orifice (O).

In Fig. 2-3, a cut-away view is shown of a suction type carburetor used on several models of a popular make small engine. This carburetor features an idle fuel passage, jet and adjustment screw. When carburetor throttle is nearly closed (engine is at low idle speed), air pressure is low (vacuum is high) at inner side of throttle plate. Therefore, atmospheric pressure in fuel tank will force fuel through the idle jet and adjusting screw orifice where it is emitted into the carburetor throat and mixes with air passing the throttle plate. The adjustment screw is turned in or out until an optimum fuel-air mixture is obtained and engine runs smoothly at idle speed. When the throttle is opened to increase engine speed, air velocity through the venturi increases, air

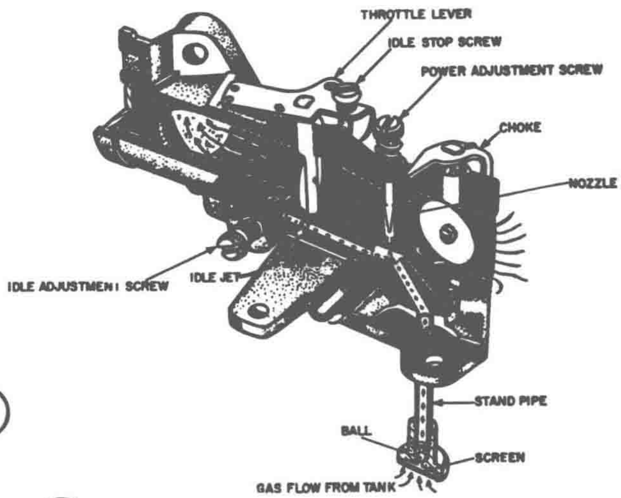

Fig. 2-3—Cut-away drawing of a suction lift carburetor used on one well known make engine. Ball in stand pipe prevents fuel in carburetor from flowing back into fuel tank.

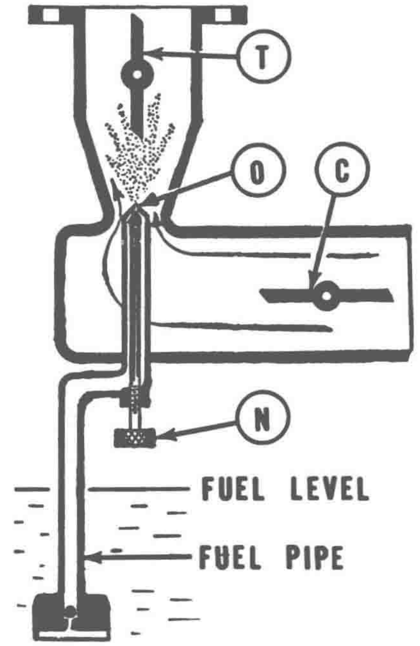

Fig. 2-4—Principle of suction lift carburetor is illustrated in above drawing. Atmospheric pressure on fuel forces fuel up through pipe and out nozzle orifice (O). Needle (N) is used to adjust amount of fuel flowing from nozzle to provide correct fuel-air mixture for engine operation. Choke (C) and throttle (T) valves are shown in wide open position.

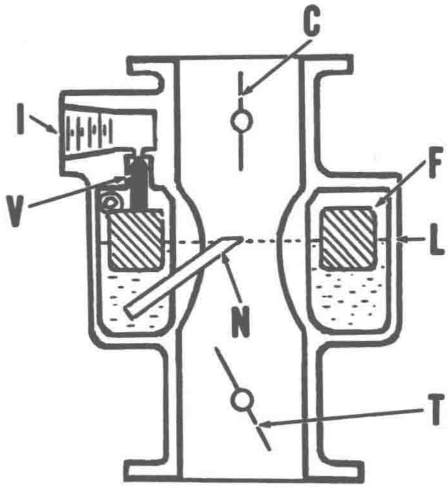

Fig. 2-5—Drawing showing basic float type carburetor design. Fuel must be delivered under pressure either by gravity or by use of fuel pump, to the carburetor fuel inlet (I). Fuel level (L) operates float (F) to open and close inlet valve (V) to control amount of fuel entering carburetor. Also shown are the fuel nozzle (N), throttle (T) and choke (C).

pressure in the venturi decreases and fuel is emitted from the nozzle. Power adjustment screw (high speed fuel needle) is turned in or out to obtain proper fuel-air mixture for engine running under operating speed and load.

FLOAT TYPE CARBURETOR. The principle of float type carburetor operation is illustrated in Fig. 2-5. Fuel is delivered at inlet (I) by gravity with fuel tank placed above carburetor, or by a fuel lift pump when tank is located below carburetor inlet. Fuel flows into the open inlet valve (V) until fuel level (L) in bowl lifts float against fuel valve needle and closes the valve. As fuel is emitted from the nozzle (N) when engine is running, fuel level will drop, lowering the float and allowing valve to open so that fuel will enter the carburetor to meet the requirements of the engine.

In Fig. 2-6, a cut-away view of a well known make of small engine float type carburetor is shown. Atmospheric pressure is maintained in fuel bowl through passage (20) which opens into carburetor air horn ahead of the choke plate (21). Fuel level is maintained at just below level of opening (O) in nozzle (22) by float (19) actuating inlet valve needle (8). Float height can be adjusted by bending float tang (5).

When starting a cold engine, it is necessary to close the choke plate (21) as shown by dotted lines so as to lower the air pressure in carburetor venturi (18) as engine is cranked. Then, fuel will flow up through nozzle (22) and will be emitted from openings (O) in nozzle. When an engine is hot, it will start on a leaner fuel-air mixture than when cold and may start without the choke plate being closed.

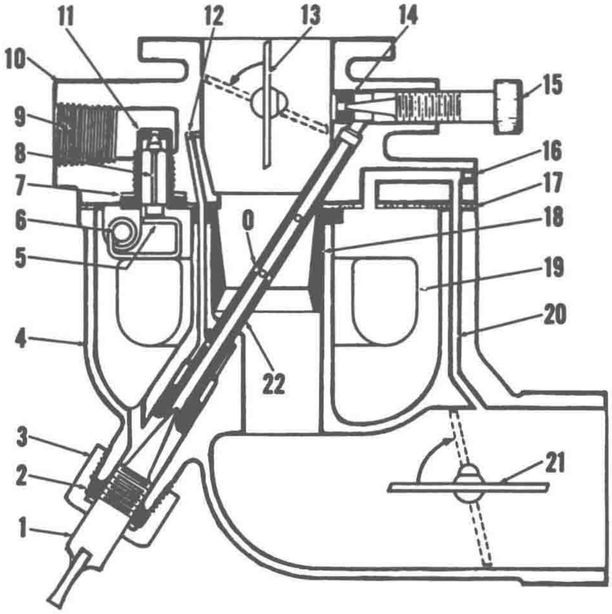

Fig. 2-6—Cross-sectional drawing of float type carburetor used on a popular small engine.

0. Orifice
1. Main fuel needle
2. Packing
3. Packing nut
4. Carburetor bowl
5. Float tang
6. Float hinge pin
7. Gasket
8. Inlet valve
9. Fuel inlet
10. Carburetor body
11. Inlet valve seat
12. Vent
13. Throttle plate
14. Idle orifice
15. Idle fuel needle
16. Plug
17. Gasket
18. Venturi
19. Float
20. Fuel bowl vent
21. Choke
22. Fuel nozzle

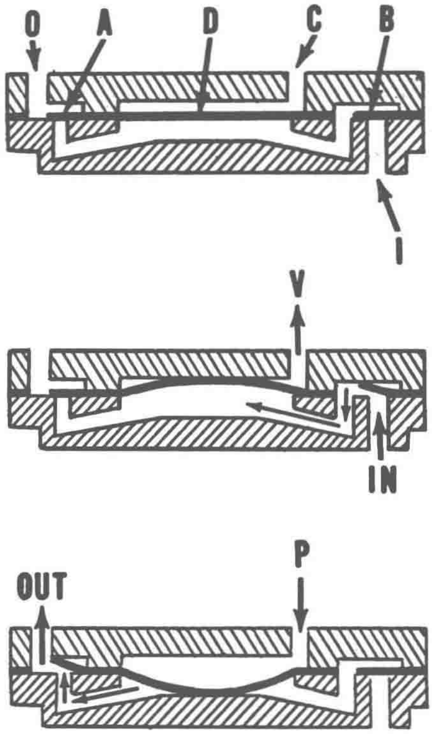

Fig. 2-9—Operating principle of diaphragm type fuel pump is illustrated in above drawings. Pump valves (A & B) are usually a part of diaphragm (D). Pump inlet is (I) and outlet is (O). Chamber above diaphragm is connected to engine crankcase by passage (C). When piston is on upward stroke, vacuum (V) at crankcase passage allows atmospheric pressure to force fuel into pump fuel chamber as shown in middle drawing. When piston is on downward stroke, pressure (P) expands diaphragm downward forcing fuel out of pump as shown in lower drawing.

When engine is running at slow idle speed (throttle plate nearly closed as indicated by dotted lines in Fig. 2-6), air pressure above the throttle plate is low and atmospheric pressure in fuel bowl forces fuel up through orifice in seat (14) where it mixes with air passing the throttle plate. The idle fuel mixture is adjustable by turning needle (15) in or out as required. Idle speed is adjustable by turning the throttle stop screw (not shown) in or out of control amount of air passing the throttle plate.

When throttle plate is opened to increase engine speed, velocity of air flow through venturi (18) increases, air pressure at venturi decreases and fuel will flow from openings (O) in nozzle instead of through orifice in idle seat (14). When engine is running at high speed, pressure in nozzle (22) is less than at vent (12) opening in carburetor throat above venturi. Thus, air will enter vent and travel down the vent into the nozzle and mix with the fuel in the nozzle. This is referred to as air bleeding and is illustrated in Fig. 2-7.

Many different designs of float type carburetors will be found when servicing the different makes and models of small engines. Reference should be made to the engine repair section of this manual for adjustment and overhaul specifications. Refer to carburetor servicing paragraphs in fundamentals sections for service hints.

DIAPHRAGM TYPE CARBURETOR. Refer to Fig. 2-8 for cross-sectional drawing showing basic design of a diaphragm type carburetor. Fuel is delivered to inlet (I) by gravity with fuel tank above carburetor, or under pressure from a fuel pump. Atmospheric pressure is maintained on lower side of diaphragm (D) through vent hole (V). When choke plate (C) is closed and engine is cranked, or when engine is running, pressure at orifice (O) is less than atmospheric pressure; this low

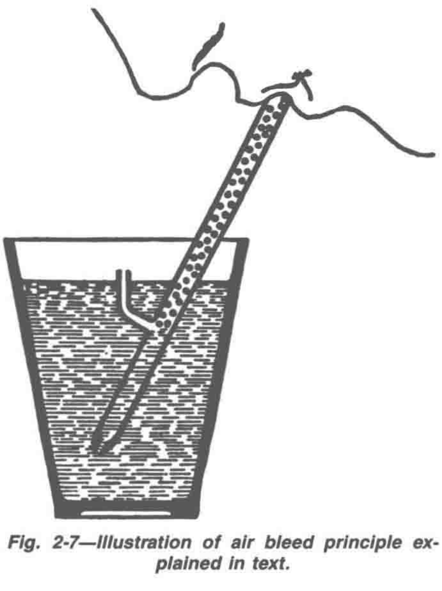

Fig. 2-7—Illustration of air bleed principle explained in text.

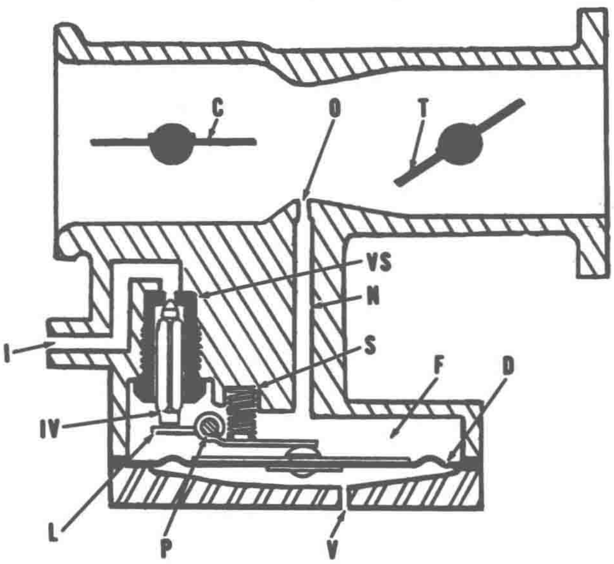

Fig. 2-8—Cross-section drawing of basic design diaphragm type carburetor. Atmospheric pressure actuates diaphragm (D).

C. Choke
D. Diaphragm
F. Fuel chamber
I. Fuel inlet
IV. Inlet valve needle
L. Lever
N. Nozzle
O. Orifice
P. Pivot pin
S. Spring
T. Throttle
V. Vent
VS. Valve seat

pressure, or vacuum, is transmitted to fuel chamber (F) above diaphragm through nozzle channel (N). The higher (atmospheric) pressure at lower side of diaphragm will then push the diaphragm upward compressing spring (S) and allowing inlet valve (IV) to open and fuel will flow into the fuel chamber.

Some diaphragm type carburetors are equipped with an integral fuel pump. Although design of the pump may vary as to type of check valves, etc., all operate on the principle shown in Fig. 2-9. A channel (C) (or pulsation passage) connects one side of the diaphragm to the engine crankcase. When engine piston is on upward stroke, vacuum (V) (lower than atmospheric pressure) is present in channel; thus atmospheric pressure on fuel forces inlet valve (B) open and fuel flows into chamber below the diaphragm as shown in middle view. When piston is on downward stroke, pressure (P) (higher than atmospheric pressure) is present in channel (C); thus, the pressure forces the diaphragm downward closing the inlet valve (B) and causes the fuel to flow out by the outlet valve (A) as shown in lower view.

In Fig. 2-10, a cross-sectional view of a popular make diaphragm type carburetor, with integral diaphragm type pump, is shown.

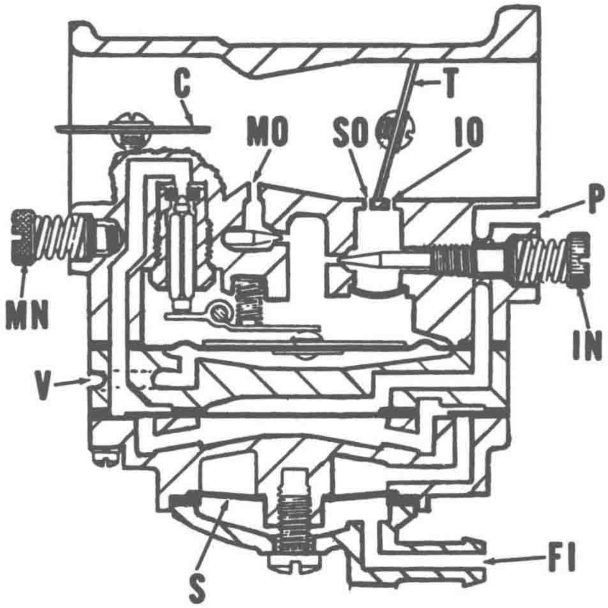

Fig. 2-10—Cross-sectional view of a popular make diaphragm type carburetor with integral fuel pump. Refer to Fig. 2-8 for view of basic diaphragm carburetor and to Fig. 2-9 for views showing operation of the fuel pump.

C. Choke
FI. Fuel inlet
IN. Idle fuel adjusting needle
IO. Idle orifice
MN. Main fuel adjusting needle
MO. Main orifice
P. Pulsation channel (fuel pump)
S. Screen
SO. Secondary orifice
T. Throttle
V. Vent (atmosphere to carburetor diaphragm)

IGNITION SYSTEM FUNDAMENTALS

The ignition system provides a properly timed surge of extremely high voltage electrical energy which flows across the spark plug electrode gap to create the ignition spark. Small engines may be equipped with either a magneto or battery ignition system. A magneto ignition system generates electrical energy, intensifies (transforms) this electrical energy to the extremely high voltage required and delivers this electrical energy at the proper time for the ignition spark. In a battery ignition system, a storage battery is used as a source of electrical energy and the system transforms the relatively low electrical voltage from the battery into the high voltage required and delivers the high voltage at proper time for the ignition spark. Thus, the function of the two systems is somewhat similar except for the basic source of electrical energy. The fundamental operating principles of ignition systems are explained in the following paragraphs.

MAGNETISM AND ELECTRICITY

The fundamental principles upon which ignition systems are designed are presented in this section. As the study of magnetism and electricity is an entire scientific field, it is beyond the scope of this manual to fully explore these subjects. However, the following information will impart a working knowledge of basic principles which should be of value in servicing small engines.

MAGNETISM. The effects of magnetism can be shown easily while the theory of magnetism is too complex to be presented here. The effects of magnetism were discovered many years ago when fragments of iron ore were found to attract each other and also attract other pieces of iron. Further, it was found that when suspended in air, one end of the iron ore fragment would always point in the direction of the North Star. The end of the iron ore fragment pointing north was called the "north pole" and the opposite end the "south pole." By stroking a piece of steel with a "natural magnet," as these iron ore fragments were called, it was found that the magnetic properties of the natural magnet could be transferred or "induced" into the steel.

Steel which will retain magnetic properties for an extended period of time after being subjected to a strong magnetic field are called "permanent magnets;" iron or steel that loses such magnetic properties soon after being subjected to a magnetic field are called "temporary magnets." Soft iron will lose magnetic properties almost immediately after being removed from a magnetic field, and so is used where this property is desirable.

The area affected by a magnet is called a "field of force." The extent of this field of force is related to the strength of the magnet and can be determined by use of a compass. In practice, it is common to illustrate the field of force surrounding a magnet by lines as shown in Fig. 3-1 and field of force is usually called "lines of force" or "flux." Actually, there are no "lines," however, this is a convenient method of illustrating the presence of the invisible magnetic forces and if a certain magnetic force is defined as a "line of force," then all magnetic forces may be measured by comparison. The number of "lines of force" making up a strong magnetic field is enormous.

Most materials when placed in a magnetic field are not attracted by the magnet, do not change the magnitude or direction of the magnetic field, and so are called "non-magnetic materials." Materials such as iron, cobalt, nickel or their alloys, when placed in a magnetic field will concentrate the field of force and hence are magnetic conductors or "magnetic materials." There are no materials known in which magnetic fields will not penetrate and magnetic lines of force can be deflected only by magnetic materials or by another magnetic field.

Alnico, an alloy containing aluminum, nickel and cobalt, retains magnetic properties for a very long period of time after being subjected to a strong magnetic field and is extensively used as a permanent magnet. Soft iron, which loses magnetic properties quickly, is used to concentrate magnetic fields as in Fig 3-1.

ELECTRICITY. Electricity, like magnetism, is an invisible physical force whose effects may be more readily explained than the theory of what electricity consists of. All of us are familiar with the property of electricity to produce light, heat and mechanical power. What must be explained for the purpose of understanding ignition system operation is the inter-relationship of magnetism and electricity and how the ignition spark is produced.

Electrical current may be defined as a flow of energy in a conductor which, in some ways, may be compared to flow of water in a pipe. For electricity to flow, there must be a pressure (voltage) and a complete circuit (closed path) through which the electrical energy may return, a comparison being a water pump and a pipe that receives water from the outlet (pressure) side of the pump and returns the water to the inlet side of the pump. An electrical circuit may be completed by electricity flowing through the earth (ground), or through the metal framework of an engine or other equipment ("grounded" or "ground" connections). Usually, air is an insulator through which electrical energy will not flow. However, if the force (voltage) becomes great, the resistance of air to the flow of electricity is broken down and a current will flow, releasing energy in the form of a spark. By high voltage electricity breaking down the resistance of the air gap between the spark plug electrodes, the ignition spark is formed.

ELECTROMAGNETIC INDUCTION. The principle of electro-magnetic induction is as follows: When a wire (conductor) is moved through a field of magnetic force so as to cut across the lines of force (flux), a potential voltage or electromotive force (emf) is induced in the wire. If the wire is part of a completed electrical circuit, current will flow through the circuit as illustrated in Fig. 3-2. It should be noted that the movement of the wire through the lines of magnetic force is a relative motion; that is, if the lines of force of a moving magnetic field cut across a wire, this will also induce an emf to the wire.

The direction of an induced current is related to the direction of magnetic force and also to the direction of movement of the wire through the lines of force, or flux. The voltage of an induced current is related to the strength, or concentration of lines of force, of the magnetic field and to the rate of speed at which the wire is moved through the flux. If a length of wire is wound into a coil and a section of the coil is moved through magnetic lines of force, the voltage induced will be proportional to the number of turns of wire in the coil.

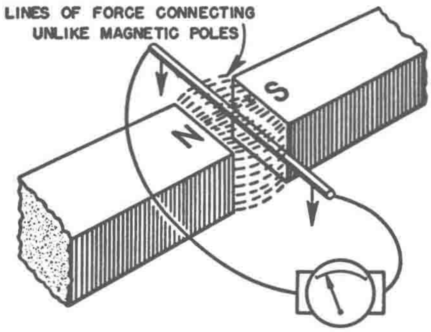

Fig. 3-2—When a conductor is moved through a magnetic field so as to cut across lines of force, a potential voltage will be induced in the conductor. If the conductor is a part of a completed electrical circuit, current will flow through the circuit as indicated by the gage.

ELECTRICAL MAGNETIC FIELDS. When current is flowing in a wire, a magnetic field is present around the wire as illustrated in Fig. 3-3. The direction of lines of force of this magnetic field is related to the direction of current in the wire. This is known as the left hand rule and is stated as follows: If a wire carrying a current is grasped in the left hand with thumb pointing in direction current is flowing, the curved fingers will point the direction of lines of magnetic force (flux) encircling the wire.

If a current is flowing in a wire that is wound into a coil, the magnetic flux surrounding the wire converge to form a stronger magnetic field as shown in Fig. 3-4. If the coils of wire are very close together, there is little tendency for magnetic flux to surround individual loops of the coil and a strong magnetic field will surround the entire coil. The strength of this field will vary with the current flowing through the coil.

STEP-UP TRANSFORMERS (IGNITION COILS). In both battery and magneto ignition systems, it is necessary to step-up, or transform, a relatively low primary voltage to the 15,000 to 20,000 volts required for the ignition spark. This is done by means of an ignition coil which utilizes the inter-relationship of magnetism and electricity as explained in preceding paragraphs.

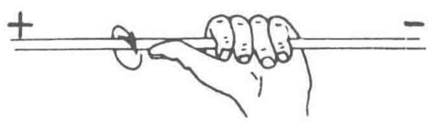

Fig. 3-3—A magnetic field surrounds a wire carrying an electrical current. The direction of magnetic force is indicated by the "left hand rule"; that is, if thumb of left hand points in direction that electrical current is flowing in conductor, fingers of left hand will indicate direction of magnetic force.

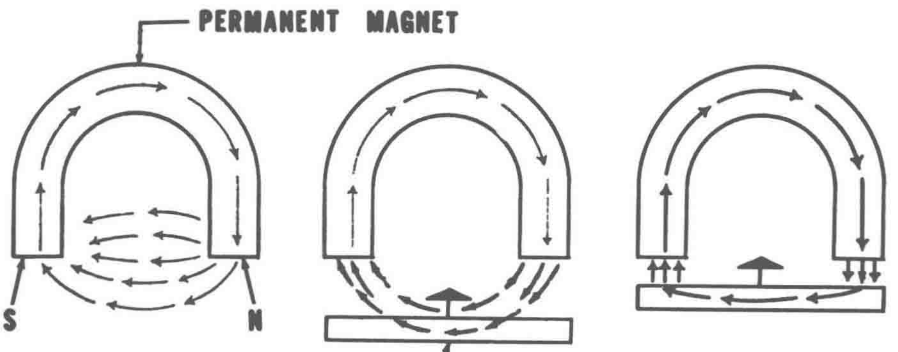

Fig. 3-1—In left view, field of force of permanent magnet is illustrated by arrows showing direction of magnetic force from north pole (N) to south pole (S). In center view, lines of magnetic force are being attracted by soft iron bar that is being moved into the magnetic field. In right view, the soft iron bar has been moved close to the magnet and the field of magnetic force is concentrated within the bar.

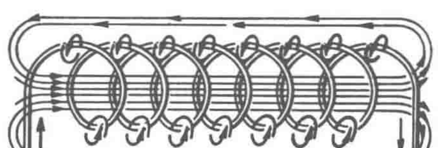

Fig. 3-4—When a wire is wound in a coil, the magnetic force created by a current in the wire will tend to converge in a single strong magnetic field as illustrated. If the loops of the coil are wound closely together, there is little tendency for lines of force to surround individual loops of the coil.

Basic ignition coil design is shown in Fig. 3-5. The coil consists of two separate coils of wire which are called the primary coil winding and the secondary coil winding, or simply the primary winding and secondary winding. The primary winding as indicated by the heavy, black line is of larger diameter wire and has a smaller number of turns when compared to the secondary winding indicated by the light line.

A current passing through the primary winding creates a magnetic field (as indicated by the "lines of force") and this field, concentrated by the soft iron core, surrounds both the primary and secondary windings. If the primary winding current is suddenly interrupted, the magnetic field will collapse and the lines of force will cut through the coil windings. The resulting induced voltage in the secondary winding is greater than the voltage of the current that was flowing in the primary winding and is related to the number of turns of wire in each winding. Thus:

$$\text{Induced secondary voltage} = \text{primary voltage} \times \frac{\text{No. of turns in secondary winding}}{\text{No. of turns in primary winding}}$$

For example, if the primary winding of an ignition coil contained 100 turns of wire and the secondary winding contained 10,000 turns of wire, a current having an emf of 200 volts flowing in the primary winding, when suddenly interrupted, would result in an emf of:

$$200 \text{ Volts} \times \frac{10{,}000 \text{ turns of wire}}{100 \text{ turns of wire}} = 20{,}000 \text{ volts}$$

SELF-INDUCTANCE. It should be noted that the collapsing magnetic field resulting from the interrupted current in the primary winding will also induce a current in the primary winding. This effect is termed "self-inductance." This self-induced current is such as to oppose any interruption of current in the primary winding, slowing the collapse of the magnetic field and reducing the efficiency of the coil. The self-induced primary current flowing across the slightly open breaker switch, or contact points, will damage the contact surfaces due to the resulting spark.

To momentarily absorb, then stop the flow of current across the contact points, a capacitor or, as commonly called, a condenser is connected in parallel with the contact points. A simple condenser is shown in Fig. 3-6a; however, the capacity of such a condenser to absorb current (capacitance) is limited by the small surface area of the plates. To increase capacity to absorb current, the condenser used in ignition systems is constructed as shown in Fig. 3-7.

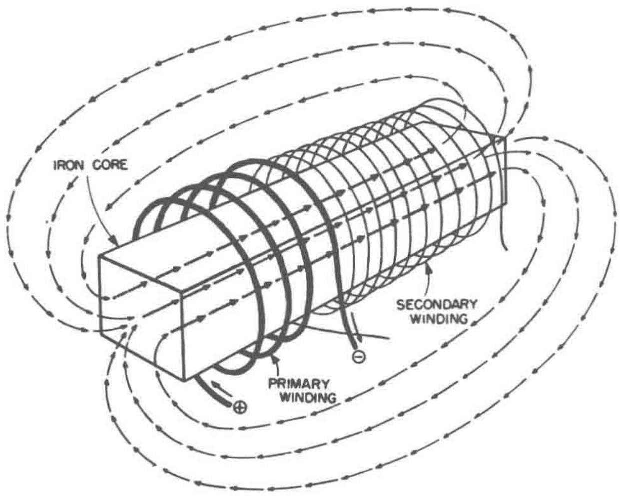

Fig. 3-5—Drawing showing principles of ignition coil operation. A current in primary winding will establish a magnetic field surrounding both the primary and secondary windings and the field will be concentrated by the iron core. When primary current is interrupted, the magnetic field will "collapse" and the lines of force will cut the coil windings inducing a very high voltage in the secondary winding.

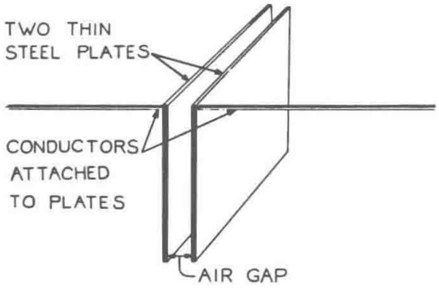

Fig. 3-6a—Drawing showing construction of a simple condenser. Capacity of such a condenser to absorb current is limited due to the relatively small surface area. Also, there is a tendency for current to arc across the air gap. Refer to Fig. 3-7 for construction of typical ignition system condenser.

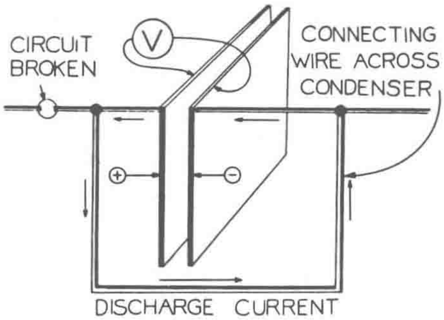

Fig. 3-6c—When flow of current is interrupted in circuit containing condenser (circuit broken), the condenser will retain a potential voltage (V). If a wire is connected across the condenser, a current will flow in reverse direction of charging current until condenser is discharged (voltage across condenser plates is zero).

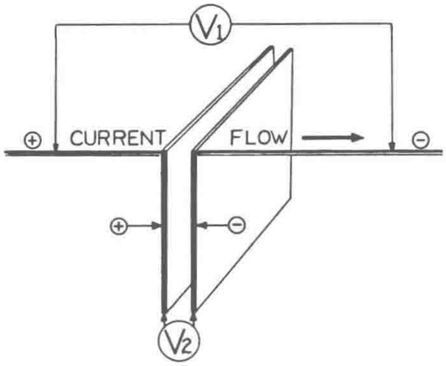

Fig. 3-6b—A condenser in an electrical circuit will absorb flow of current until an opposing voltage (V2) is built up across condenser plates which is equal to the voltage (V1) of the electrical current.

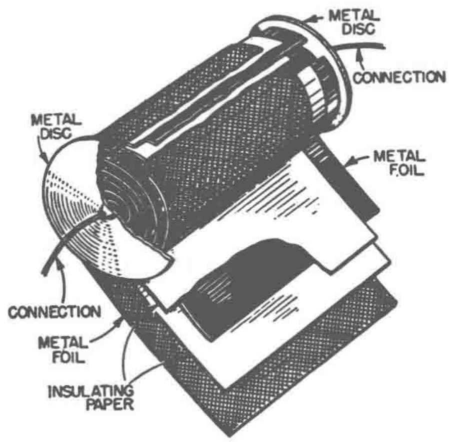

Fig. 3-7—Drawing showing construction of typical ignition system condenser. Two layers of metal foil, insulated from each other with paper, are rolled tightly together and a metal disc contacts each layer, or strip, of foil. Usually, one disc is grounded through the condenser shell.

EDDY CURRENTS. It has been found that when a solid soft iron bar is used as a core for an ignition coil, stray electrical currents are formed in the core. These stray, or "eddy currents," create opposing magnetic forces causing the core to become hot and also decrease the efficiency of the coil. As a means of preventing excessive formation of eddy currents within the core, or other magnetic field carrying parts of a magneto, a laminated plate construction as shown in Fig. 3-8 is used instead of solid material. The plates, or laminations, are insulated from each other by a natural oxide coating formed on the plate surfaces or by coating the plates with varnish. The cores of some ignition coils are constructed of soft iron wire instead of plates and each wire is insulated by a varnish coating. This type construction serves the same purpose as laminated plates.

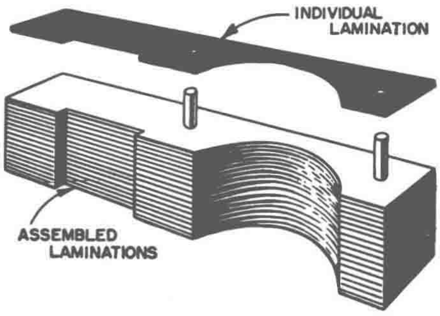

Fig. 3-8—To prevent formation of "eddy currents" within soft iron cores used to concentrate magnetic fields, core is assembled of plates or "laminations" that are insulated from each other. In a solid core, there is a tendency for counter-acting magnetic forces to build up from stray currents induced in the core.

BATTERY IGNITION SYSTEMS

Some small engines are equipped with a battery ignition system. A schematic diagram of a typical battery ignition system for a single cylinder engine is shown in Fig. 3-9. Designs of battery ignition systems may vary, especially as to location of breaker points and method for actuating the points; however, all operate on the same basic principles.

BATTERY IGNITION SYSTEM PRINCIPLES. Refer to the schematic diagram on Fig. 3-9. When the timer cam is turned so that the contact points are closed, a current is established in the primary circuit by the emf of the battery. This current flowing through the primary winding of the ignition coil establishes a magnetic field concentrated in the core laminations and surrounding the windings. A cutaway view of a typical ignition coil is shown in Fig. 3-10. At the proper time for the ignition spark, the contact points are opened by the timer cam and the primary ignition circuit is interrupted. The condenser, wired in parallel with the breaker contact points between the timer terminal and ground, absorbs the self-induced current in the primary circuit for an instant and brings the flow of current to a quick, controlled stop. The magnetic field surrounding the coil rapidly cuts the primary and secondary windings creating an emf as high as 250 volts in the primary winding and up to 25,000 volts in the secondary winding. Current absorbed by the condenser is discharged as the cam closes the breaker points, grounding the condenser lead wire.

Due to resistance of the primary winding, a certain period of time is required for maximum primary current flow after the breaker contact points are closed. At high engine speeds, the points remain closed for a smaller interval of time, hence the primary current does not build up to maximum and secondary voltage is somewhat less than at low engine speed. However, coil design is such that the minimum voltage available at high engine speed exceeds the normal maximum voltage required for the ignition spark.

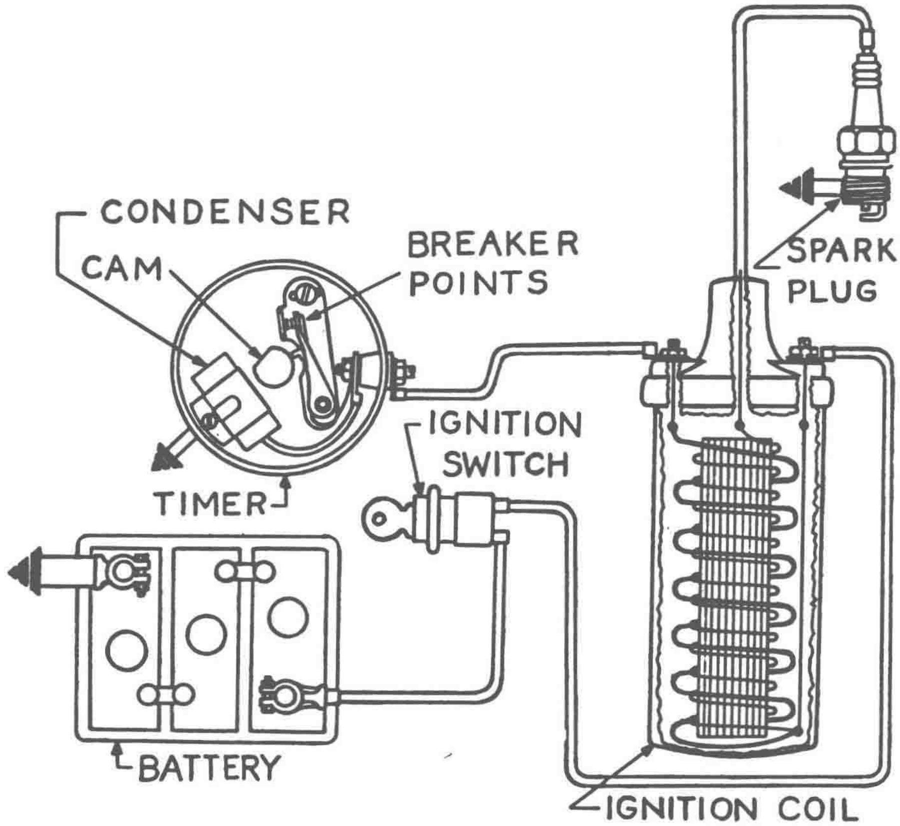

Fig. 3-9—Schematic diagram of typical battery ignition system. On unit shown, breaker points are actuated by timer cam; on some units, the points may be actuated by cam on engine camshaft. Refer to Fig. 3-10 for cutaway view of typical battery ignition coil. In view above, primary coil winding is shown as heavy black line (outside coil loops) and secondary winding is shown by lighter line (inside coil loops).

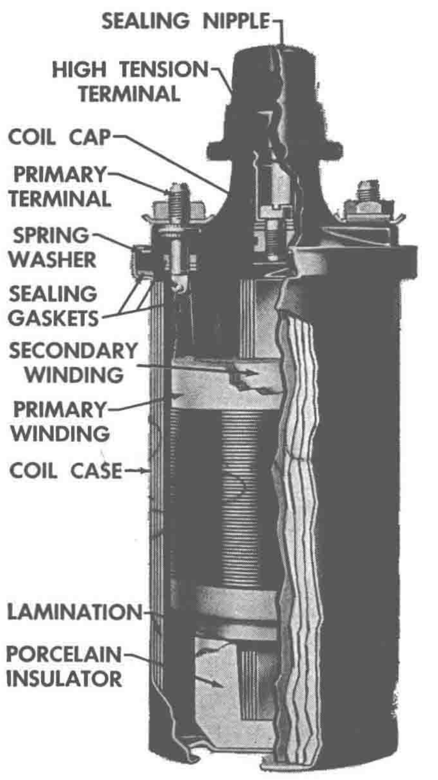

Fig. 3-10—Cutaway view of typical battery ignition system coil. Primary winding consists of approximately 200-250 turns (loops) of heavier wire; secondary winding consists of several thousand turns of fine wire. Laminations concentrate the magnetic lines of force and increase efficiency of the coil.

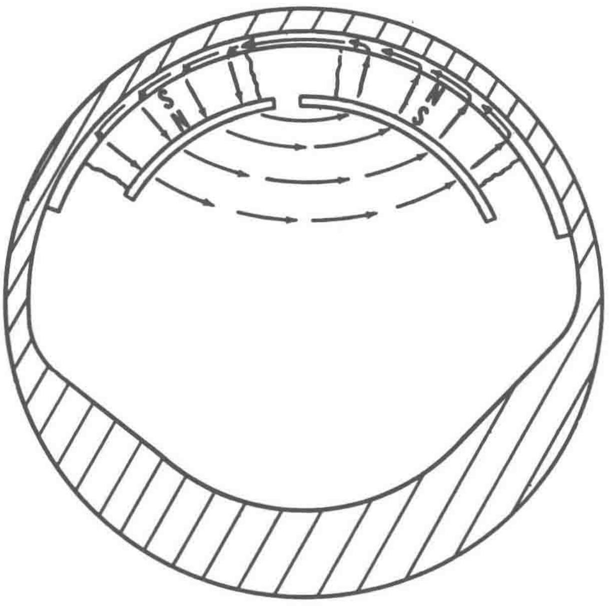

Fig. 3-11—Cutaway view of typical engine flywheel used with flywheel magneto type ignition system. The permanent magnets are usually cast into the flywheel. For flywheel type magnetos having the ignition coil and core mounted to outside of flywheel, magnets would be flush with outer diameter of flywheel.

MAGNETO IGNITION SYSTEMS

By utilizing the principles of magnetism and electricity as outlined in previous paragraphs, a magneto generates an electrical current of relatively low voltage, then transforms this voltage into the extremely high voltage necessary to produce the ignition spark. This surge of high voltage is timed to create the ignition spark and ignite the compressed fuel-air mixture in the engine cylinder at the proper time in the Otto cycle as described in the paragraphs on fundamentals of engine operation principles.

Two different types of magnetos are used on small engines and, for discussion in this section of the manual, will be classified as "flywheel type magnetos" and "self-contained unit type magnetos." The most common type of ignition system found on small engines is the flywheel type magneto.

Flywheel Type Magnetos

The term "flywheel type magneto" is derived from the fact that the engine flywheel carries the permanent magnets and is the magneto rotor. In some similar systems, the magneto rotor is mounted on the engine crankshaft as is the flywheel, but is a part separate from the flywheel.

FLYWHEEL MAGNETO OPERATING PRINCIPLES. In Fig. 3-11, a cross-sectional view of a typical engine flywheel (magneto rotor) is shown. The arrows indicate lines of force (flux) of the permanent magnets carried by the flywheel. As indicated by the arrows, direction of force of the magnetic field is from the north pole (N) of the left magnet to the south pole (S) of the right magnet.

Figs. 3-12, 3-13, 3-14, and 3-15 illustrate the operational cycle of the flywheel type magneto. In Fig. 3-12, the flywheel magnets have moved to a position over the left and center legs of the armature (ignition coil) core. As the magnets moved into this position, their magnetic field was attracted by the armature core as illustrated in Fig. 3-1 and a potential voltage (emf) was induced in the coil windings. However, this emf was not sufficient to cause current to flow across the spark plug electrode gap in the high tension circuit and the points were open in the primary circuit.

In Fig. 3-13, the flywheel magnets have moved to a new position to where

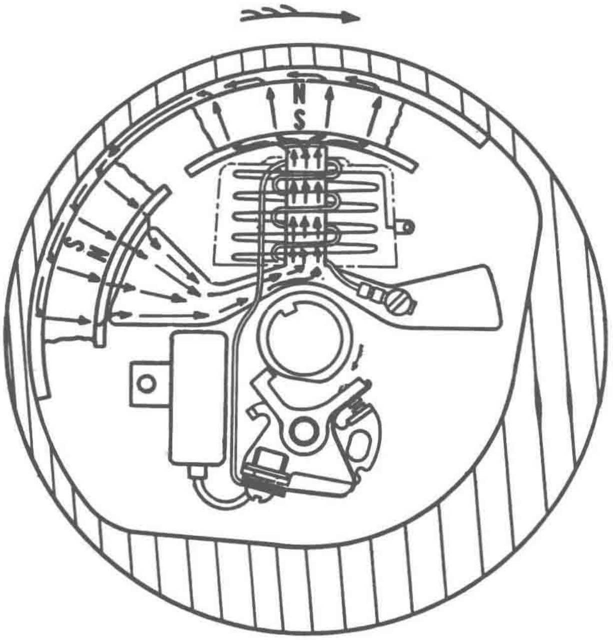

Fig. 3-12—View showing flywheel turned to a position so that lines of force of the permanent magnets are concentrated in the left and center core legs and are interlocking the coil windings.

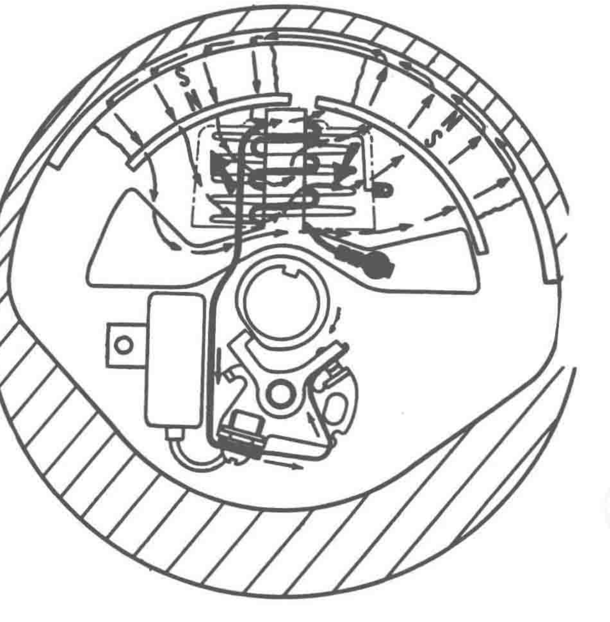

Fig. 3-13—View showing flywheel turned to a position so the lines of force of the permanent magnets are being withdrawn from the left and center core legs and are being attracted by the center and right core legs. While this event is happening, the lines of force are cutting up through the coil windings section between the left and center legs and are cutting down through the section between the right and center legs as indicated by the heavy black arrows. As the breaker points are now closed by the cam, a current is induced in the primary ignition circuit as the lines of force cut through the coil windings.