TM 1-406

WAR DEPARTMENT TECHNICAL MANUAL

AIRCRAFT ELECTRICAL SYSTEMS

WAR DEPARTMENT • FEBRUARY 1945

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This manual supersedes TM 1-406, 16 April 1942.

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For explanation of symbols, see FM 21–6.

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SECTION I

GENERAL

1. GENERAL. **a.** This manual is intended as a source of general information regarding the principles of operation and maintenance of electrical equipment used on aircraft. Specific information and the most recently authorized maintenance procedures for each type of equipment will be found in Technical Orders, which should be followed in all cases.

b. Electricity is used on aircraft for many purposes. It furnishes light, heat, and power. Some examples are: starting the engines; igniting the fuel charge in the cylinders (fig. 1); operating various types of lights (fig. 2), instruments, radio equipment, turrets, bomb-bay doors, signal devices, etc. The advantages of electricity lie in its ease of control, ease of distribution and the many uses to which it can be adapted.

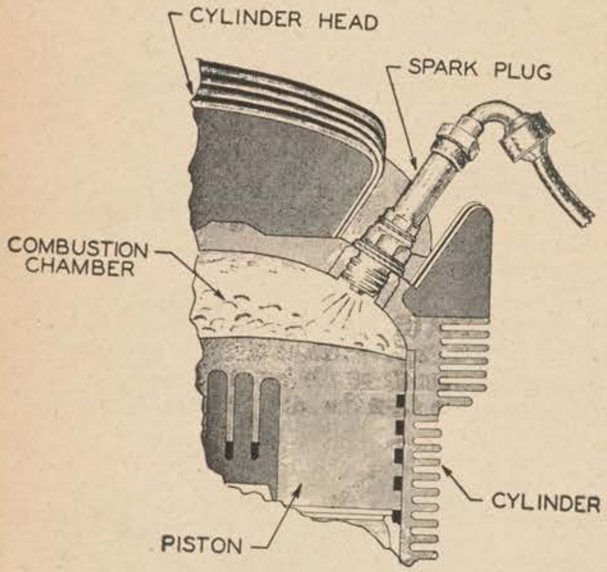


Figure 1. Electricity ignites the fuel charge in cylinders.

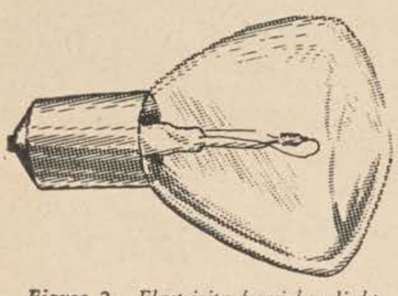


Figure 2. Electricity furnishes light.

c. To maintain electrical equipment, one should know the fundamentals and principles of electricity. The first 7 sections of this manual cover electrical fundamentals and should be studied thoroughly.

d. Analogies have occasionally been used to make electrical fundamentals easier to understand; however, they sometimes do not exactly represent the scientific explanation of the fundamentals.

2. WORK. Electricity is one form of energy. Energy may be briefly defined as the ability to do work. Mechanical energy, heat, and chemical energy are other forms. Surrounding every person there is some form of energy and man is able to transform one form of energy to another. In aircraft, mechanical energy is transformed (converted) to electrical energy and electrical to mechanical. Electrical energy is doing work when it operates a motor for bomb-bay doors, landing gear, gun turrets, starters, etc.

3. ELECTRICAL VOLTAGE. **a.** Electromotive force, electrical pressure, voltage, and difference of potential are names given to the force in electricity that pushes small charged particles through the wires (conductors). Most of the present aircraft have 12 or 24 volts of pressure. Generators and storage batteries are two sources of this electrical pressure or force. The alternator (alternating-current generator) is also used on modern aircraft as a source of electrical energy and can set up a pressure of 115 volts. Some airplanes now being designed will have 3-phase, 4-wire alternators, the voltage between phases being 208 and between any phase and neutral, 120 volts. These generators make possible the operation of 3-phase, 208-volt equipment and single-phase 120-volt equipment from the same circuit (par. 53e).

b. The amount of voltage or difference of potential is measured by a voltmeter the construction of which is described in paragraph 31. The two wires (leads) of the voltmeter are connected to the terminals of the unit the voltage of (or at) which is to be measured (fig. 3).

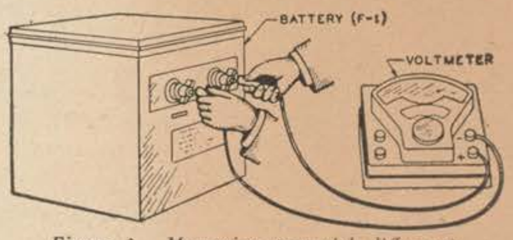


Figure 3. Measuring potential difference.

4. ELECTRIC CURRENT. **a.** When a generator, alternator or battery produces a voltage or force on a conductor, this voltage pushes little charged particles (called electrons) through the conductor. The movement of these electrons through a conductor is referred to as electrical current.

b. Current is measured in amperes by an ammeter (fig. 4) which is described in paragraph 32. The symbols used to express current are *I* and (sometimes) *A*.

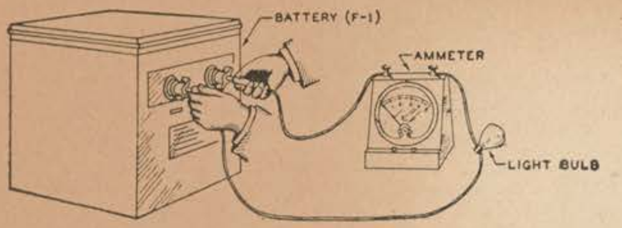


Figure 4. Measuring current with an ammeter.

5. ELECTRICAL RESISTANCE. **a.** When electrons pass through conductors they meet with varying degrees of difficulty. This difficulty is called electrical resistance. If a wire is of large diameter, the degree of difficulty is less than when of small diameter (fig. 5). The wire (conductor) will get hot if the electrons find great difficulty in moving. Resistance is also affected by length of the conductor, material of which the conductor is made, the temperature of the conductor.

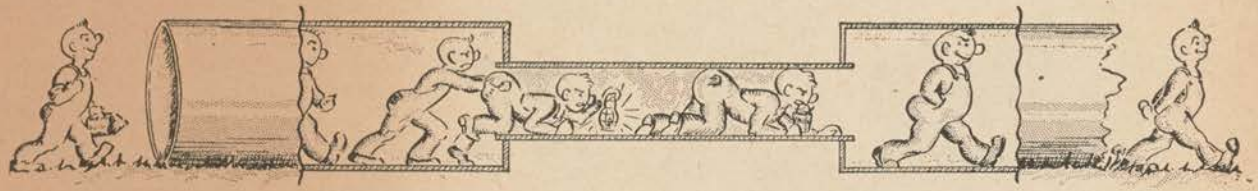


Figure 5. Resistance in a conductor.

b. The electrical resistance of a substance is measured by a unit of resistance called "ohm." The symbol used to express resistance is *R*, *r* or Ω, the latter frequently being used as an abbreviation for "ohm."

6. CONDUCTORS. **a.** A conductor is a substance which is able to transfer electrons with comparative ease; in general, metals and their alloys are good conductors. In aircraft, copper is the common conductor used to transfer electrons (to conduct electricity) to and from electrical devices such as navigation, landing, and instrument lights; motors operating landing gear mechanism, bomb-bay doors, flaps, etc.

b. A substance that cannot transfer electrons with ease is an insulator or non-conductor. Non-conductors are used to cover or insulate a conductor (wire). Some common non-conductors (insulators) are mica, glass, rubber and bakelite. Specially treated cambric and nylon are materials commonly used to insulate electrical conductors in aircraft.

7. STATIC ELECTRICITY. **a.** A conductor or non-conductor can have an excess or deficiency of electrons. In this unbalanced state, it has a static (not moving) charge of electricity. Whenever a charged body comes close to another non-conductor or to a conductor oppositely charged, the electrons will jump from the one body to the other and thus produce a spark. Almost everyone has experienced this spark when shuffling across a rug on a cold dry day and then touching a metallic object. This spark could be avoided by holding a wire connected to the metallic object in one's hand while shuffling across the rug. Such a wire provides for the harmless non-sparkling discharge of static electricity. Since wires used for this purpose are generally connected to (or touch) the ground, they are frequently referred to as ground wires.

b. Electrons may pile up on an airplane while in flight so that there is a heavy static charge remaining on the airplane after it is landed. A discharge of this static electricity between a gasoline hose and the tank might result in a dangerous explosion. For this reason, airplanes are equipped with a ground wire which is fastened to the metallic part of the airplane and drags on the ground to discharge this static electricity as soon as the airplane touches the ground (fig. 6). On some airplanes, wheel tires which will conduct electricity are used instead of a ground wire. Many other precautions are taken to prevent the dangerous discharges of static electricity.

8. SYMBOLS. Figure 7 shows the conventional electrical symbols.

9. ELECTRICAL CIRCUIT. **a.** An electrical circuit is a closed path through which an electric current can flow. A copper conductor usually forms this path. In figure 8, a wire is run from the battery to a fuel pump motor

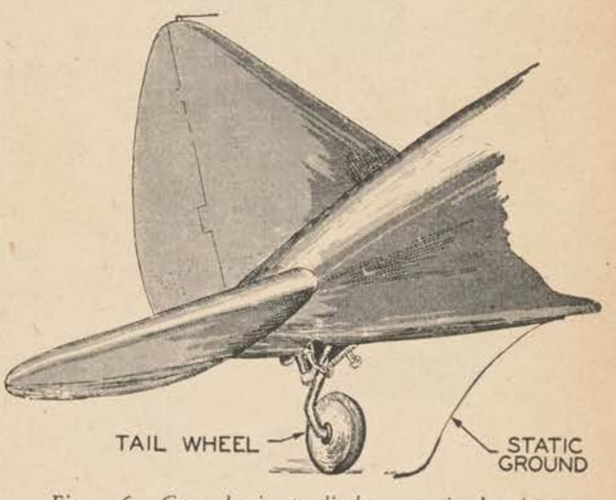


Figure 6. Ground wire to discharge static electricity.

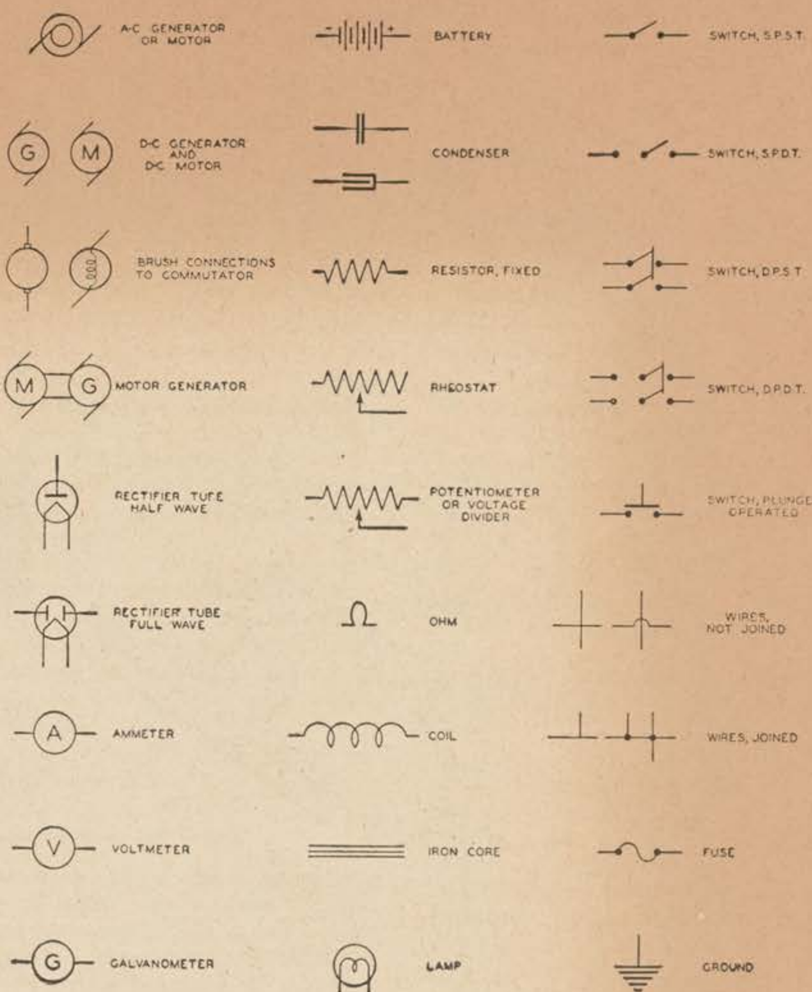


Figure 7. Conventional electrical symbols.

and back to the battery to complete an electrical circuit. In most airplanes, the return path is through the framework or other metal portion of the airplane's structure.

b. A short circuit is frequently the cause of electrical troubles. If the wire leading from a battery to the fuel-pump motor and back to the battery completes a path before it reaches the motor it will have its circuit shortened (fig. 9). Therefore, the motor will not run, when a short circuit is present.

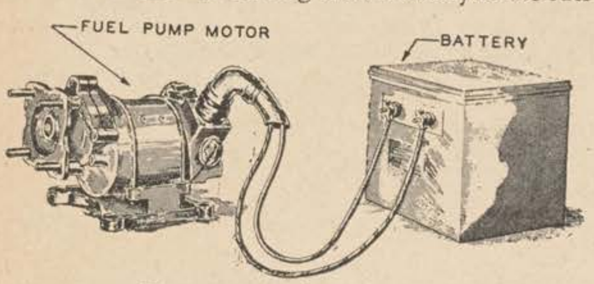


Figure 8. An electrical circuit.

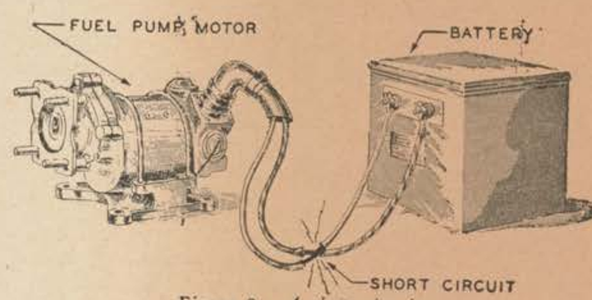


Figure 9. A short circuit.

SECTION II

DIRECT-CURRENT CIRCUITS

10. OHM'S LAW. **a.** The symbol for voltage difference between terminals of a *load unit* (starter motor, formation lights, etc.) is *E*. *I* represents current, measured in amperes. *R* represents the resistance of the load unit and is measured in ohms. The relationship between the three is known as Ohm's law and may be expressed by the following formulas:

(1) Amperes — volts divided by ohms; or $I = \frac{E}{R}$
If $I = 4$, $E = 8$, and $R = 2$, the following is obtained: $(4 = \frac{8}{2})$.

(2) Volts — amperes multiplied by ohms; or $E = IR$. Substituting values given in (1): $8 = 4 \times 2$.

(3) Ohms — volts divided by amperes; $R = \frac{E}{I}$
Substituting values given in (1): $2 = \frac{8}{4}$

b. If voltage and resistance are known, formula (1) can be used to find the amount of current (amperes) used; if current and resistance are known formula (2) can be used to find voltage; if current and voltage are known formula (3) may be used to find resistance.

c. A convenient way to remember these relationships is by the use of the diagram in figure 10. If one places a finger over the symbol representing the unknown quantity, the operation to be performed with the other two quantities is shown by the direction of the line between them (the vertical line signifies multiplication and the horizontal line signifies division).

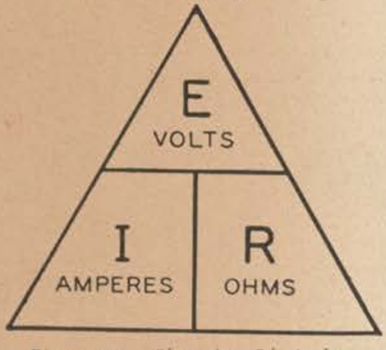


Figure 10. Chart for Ohm's law.

11. AIRCRAFT ELECTRICAL CIRCUITS. An electrical circuit is a closed path through which electricity can flow. A typical electrical circuit consists of a *battery, generator,* or *alternator* as a source of voltage to force current through a path; a *conductor* (wire) which carries the current; a *switch* (control device) to stop the flow of electricity or to permit electricity to flow; and an *electrical device* to use the electrical energy (fig. 11).

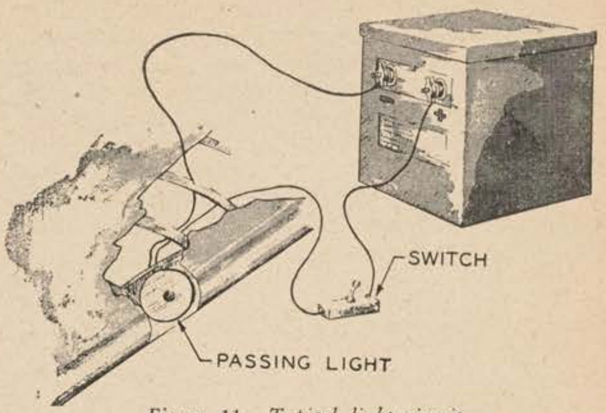


Figure 11. Typical light circuit.

Connecting a wire from the source of electricity (generally through a switch) to the electrical device requiring electric energy for its operation and back to the source forms an electrical circuit. There are three types of electrical circuits used in aircraft; series, parallel, and series-parallel.

12. SERIES CIRCUIT. A series circuit has *one* closed path through which voltage can push the current. Several resistances may be connected to form a series circuit as in figure 12. The same amount of current as forced through the first unit is also forced through the others. To find amperage, voltage, or resistance, Ohm's law is used. If four coils are connected in series and a current of 7 amperes is forced through the circuit by 28 volts, the total resistance may be found by using for-

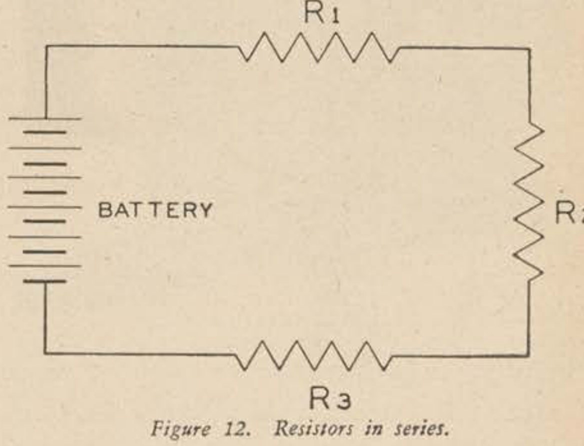


Figure 12. Resistors in series.

mula (3), paragraph 10. In a series circuit, the total current flows through each unit. The total voltage is equal to the sum of the voltages across each separate unit. Total resistance is equal to the sum of the resistances of the separate units.

13. PARALLEL CIRCUITS. Most of the electrical devices on aircraft are connected in parallel. A parallel circuit is one in which two or more electrical appliances offer independent paths through which the current may flow (fig. 13). The voltage across each appliance is the same. The total current is equal to the sum of the currents in each appliance. The total resistance is less than the smallest resistance. The more electrical devices or resistors connected in parallel the smaller the resistance of the complete circuit. Electrical appliances are connected in parallel to decrease resistance and to allow them to be operated separately. If one appliance in a parallel circuit burns out, the others will remain in operation. To find the total resistance of a parallel circuit, use the following formula:

$$\frac{R}{T} = \frac{1}{\frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_3} - \text{etc.}}$$

or:

$$\frac{1}{R_T} = \frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_3}$$

When the load units in parallel have equal resistance, this formula may be simplified:

$$R = \frac{\text{resistance of one unit}}{\text{the number of units}}$$

For example, the total resistance of ten 5-ohm units connected in parallel is 5/10 ohm. This shows again that where two or more units are connected in parallel, the effective resistance of all units together is less than that for the unit with the smallest resistance.

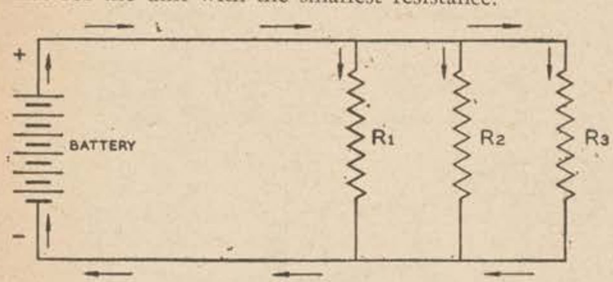


Figure 13. Simple parallel circuit.

14. SERIES-PARALLEL CIRCUITS. There are a few series-parallel circuits in an airplane. Some aircraft starter-motor field circuits are connected in series-parallel. A rheostat in series with the formation lights is a series-parallel circuit (fig. 14). Each unit is grounded, that is, one terminal of each unit is connected to the metallic airplane structure; thus the metallic airplane structure provides the return path to the battery.

15. POWER IN DIRECT-CURRENT CIRCUITS. Power is the *rate* of doing work. For instance, an aircraft engine is rated in horsepower. One horsepower is equal to the work done in raising a 550-pound weight 1 foot in 1 second (fig. 15). Some aircraft engines will develop 2,000 horsepower or more. The electrical unit of power is the watt. 746 watts of electrical energy is equal to 1 horsepower. The number of watts used is calculated by multiplying amperes by volts; for example, a starter motor using 70 amperes with a pressure of 24 volts uses 1,680 watts of electrical power. By dividing 1,680 watts by 746 watts (the electrical equivalent of 1 horsepower) it will be found that such a starter motor will develop approximately 2 horsepower.

16. SOLUTION OF SIMPLE PROBLEMS. a. Table I is a summary of the relationships between *E, I, R,* and *P.*

b. The solution of typical electrical problems follows.

(1) *Single load unit.* (*a*) *Problem.* A typical 12-volt aircraft landing light is rated to draw a current of 20 amperes. What is its resistance when in use (hot*)? What is its wattage?

(*b*) *Solution.* Find the known and unknown values as follows:

$E = 12$ volts. $R = ?$ ohms.
$I = 20$ amperes. $P = ?$ ohms.

Choose the appropriate formula from paragraph 10a to determine the unknown value. In this case, by use of formula (3)

$$R = \frac{E}{I} \text{ or } R = \frac{12}{20} = 0.60 \text{ ohms resistance.}$$

To determine the wattage, use power formula given in paragraph 16, table I. Thus, by use of this formula:

$$P = 12 \times 20 = 240 \text{ watts.}$$

* Unless otherwise specified, current ratings of electrical devices are given under operating conditions (in this case "hot").

Table I. Electrical relationships

	Volts Pressure	Amperes Current flow	Ohms Resistance	Power
Meter used	Voltmeter in parallel	Ammeter in series	Measured with ohmmeter or figured from formula.	Voltmeter and ammeter
Series circuit	$E_T = E_1 + E_2 + E_3$	$I_T = I_1 = I_2 = I_3$	$R_T = R_1 + R_2 + R_3$	$I \times E = P$ (watts) $\frac{\text{Watts}}{746} = \text{hp}$
Parallel	$E_T = E_1 = E_2 = E_3$	$I_T = I_1 + I_2 + I_3$	$\frac{I}{R_T} = \frac{I}{R_1} + \frac{I}{R_2} + \frac{I}{R_3}$	$I \times E = P$ (watts) $\frac{\text{Watts}}{746} = \text{hp}$

(2) *Load units in series.* (*a*) *Problem.* A small 3-volt cockpit instrument lamp, similar to a tiny flashlight bulb, is operated successfully on the 12-volt d-c circuit of an airplane by use of 68-ohm series resistor. Figure all of the unknown values.

(*b*) *Solution.* Draw a diagram and indicate the known values at the appropriate places. Tabulate the known and unknown values for each load unit and the complete circuit, as follows:

Lamp	*Resistor*	*Complete Circuit*
$E = 3$ volts.	$E = ?$ volts.	$E = 12$ volts.
$I = ?$ amperes.	$I = ?$ amperes.	$I = ?$ amperes.
$R = ?$ ohms.	$R = 68$ ohms.	$R = ?$ ohms.
$P = ?$ watts.	$P = ?$ watts.	$P = ?$ watts.

No set procedure of solution is recommended inasmuch as the procedure must be designed to fit each case, as will now be shown. First, it is to be noted that the formulas cannot be successfully applied in the case of either of the load units, or the entire circuit, inasmuch as only one of the terms *E, I, R,* and *P* (and not two as required) is known in each case. Therefore, it is necessary to make use of known relationships between the load units and the entire circuit. The sum of *E* for the resistor and *E* for the lamp should be equal to *E* for the entire circuit (paragraph 12). Therefore, *E* for the resistor must be 9 volts. This having been determined, *I* and *P* for the resistor can be determined as follows:

$$I = \frac{E}{R} = \frac{9}{68} = 0.132 \text{ amperes.}$$

$$P = EI = 9 \times 0.132 = 1.19 \text{ watts.}$$

Inasmuch as the current *I* must be the same throughout the series circuit, it follows that *I* in the lamp and in the entire circuit is 0.132 amperes. *R* and *P* for the lamp may now be determined as follows:

$$R = \frac{E}{I} = \frac{3}{0.132} = 22.7 \text{ ohms.}$$

$$P = EI = 3 \times 0.132 = 0.396 \text{ watts.}$$

For the entire circuit:

$$R = \frac{E}{I} = \frac{12}{0.132} = 90.9 \text{ ohms.}$$

$$P = EI = 12 \times 0.132 = 1.58 \text{ watts.}$$

The sum of the wattages of the lamp and the resistor should be equal to the wattage for the entire circuit. Also, the sum of the resistances of the load units should equal the total resistance of the circuit (par. 12). These conditions are satisfied within allowable limits by the foregoing solutions, and the accuracy of the calculations is thus verified.

(3) *Load units in series-parallel.* (*a*) *Problem.* Three resistors are connected to a 12-volt battery in such manner that current flows first through R_1, then through R_2 and R_3 in parallel, and back to the battery. The resistance values of R_1, R_2, and R_3 are 2 2/3, 2, and 4 ohms, respectively. Calculate the rate at which charge will flow out of the battery.

(*b*) *Solution.* Draw a diagram and indicate the known values at the appropriate places (fig. 16). The net resistance of R_2 and R_3 is found as follows:

$$R = \frac{1}{\frac{1}{R_2} - \frac{1}{R_3}} = \frac{1}{\frac{1}{2} + \frac{1}{4}} = \frac{1}{0.50 + 0.25} = \frac{1}{0.75} = 1.333 = 1\tfrac{1}{3} \text{ ohms.}$$

The addition of this resistance to that of R_1 (2 2/3 ohms) gives a total of 4 ohms for the net resistance of the circuit. The current drawn from the battery will then be—

$$I = \frac{E}{R} = \frac{12}{4} = 3 \text{ amperes.}$$

(4) *Load units in parallel.* (*a*) *Problem.* Six 4-watt navigation lamp bulbs are operated in parallel on a particular aircraft which uses a 12-volt d-c system. How much current does each bulb draw? What is the resistance of each when hot? What is the total current drawn? What is the resistance of the entire circuit? What is the total power demand?

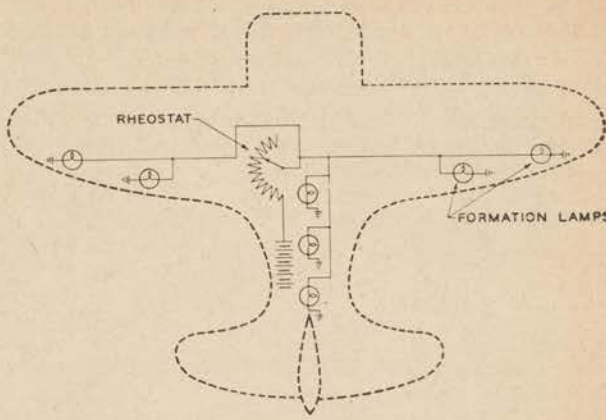


Figure 14. A series-parallel circuit.

(*b*) *Solution.* Draw a diagram and indicate the known values at the appropriate places (fig. 17). Find the known and unknown values for each load unit and for the entire circuit as follows:

Each lamp bulb	*Entire circuit*
$E = 12$ volts.	$E = 12$ volts.
$I = ?$ amperes.	$I = ?$ amperes.
$R = ?$ ohms.	$R = ?$ ohms.
$P = 4$ watts.	$P = ?$ watts.

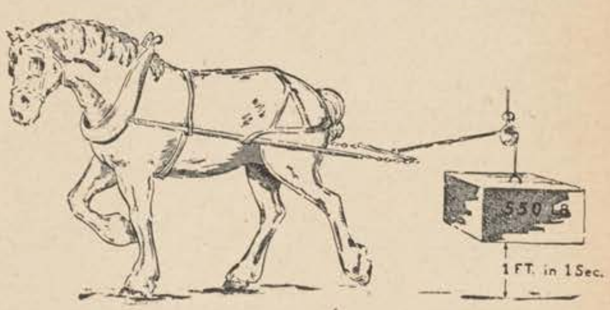


Figure 15. Horsepower.

First, attempt to apply Ohm's law to any of the units or to the entire circuit. If two of the three terms *E, I* and *R* pertaining to any one of the units or to the entire circuit are known, Ohm's law can be applied in the manner shown in paragraph 10. If only one of these three terms is known if P is known, the problem can be solved by use of the appropriate power formula. Thus, in the present example, it is seen that Ohm's law cannot be applied immediately. But the demand of each lamp is given as 4 watts. Its current, I, may be found by using the formula $P = EI$:

$$4 = 12 \times I;$$

Or,

$$I = \frac{4}{12} = \frac{1}{3} \text{ ampere}$$

The remaining unknown value for each bulb, R, can now be determined by use of Ohm's law. Applying the formula $R = \frac{E.}{I}$

$$R = \frac{12}{1/3} = 12 \times 3 = 36 \text{ ohms}$$

Since there are 6 lamp bulbs each drawing 1/3 of an ampere, it is seen that the total current will be 2 amperes. The resistance R of the entire load circuit may now be determined by use of the formula $R = \frac{E}{I}$ as follows:

$$R = \frac{12}{2} = 6 \text{ ohms}$$

The same result would be obtained by dividing the resistance of 1 lamp (36 ohms) by the number of lamps (6) since the lamps have equal resistance (par. 13). The power demand of the entire load can can be determined by use of the power formula as follows:

$$P = I \times E = 12 \times 2 = 24 \text{ watts}$$

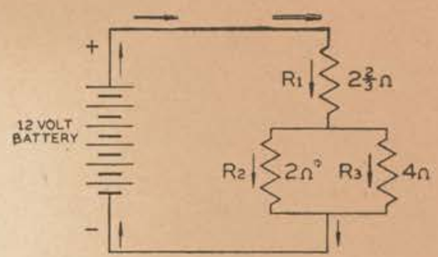


Figure 16. Load units in series-parallel.

It should be noted that the same total power could be obtained by multiplying the 4-watt demand of each lamp by the total number of lamps (6). The first procedure would work if the load units were to possesss unequal resistance; the second procedure would not.

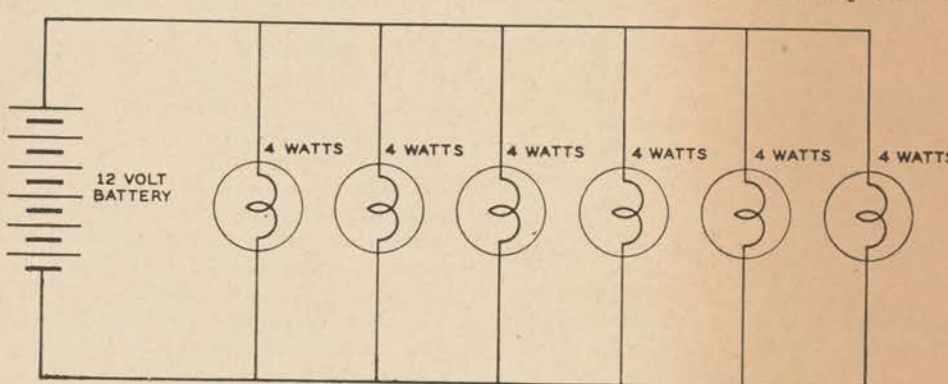


Figure 17. Load units in parallel.

SECTION III

MAGNETISM AND MAGNETIC DEVICES

17. CHARACTERISTICS OF MAGNETISM. **a.** The following facts may be observed with respect to the behavior of magnets:

(1) The ends of a magnet are more active (magnetically) than its central part. If a magnet is dipped into a box of iron filings, more filings will cling to the ends than to the middle (fig. 18). The ends of a magnet are called its *magnetic poles.*

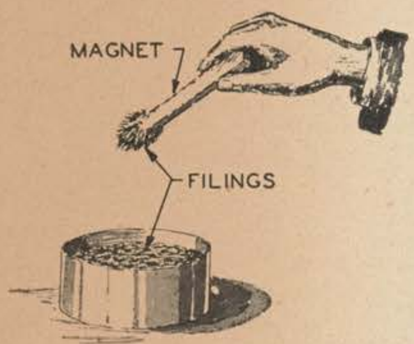


Figure 18. Attraction of filings to a magnet.

(2) If a magnet is suspended at its midpoint by a fine thread, it will always come to rest with one particular pole toward the north. This pole is called the magnet's *north pole;* the other pole is its *south pole.*

(3) If two magnets are suspended at midpoints by a string and are free to move, their like poles repel each other, whereas their unlike poles attract each other (fig. 19).

(4) The magnetic force of a pole is comparatively powerful in the area surrounding the pole but becomes weaker farther away from it. Considerable force is required to detach an iron nail from a magnet; but once the nail has been removed a short distance from the magnet it may be removed farther with relative ease.

b. The needle of every magnetic compass is in reality a magnet. It has a north and a south pole. It is mounted on a pivot having very little friction, so that it may turn easily under the magnetic influence of the earth. The end of the compass needle which points northward is a north magnetic pole (by definition).

18. MAGNETIC FIELD. **a.** A magnet is surrounded by a magnetic field. The space around a magnet in which its force may be detected is called the *magnetic field* of the magnet.

b. The magnetic field is made up of *lines of force.* The manner in which the lines of force arrange themselves in a magnetic field of force may be observed by sifting iron filings upon a piece of paper above a bar magnet. The filings will arrange themselves in accordance with these lines of force (fig. 20).

c. Tests for direction of a magnetic field around a wire are performed with a compass needle. The north pole of the needle is attracted in the direction of the field, while the south pole is pulled the other way. The two forces cause the needle to turn until it becomes

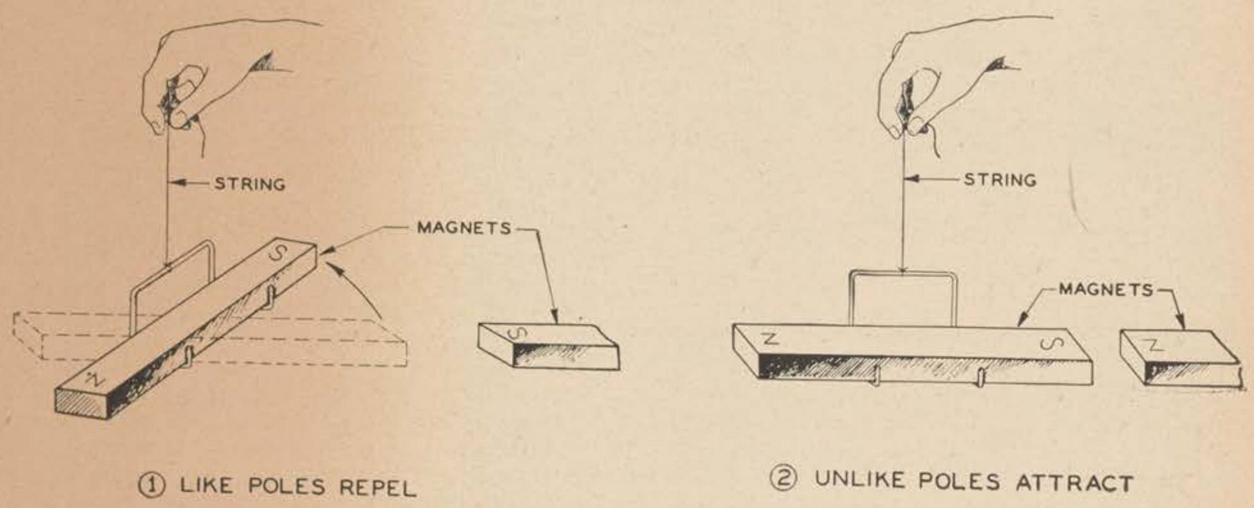


Figure 19. Inter-action of magnets.

tangent to the lines of force, with the north pole pointing in the direction of the field.

d. The magnetic field about a straight magnet is illustrated in figure 20 by means of lines of force. Small compasses have been placed in the field of a **U**-shaped

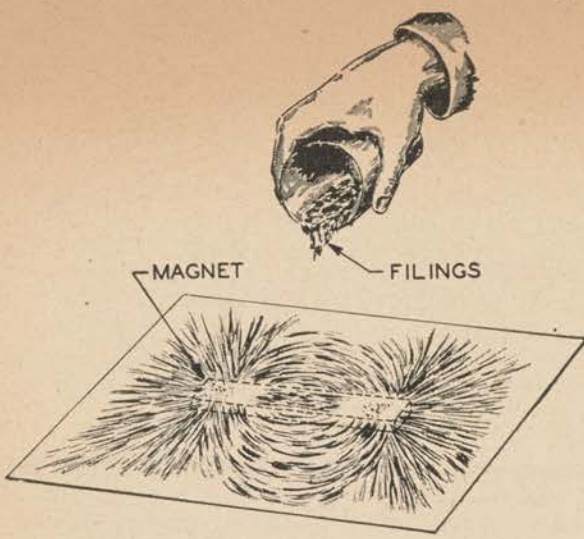


Figure 20. Pattern of lines of force.

magnet (fig. 21) to show how their needles would "set." It should be noticed that lines of force emerge from the north pole of the magnet and go into its south pole, the compass needles indicating the directions of the lines.

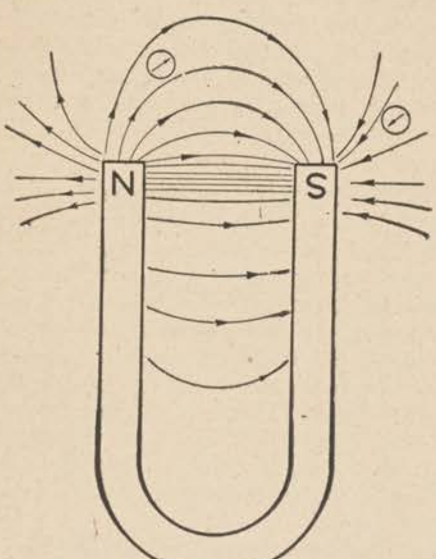


Figure 21. Magnetic field about a **U**-*shaped magnet.*

e. A compass between the poles of a magnet behaves in the same manner as it does between the poles of the earth. The earth is a big magnet. One of the earth's poles is in Northern Canada and the other is below Australia. They are near, *but not at,* the earth's geographic poles. The pole in Northern Canada is a south magnetic pole, since the north end of the compass needle points that way. The pole at the southern part of the earth is a north magnetic pole (fig. 22).

19. ELECTROMAGNETIC FIELD. a. A wire which carries current is surrounded by a magnetic field. Since this field is caused by an electric current, it is called an electro-magnetic field. It is found that the lines of

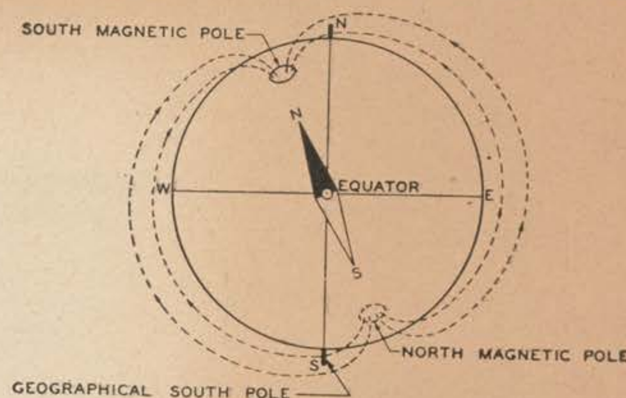


Figure 22. Earth's magnetic field.

force in the field about a straight wire are concentric circles. The force of the field is strongest close to the wire and decreases rapidly with increased distance from the wire.

b. The direction of the magnetic field about a wire may be determined by the use of the *right-hand thumb rule.* If one imagines the wire to be grasped with the right hand in such a manner that the thumb points in the direction of the current flow, then the fingers of the hand point in the direction of the field (fig. 23).

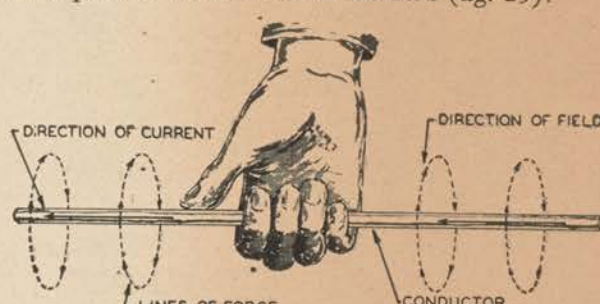
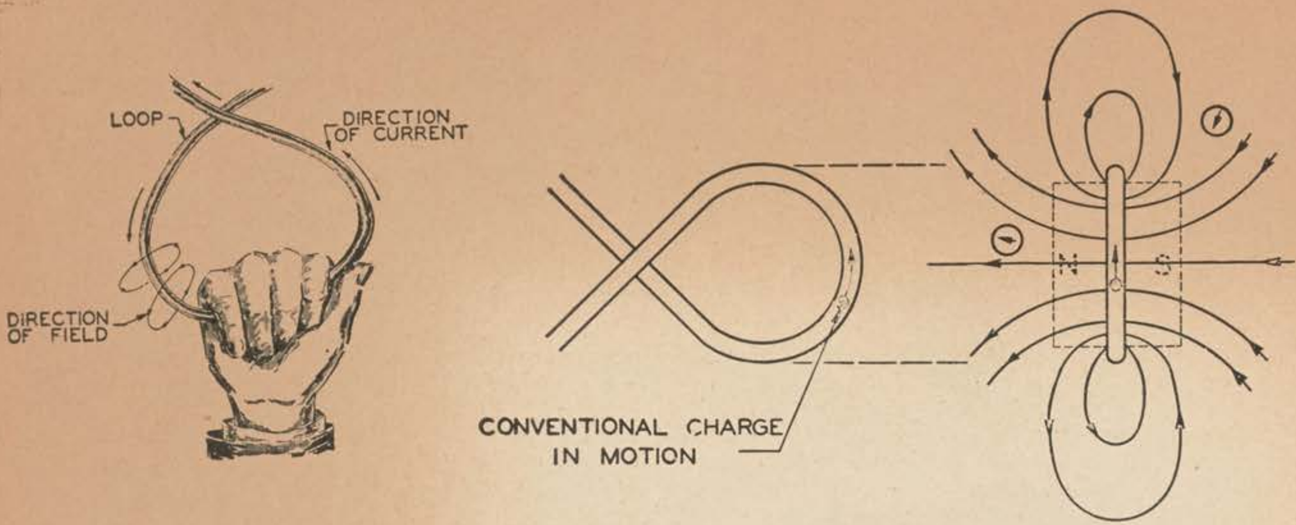


Figure 23. Right-hand thumb rule (straight conductor).

c. If a wire is made into a loop and a current passed through the loop, the direction of the field can be found by grasping the wire with the right hand, the thumb pointing in the direction of current; the fingers will then point in the direction of the field (fig. 24 ①).

d. The magnetic field associated with a loop or wire is much the same as the field of a bar magnet. The loop may be imagined to have poles (fig. 24 ②), similar to those of a bar magnet with lines of force emerging from the north pole and entering the south pole. Whatever is imagined to happen to such a magnet with respect to motion or torque, will actually happen to the loop when a current passes through it.



① *Right-hand thumb rule (loop of wire).* ② *How current-carrying loop resembles bar magnet.*

Figure 24.

20. MAGNETIC INDUCTION. The temporary magnetization of a magnetic material (one which can be magnetized) is known as magnetic induction. Magnetic induction takes place whenever a magnetic substance is brought close to, or in contact with, a magnet (fig. 25). Watch parts or other magnetic substances may become magnetized when brought into the vicinity of a magnet. Magnetism from a rotating magnet of a magneto induces magnetism in the pole shoes. When the rotating magnet does this it forms a magnetic path from the magnet, to the pole shoes and back to the magnet (fig. 26).

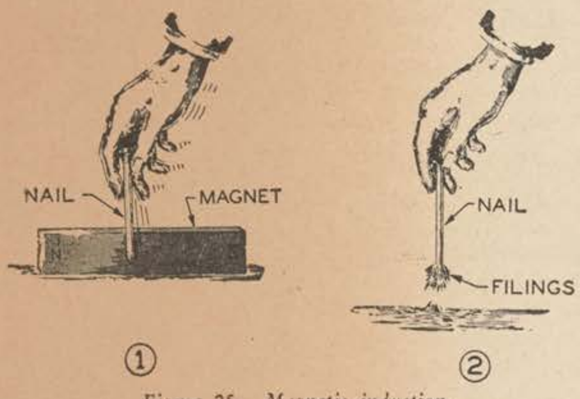


Figure 25. Magnetic induction.

21. RETENTION OF MAGNETISM. a. Retention of magnetism is the ability of a magnetized piece of metal to hold its magnetism. Some magnets will stay magnetized longer than others. The length of time a magnet retains its magnetism or stays magnetized depends on the material of which it is made, and the way it is handled. Alnico, an alloy composed of aluminum, nickel and cobalt is difficult to magnetize but will stay magnetized or retain its magnetism indefinitely if properly handled. If any magnet is heated excessively or hammered it will not retain its magnetism. Magnets made of soft iron are easy to magnetize but they will not retain magnetism long. The magneto pole shoes (fig. 26) are good examples of magnets which retain magnetism for short periods of time. These shoes can be magnetized and demagnetized readily. Generators have electromagnets that will not retain their residual magnetism if heated excessively or if abused.

b. There is usually just a little magnetic effect left in a piece of iron which has been temporarily magnetized by induction. This remaining magnetism is known as *residual magnetism.* Generator and motor pole pieces have a little magnetism retained as residual magnetism when the unit is not operating; however, this magnetism is not retained long. If a generator or motor is not used for a long period of time, if it is heated excessively, or if it is handled roughly, the pole pieces may lose their residual magnetism.

22. MAGNETIC CIRCUIT. a. General. An unmagnetized piece of soft iron will become temporarily but powerfully magnetized by induction if placed across the ends of a **U**-shaped (horseshoe) magnet (fig. 27). The rotating magnet in a magneto can temporarily and powerfully magnetize the pole shoes and coil core. If the area surrounding the **U**-shaped magnet or magneto pole shoes is checked for magnetic field strength, the field will be weak since the magnetic field is concentrated in the soft iron and magnet which make up a *magnetic circuit.* The field within the circuit may be represented by lines which are given the usual directions with respect to the poles in the circuit.

b. Magnetomotive force. Magnetomotive force, or m.m.f., is the name applied to the magnetizing influence which a magnet or coil of current-carrying wire can exert in a magnetic circuit. It corresponds to e.m.f. (par. 3) in electrical circuits. The field coils of a generator when carrying electric current exert a m.m.f. The amount of magnetomotive force these field coils exert is expressed in ampere-turns. One ampere of current flowing through 1 turn of a coil constitutes 1 ampere-turn. A generator pole having 20 turns of wire around the pole with 10

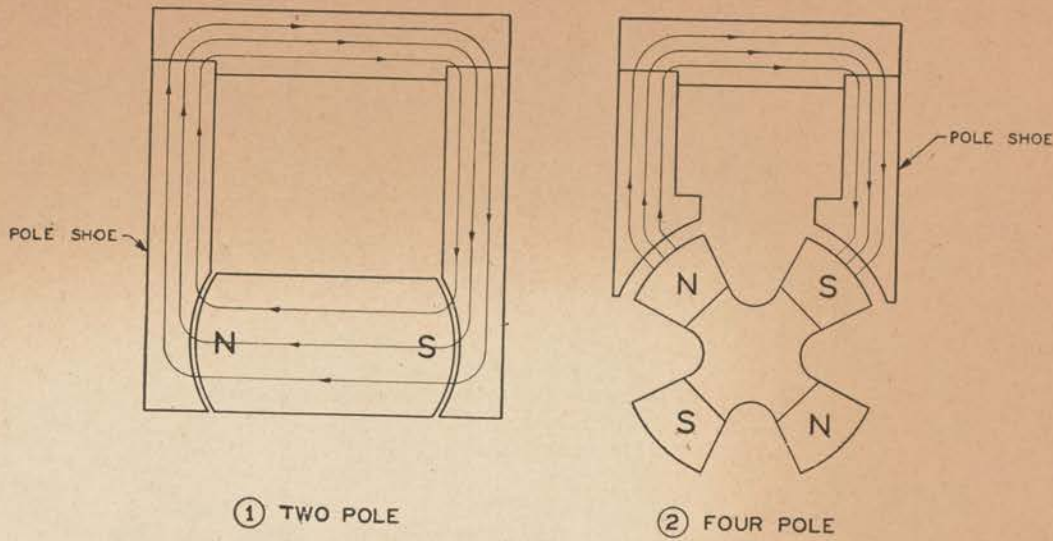


Figure 26. Magnetic path of a magneto.

amperes flowing through it will exert 200 ampere-turns of magnetomotive force.

c. Flux. Flux in a magnetic circuit is similar to current in an electrical circuit. Flux may be represented by lines of force which are imagined to exist in the circuit. The greater the number of turns of wire (that is, the greater the number of ampere-turns) a generator pole contains and the greater the current through them, the greater the magnetc flux.

d. Reluctance. Reluctance in a magnetic circuit is similar to resistance in an electrical circuit. Reluctance determines how much flux will be established when a given amount of m.m.f. is applied to the circuit. The greater the reluctance, the fewer will be the flux lines which a given m.m.f. can establish in a magnetic circuit. The shorter the length and the thicker the cross section of parts of the magnetic circuit, the smaller will be its reluctance. The closer the pole pieces are to the armature, the less the reluctance.

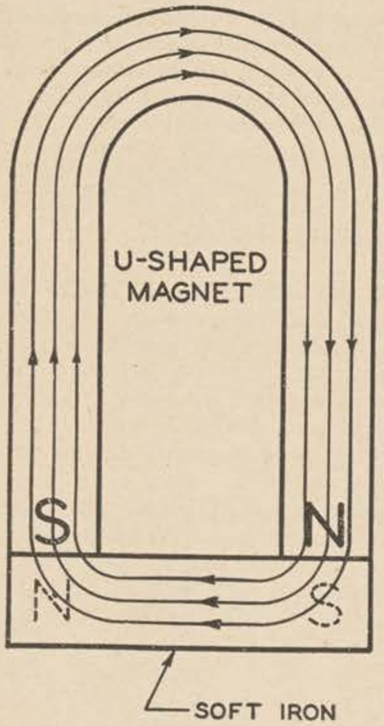


Figure 27. Magnetic circuit formed by permanent magnet and piece of soft iron.

e. Interrelationship. Magnetomotive force, flux, and reluctance are interrelated in a manner similar to the Ohm's law relationship between the corresponding quantities in the electrical circuit (voltage, amperes, and resistance).

23. ELECTROMAGNETIC FIELDS OF COILS. a. If a current is passed through a coil of wire consisting of 8 turns closely wound, and an equal current is passed through a single-turn loop of the same diameter as the coil, the magnetic fields will be found to be almost identical in direction at every point. However, the magnetic field strength of the 8-turn coil will be approximately 8 times that of a single-turn loop since the fields of the eight turns are virtually parallel with each other at every point, and their effects are therefore cumulative at every point.

b. If, however, the 8 turns are spread out into a helical coil or solenoid, the magnetic field will be as shown in figure 28. The field is very weak between the turns, because the fields of adjacent turns are opposite in direction and tend to cancel each other. But inside the solenoid, the fields are cumulative for the most part, and the net result is a strong field of fairly uniform intensity, represented by nearly straight lines of force.

c. Each of the coils mentioned will have a north magnetic pole at one end and a south magnetic pole at the other. The direction of the field depends upon the direction of current flow and may be determined by use of the right-hand rule.

24. SOLENOID AND ELECTROMAGNET. a. Solenoid. A solenoid may be defined as a coil of wire wound around a hollow cylinder, and used to produce a magnetic field. In aircraft electrical equipment, a "sole-

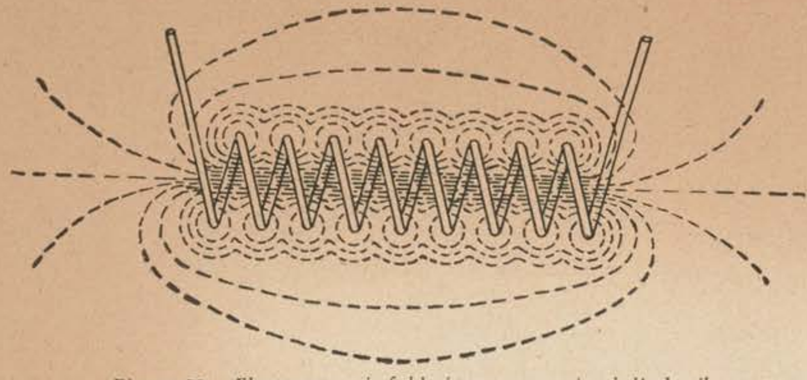


Figure 28. Electromagnetic field of current-carrying helical coil.

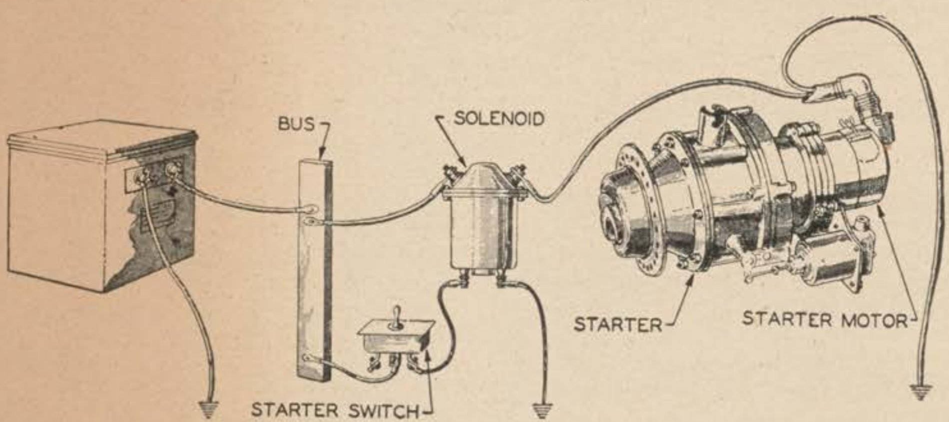


Figure 29. Starter circuit.

noid" has a core the whole or part of which is free to move. The field of the coil tends to pull the core into the coil when the current is turned on. Many electrical appliances can be controlled by this means. The starter motor has a solenoid whose movable core opens and closes (controls) the circuit permitting current to operate the motor (fig. 29). A small wire from the solenoid to the cockpit and from cockpit to battery supplies enough current to operate the solenoid. A spring is placed in the solenoid to push the core back to its normal position after the current has been turned off.

b. Electromagnet. (1) The magnetic strength of an electromagnet (a solenoid with a fixed core) depends on the number of turns of wire wound around the core, the kind of metal in the core, and the amount of current sent through the coil.

(2) Electromagnets are used frequently in aircraft electrical equipment such as landing-light relay, voltage regulator, current cut-out relay switch, and generator field coils. The electromagnet is frequently employed as the essential part of an actuating device, such as is found in the landing-light relay or the generator control panel. The principle of operation of the electromagnetic actuating device will be discussed with the aid of the elementary relay shown in figure 30. A small piece of soft iron is fastened to a strip of non-conducting material which is pivoted at one end. The iron is held away from the core of the electromagnet by a spring. When the current is turned on, the iron is pulled toward the core. In some cases, it is restrained by means of a stop pin from actually making contact with the core. At the other end of the non-conducting strip there are contact points, arranged (depending upon the type of relay) to close or open one or more circuits when the relay is actuated. The relay illustrated has 4 terminals, 2 for its coil, and 2 which are connected to the contact points. In aircraft, the relay is employed as a remote-control device. By its use, the total weight of wire is reduced and wires which carry large amounts of current are eliminated from the cockpit.

25. FORCE ON CURRENT-CARRYING CONDUCTOR.

When a wire which carries current is placed in a magnetic field, the field of the wire reacts with the other field, resulting in a force on the wire. Figure 31 ① shows a straight wire (resembling a wire from either a motor or generator) without current. It is placed in a magnetic field perpendicular to the lines of force passing from the north pole to the south pole. In figure 31 ② a current is flowing in the conductor. The field surrounding the current-carrying conductor and the magnetic field from the pole pieces will result in a force (fig. 31 ③). The direction of this force is found by the *left-hand rule* (fig. 32). The left-hand thumb gives direction of motion, the index finger gives the direction of magnetic field, and the second finger indicates current direction. As stated before, magnetic fields add to or subtract from each other, depending upon their directions. If, in an armature wire, the current is flowing in such direction as to create a clockwise field around the

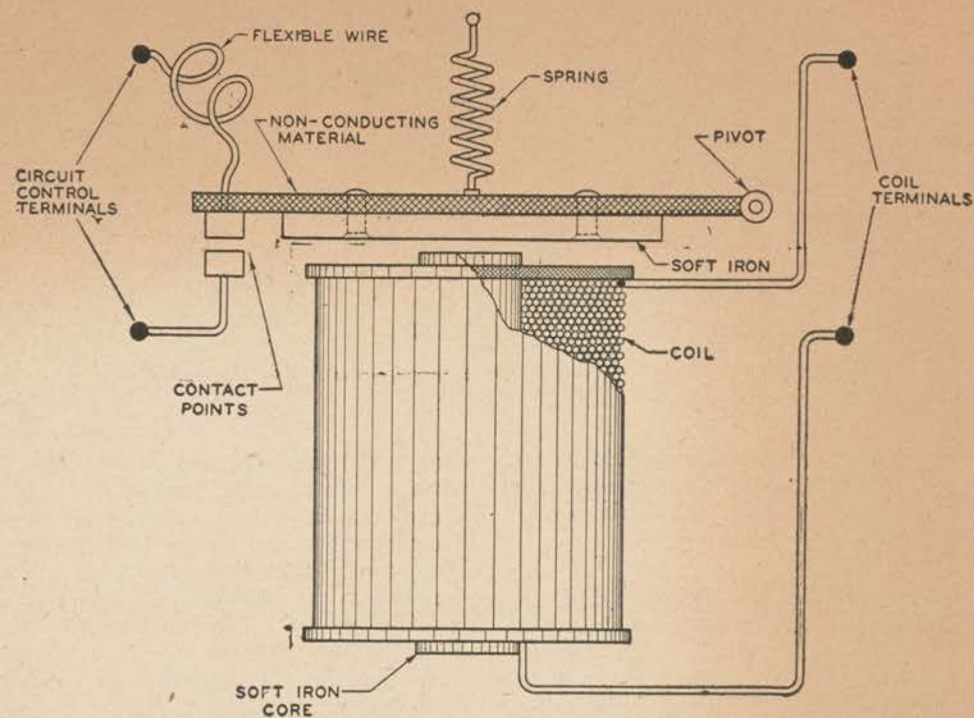


Figure 30. Elementary relay.

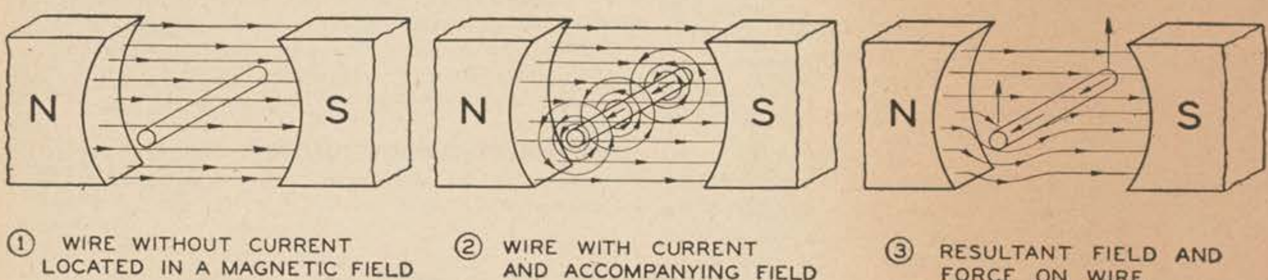


Figure 31. Torque on current-carrying wire.

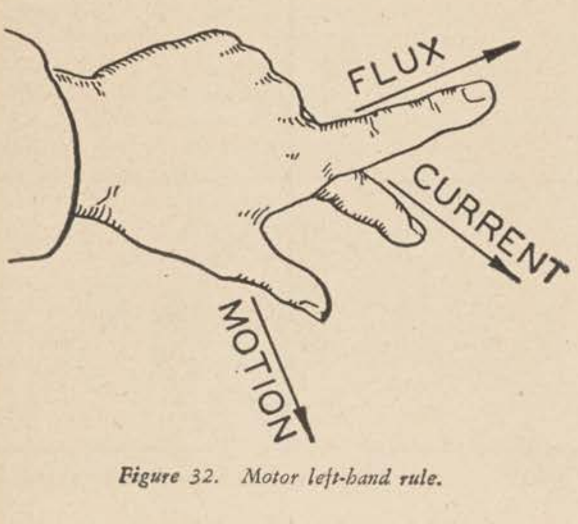


Figure 32. Motor left-hand rule.

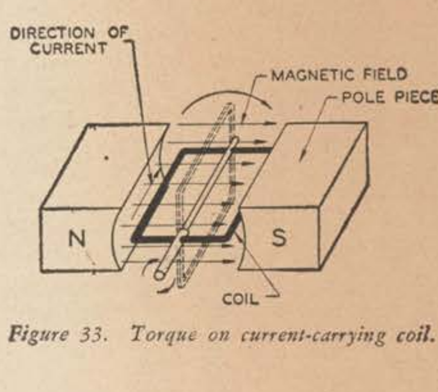


Figure 33. Torque on current-carrying coil.

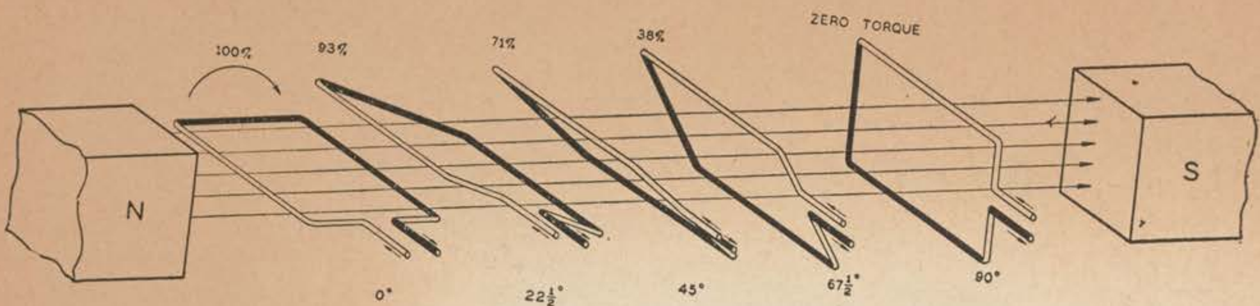


Figure 34. Torque on a coil at various angles with respect to this field.

wire, and the field from the poles is from right to left, the fields will add on the bottom of the armature wire and subtract or neutralize at the top. This difference of magnetic field will push the wire up.

26. TORQUE ON CURRENT-CARRYING COIL. a. The tendency to produce a turning motion is known as torque (twisting force). If free to act, torque will produce rotation. For purposes of theoretical reasoning, consider a rectangular coil to be located between two pole pieces, figure 33, with current passing through the coil in the direction indicated. One conductor will be forced up, the other down.

b. The existence and direction of the torque created on a current-carrying coil situated in a magnetic field may also be considered on the basis of interaction between the pole pieces and the poles of the imaginary magnet within a current-carrying coil. One may determine the polarity of this imaginary magnet by use of the right-hand rule.

c. The amount of torque developed in a coil depends directly upon four factors; the current, the strength of the field in which the coil is situated, the number of turns of wire in the coil, and the position of the coil with respect to the field. If the coil carries a steady current and is situated in a uniform field, the torque at successive positions of the coil will vary with the values shown in figure 34. When the plane of the coil is parallel with the field, the torque is at a maximum. When the plane of the coil is perpendicular to the field, the torque is zero.

27. D'ARSONVAL METER MOVEMENT. a. The D'Arsonval type of meter movement has wide application in Army Air Forces electrical instruments. The essential features of the movement are shown in figure 35. *N* and *S* are the pole pieces of a yoke-shaped magnet made of an alloy which is capable of remaining magnetized at a constant value over a long period of time. A cylinder of readily magnetized metal, situated midway between the pole pieces, draws the magnetic field within itself and thereby makes the lines of force between itself and the pole pieces approximately radial in direction. The cylinder becomes a part of the magnetic circuit, and increases the flux by reducing the reluctance of the circuit. A movable coil composed of a number of turns of very fine wire, is mounted on jeweled bearings. Spiral hair-springs, located at the front and back of the coil, hold the coil in zero-current position. If rotated either way from this position (no current flowing), the springs bring the coil back into the original position. A pointer attached to the coil indicates the degree of rotation on a calibrated scale. Electrical connections to the coil are generally made through the spiral springs.

b. If current is passed through the coil in the direction indicated,* clockwise motion results. If the current is reversed, the coil is rotated the opposite way. Inasmuch as the current is limited, in normal use, to values which will not carry the coil outside the radial portion of the magnetic field, the torque developed will be proportional to the current. The hair-springs are so designed that their opposing torque, regardless of the direction of rotation, is exactly proportional to the degree of their twist. Therefore, the deflection of the pointer is proportional to the current in the coil.

28. DIRECT-CURRENT MOTOR. a. The d-c motor operates on the same basic principle as the D'Arsonval movement.

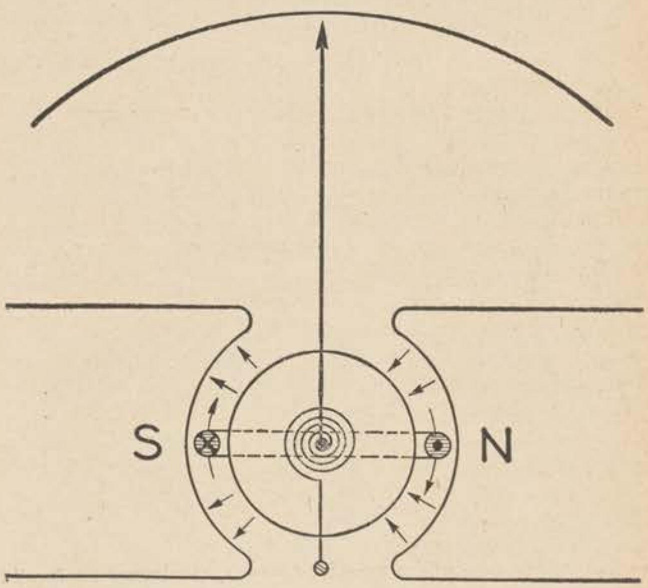


Figure 35. Electrical features of D'Arsonval meter movement.

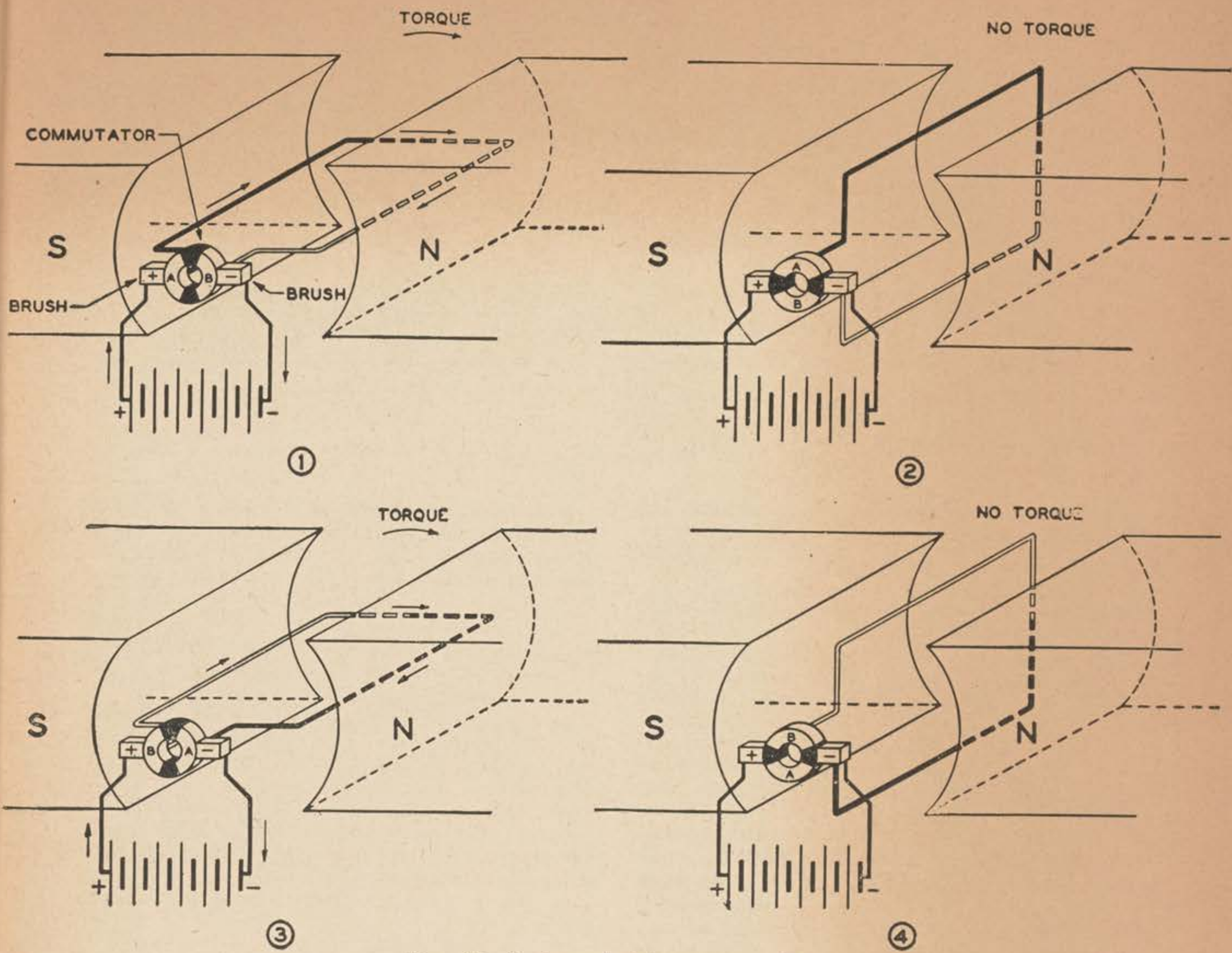
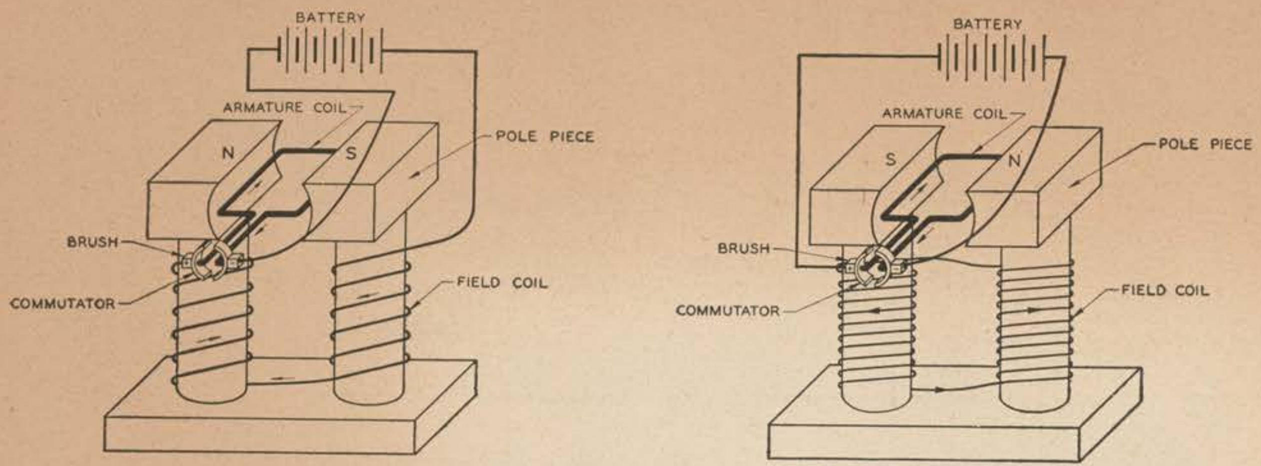


Figure 36. Fundamentals of d-c motor operation.

b. Suppose a coil to be in the position shown in figure 36 ① and that connections for current are made by a pair of brushes which ride on a commutator. Current will flow from the positive terminal of a battery to the positive (+) brush, to segment A, through the coil to segment B, to the negative (—) brush, and finally to the negative terminal of the battery. By using the right-hand rule, it will be seen that the armature will rotate clockwise. The torque, which was at a maximum with the coil in the position shown in figure 36 ①, decreases as the coil rotates, and is at a minimum when the coil has rotated through the 90 degrees into position shown in figure 36 ②. At this moment, segments A and B slide from under the brushes, breaking the battery circuit. The brushes are then on an insulator and current will not flow through the coil. The coil will coast past this position and the segments which conduct current will again contact the brushes. Current will again flow through the coil. This current will flow in the opposite direction with respect to the coil but will continue to enter and leave the armature (coil) as before. The coil will have torque in the same direction as before. When the coil passes through the position shown in figure 36 ③, this twisting force (torque) will again be at a maximum. The torque will again be at zero when the position shown in figure 36 ④ is reached, but once more the momentum carries the coil past the "point of commutation." Commutation, or reversal of the coil terminals from + to — and — to + occurs twice per revolution.

c. In order to obtain a steady torque, in practical motors a number of coils are spaced uniformly about an iron cylinder similar to that in the D'Arsonval meter movements. This coil assembly is known as an *armature*. The use of a number of coils results in an increase in the number of commutator segments. The coils may be wired together in several ways. The efficiency of the

* + is conventional sign for current flowing from observer while — is conventional sign for current flowing toward observer.



① *Series wound.* ② *Shunt wound.*

Figure 37. Elementary d-c motors.

motor may be increased by using four pole pieces and four brushes instead of two of each. The principle of operation, however, remains the same as previously described.

d. The torque developed by the armature is increased in several ways.

(1) The slotted soft iron cylinder on which the armature coils are wound, reduces the reluctance in the magnetic circuits of the motor and thus increases the flux in which the coils rotate. The field in which the coils move is made more nearly radial by this cylinder. The cylinder itself becomes magnetized by the current flowing in the coils, thus improving the interaction of the armature with the pole pieces.

(2) The magnetic circuits of the machine are magnetized by means of one or more *field coils*. These coils are energized by the same source of electricity which energizes the armature coils. The flux thus created is greater than could be obtained solely by use of permanent magnets. This being the case, the iron selected for use in practical motors is not chosen for its ability to retain magnetism, but for its ability to be magnetized strongly by induction.

e. Two common ways of connecting the field and armature circuits of a motor are shown in figure 37. When connected in series, as in ①, the motor is said to be a "series wound" or *series motor*. If the circuits are connected in parallel, as in ②, the motor is said to be a "shunt wound" or *shunt motor*. Each type of winding has its own advantages and appropriate uses.

f. The direction of rotation of a motor may be reversed by reversing either the connections of the brushes or the field coils. This will reverse the magnetism of either the armature coils or the magnetic field in which the coils are located. If the wires to the motor are interchanged, the direction of rotation will not be reversed, since exchanging these wires will reverse the magnetism of both the armature and the field, and the torque will have the same direction as before.

g. A part of the energy supplied to a motor is used to overcome its resistance. This energy is converted into heat and causes the temperature of the motor to rise as it is operated. For example, suppose a certain 12-volt motor, when running under a constant load, draws 70 amperes. The unit is absorbing energy at the rate of 840 watts ($P = EI$). Suppose the resistant between the terminals of the motor has been found to be 1/50 of an ohm. The rate at which energy is being used to create heat is—

$$\begin{aligned} P &= I^2R \\ &= 70 \times 70 \times 1/50 \\ &= 98 \text{ watts} \end{aligned}$$

It would, hence, appear that electrical energy is being used at the rate of 840 minus 98, or 742 watts to produce motion. But a portion of this energy is being converted into frictional heat in the bearings of the motor, so that the actual rate of mechanical energy output may be reduced to approximately 740 watts. Since 746 watts equal 1 horsepower, the motor is developing mechanical energy at a rate of approximately 1 horsepower.

SECTION IV

MEASURING DEVICES

29. GENERAL. In the inspection, maintenance, and operation of the aircraft electrical equipment, it is often necessary to *measure* one or more of the electrical quantities (voltage, current, or resistance). A number of instruments or meters developed for this purpose will be discussed in the following paragraphs.

30. GALVANOMETER. a. The galvanometer is an instrument used to measure very small currents. In the airplane, only the moving-coil galvanometer known as the D'Arsonval galvanometer is used. The galvanometer movement is used as part of the voltmeter, ammeter, thermocouple thermometer, electrical tachometer, etc. (fig. 38).

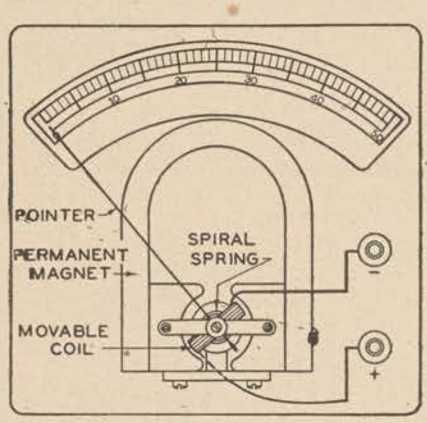


Figure 38. Galvanometer.

b. When the leads of the galvanometer are connected to 2 points between which a voltage exists, a current will flow through the coil of the galvanometer. The direction of current flow will depend upon the polarity of the voltage. The amount of current flow, which governs the extent of the deflection of the needle, will depend upon the applied voltage and the resistance of the galvanometer coil (Ohm's law).

31. VOLTMETER. a. The voltmeter is used to measure the potential difference or voltage between two points.

b. The d-c voltmeter, as used on the airplane, is a galvanometer movement connected in series with a high resistance unit (fig. 39). The purpose of the resistance is to limit the current flow through the movement. Most voltmeters will give full scale deflection with less than 0.01 of an ampere flowing through the movement. As

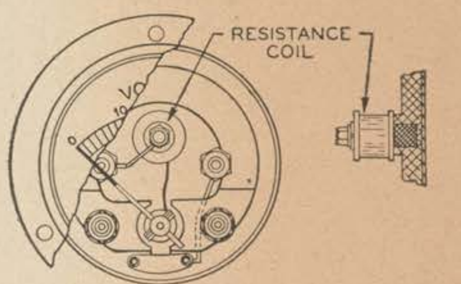


Figure 39. Cutaway of voltmeter.

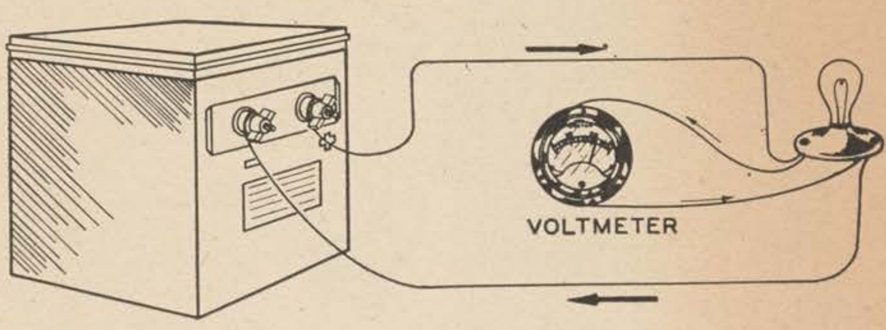


Figure 40. Voltmeter connected across an electrical unit.

the resistance of the meter is *fixed*, the current flow and deflection of the needle will depend upon the voltage applied to the terminals of the meter (Ohm's law). The sensitivity of a meter is usually measured in ohms per volt. A voltmeter with a scale calibrated from 0 to 30 volts, which has a sensitivity of 100 ohms per volt, will have a total resistance of 3,000 ohms. A current of 0.01 ampere will be required to give full scale deflection.

c. Voltmeters are always connected across the electrical unit or across points, the difference of potential of which is to be measured (fig. 40). To obtain the correct direction of deflection of the needle, the (+) terminal of the voltmeter must be connected to the point of the higher potential. Care must be exercised not to connect the voltmeter to a source of voltage which will exceed the voltmeter's scale. If the voltmeter is accidentally connected in series with the circuit, no harm will result to the meter since the current will be limited by the high resistance of the meter and the other units in the circuit will not operate.

32. AMMETER. a. The ammeter is used to measure electrical current flowing in a circuit (fig. 41). The ammeter is *always* connected in series with the load. *Never* connect the ammeter across the terminals of a battery or generator (fig. 42).

b. The ammeter uses essentially the same movement (mechanism) as the voltmeter. However, a current bypass is used instead of a current limiter as in a voltmeter. This current bypass is called a *shunt*. The shunt is a resistor made of a special alloy, the resistance of which is not affected by any change of temperature. The movement may be the same as that used in a voltmeter. If a movement is used which requires 0.01 of an ampere to

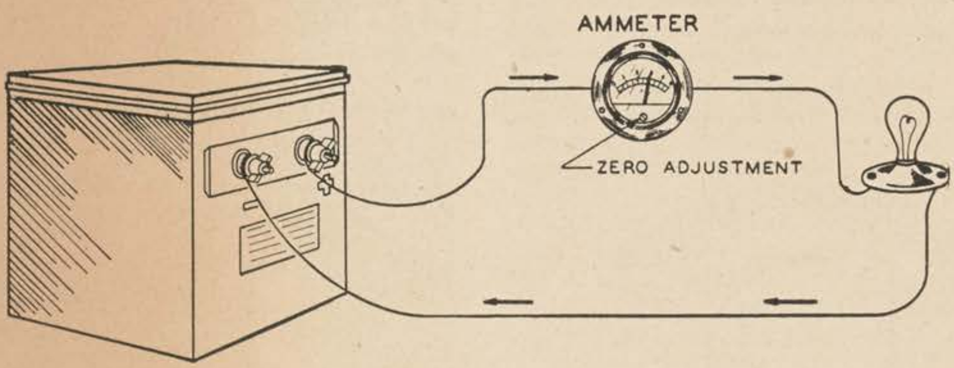


Figure 41. Ammeter in a circuit.

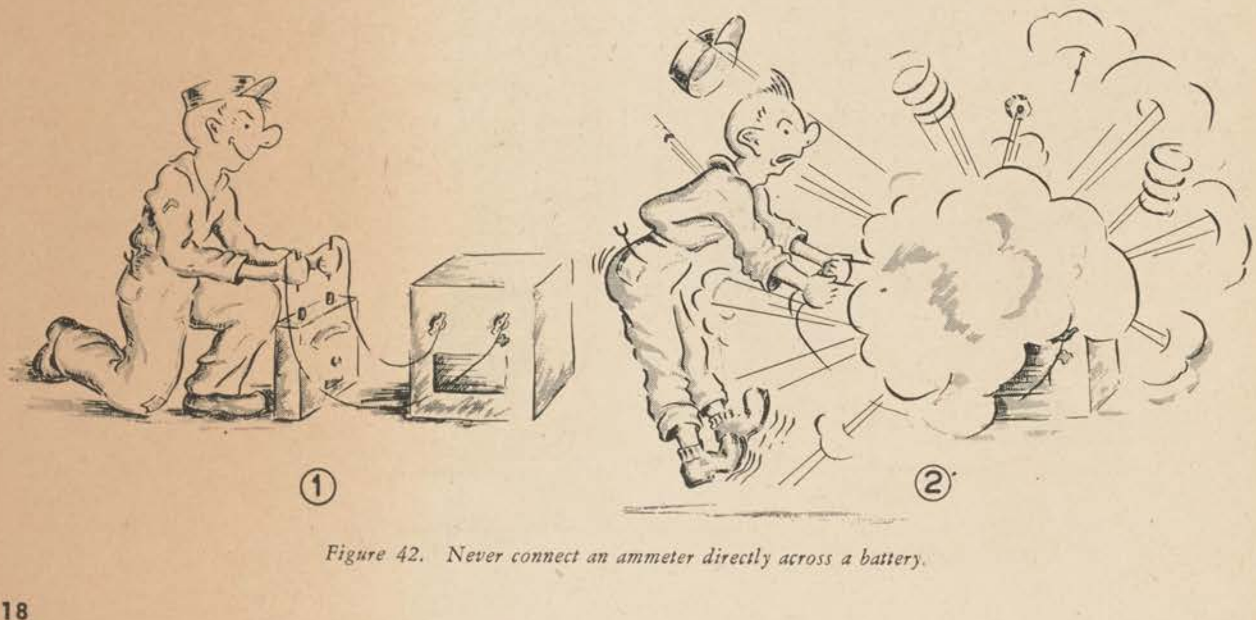


Figure 42. Never connect an ammeter directly across a battery.

give full scale deflection for a 300-ampere ammeter, only 0.01 of an ampere will flow through the meter when 300 amperes is measured. The rest of the 300 amperes or 299.99 amperes will flow through the shunt (figure 43).

c. In airplane construction, except for some small airplanes, the shunt part of the ammeter is installed in a

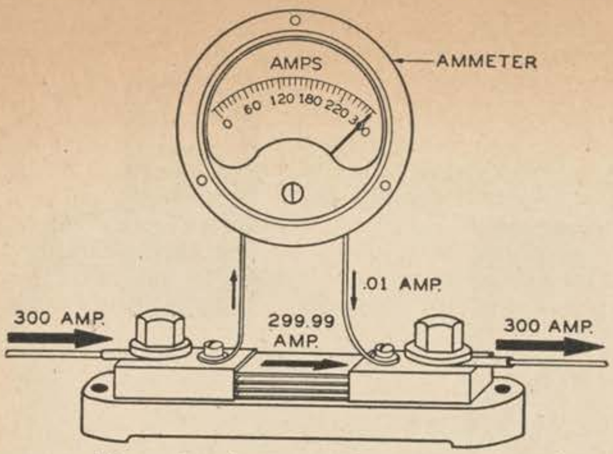


Figure 43. Ammeter with external shunt.

junction box and connected in either the plus or minus generator lead. The movement, or case, is mounted on the instrument panel. With this installation, *the proper leads must always be used.* No attempt should be made to alter their length (fig. 44).

33. OHMMETER. a. General. The ohmmeter is an instrument which measures resistance in ohms. The ohmmeter is composed of a circuit using a meter movement, network of resistors, and a small dry battery to furnish the power. The meter is calibrated to read the resistance of the unit measured directly. Most ohmmeters have several scales or ranges. One common type ohmmeter uses one direct scale and one reversed scale. Another type uses one reversed scale with multipliers.

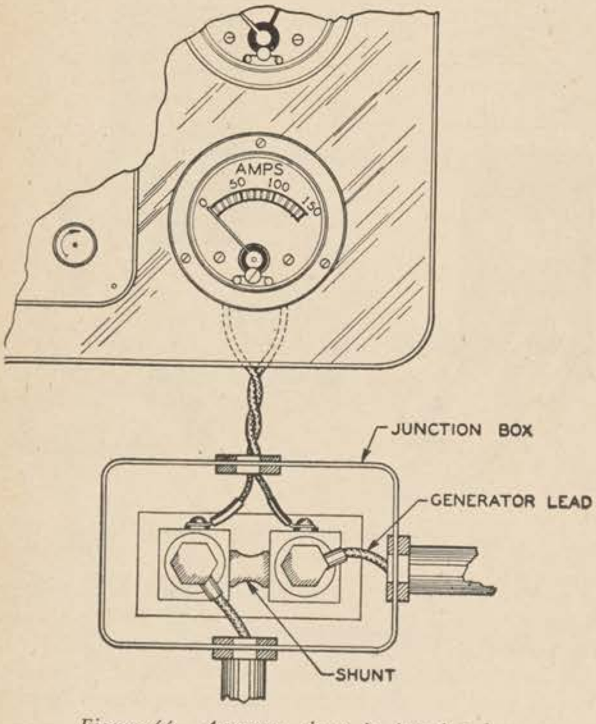


Figure 44. Ammeter shunt in junction box.

b. Volt-ohmmeter. The volt-ohmmeter is a combination voltmeter and reversed scale ohmmeter (fig. 45). The meter shown has four ranges of voltage: 0–3, 0–30, 0–300, and 0–600 volts, and four ranges of resistances: R, $R \times 10$, $R \times 100$, and $R \times 1000$.

(1) To use the meter as a voltmeter, place the toggle switch in the *VM* position. If the approximate value of the voltage is not known, use the scale having the highest range of voltage. To use the 600-volt range place the black lead in the negative (—) jack, and the red lead in the 600-volt jack which is positive (fig. 46). With the black prod connected to the negative terminal and the red prod connected to the positive terminal, read the voltage on the 600-volt scale. If the deflection is small, read the approximate voltage and move the red lead to the jack which will show a larger deflection. In using the 3- and 30-volt scales read the values on the 0 to 300-volt scale dropping the appropriate zeros.

(2) To use the meter as an ohmmeter, place the switch in the "*Res*" position. Place the test leads in jacks X (common to all ohmmeter scales) and R. Adjust meter to zero (holding prods together) by turning the battery adjustment knob until the pointer lines up

Figure 45. Volt ohmmeter.

with zero on the ohmmeter scale (fig. 47). The prods are then placed on the terminals or ends of the resistance to be measured. Do not let the metal portion of the prods make contact with the hands. Choose the scale which gives a deflection preferably between the calibration of 0 and 50. Always recheck the zero setting before measuring each resistance. When using jacks $R \times 10$, $R \times 100$, and $R \times 1000$, multiply the readings on the meter by 10, 100 or 1000 respectively. ***Caution:*** Always place the switch back to *VM* position when the meter is not in use as an ohmmeter.

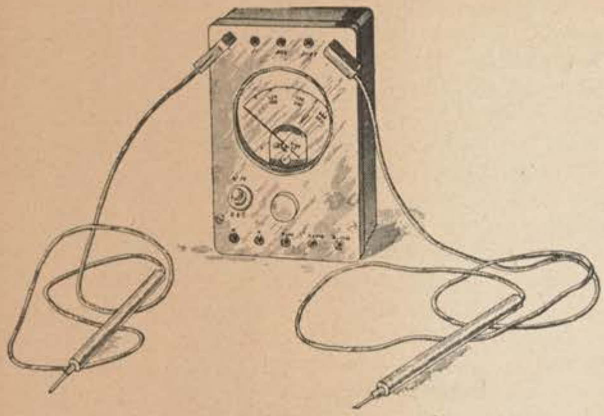


Figure 46. Using meter as a voltmeter.

c. Circuit checking with an ohmmeter. The use of an ohmmeter is a technique which requires considerable practice. However, only a few fundamental principles are used.

(1) Zero ohms indicate a completed circuit (fig. 48).

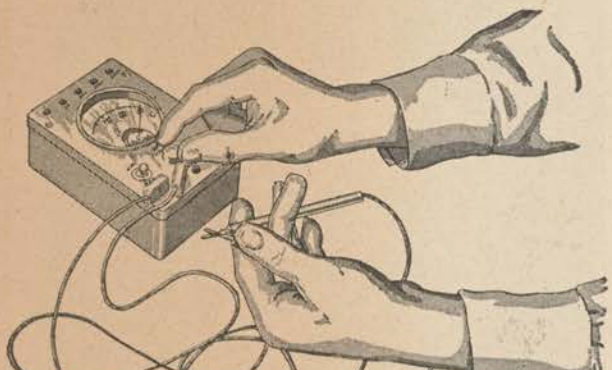


Figure 47. Setting meter for use as an ohmmeter.

(2) Infinite (*inf*) ohms indicates an open circuit (fig. 49). Before using the ohmmeter, always estimate the resistance of the unit to be measured. Whenever checking for continuity, use the *R* scale unless the unit measured has a high resistance. In checking for a short or ground, use $R \times 1{,}000$ scale. If a ground is found, recheck with the *R* scale to determine the extent of the ground. Before using an ohmmeter, isolate the unit being measured by disconnecting it from the source of power.

34. VOLTAGE DIVIDER AND BRIDGE CIRCUITS.

a. Much of the equipment on the modern airplane uses special circuits in connection with galvanometers as indicators and gages. The voltage divider and bridge circuit are the two fundamental circuits usually used.

b. The voltage divider, or potentiometer, is similar to a rheostat (variable resistor) except that it has three connections instead of two (fig. 50). In using the voltage divider, the fixed ends of the resistance are connected to a source of voltage. The movable contact and one end then form a source of variable voltage which can be used to operate an instrument, etc.

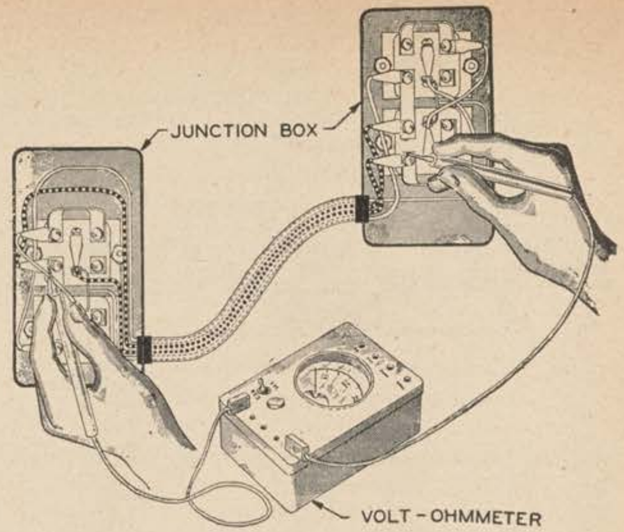


Figure 48. Circuit checking (completed circuit).

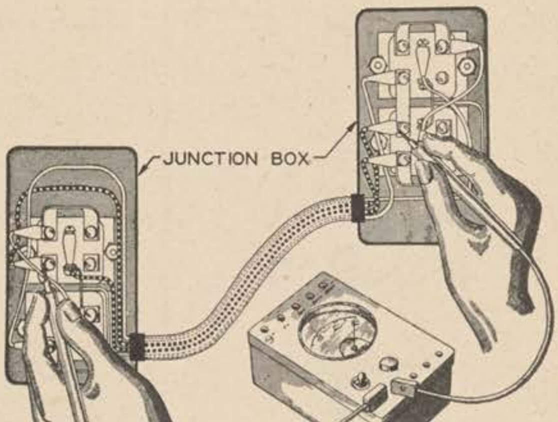


Figure 49. Circuit checking (open circuit).

c. The bridge circuit can also be used as a voltage divider. It has the advantage of being able to change the polarity as it has two movable contacts (fig. 51). It may be considered as a double potentiometer. This device is used to regulate turbo superchargers, to operate gun turrets, fuel ratiometers, etc.

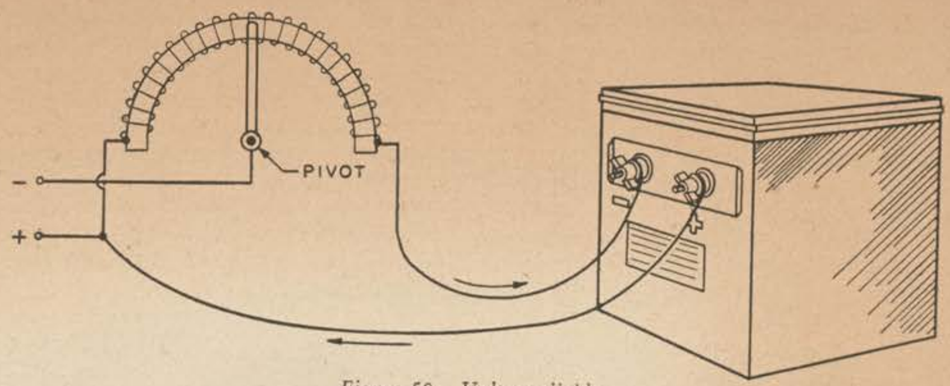


Figure 50. Voltage divider.

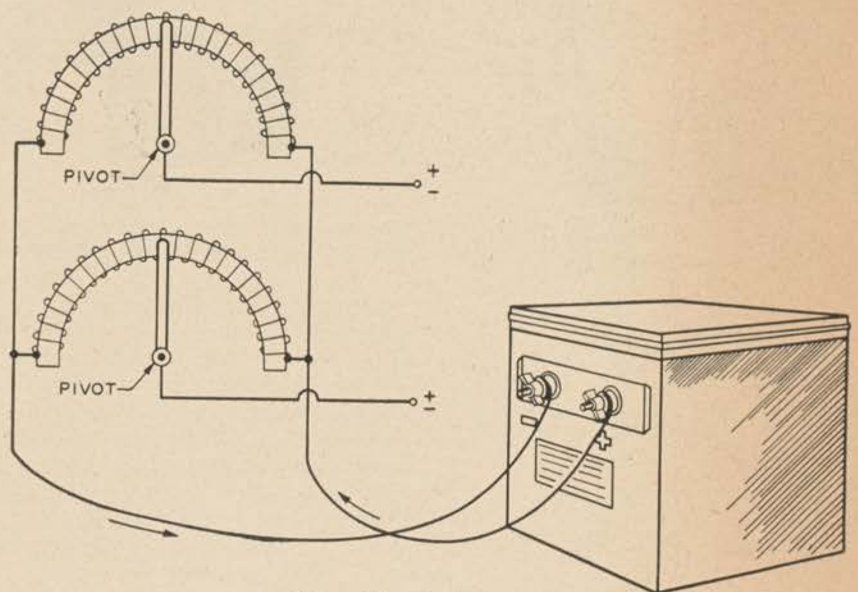


Figure 51. Bridge circuit.

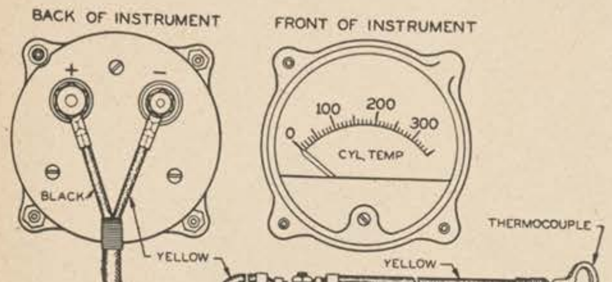


Figure 52. Thermocouple thermometer.

Figure 53. Thermocouple.

35. THERMOCOUPLE THERMOMETER. **a.** A thermocouple thermometer is used to measure the cylinder-head temperature of a radial engine.

b. The thermocouple thermometer consists of a thermocouple, connecting leads, and an indicating meter (fig. 52). The thermocouple is a junction of two dissimilar metals (constantan and iron) with a copper gasket (fig. 53). Whenever the copper gasket becomes heated, a voltage is set up at the junction according to the difference in temperature between the cylinder head and the indicating meter. This is registered in the cockpit on an indicating meter (fig. 54). Special leads of materials similar to the thermocouple itself are used to connect the thermocouple with the indicating meter in the cockpit. The indicating meter is a delicate voltmeter calibrated in degrees of temperature instead of volts.

c. The thermocouple is mounted on the cylinder which operates at the highest temperature. On twin radial engines it is usually placed under the rear spark plug of the master rod cylinder in the rear bank (fig. 55). Only the leads *provided* for the instrument can be used, and at no time should the leads be lengthened or shortened.

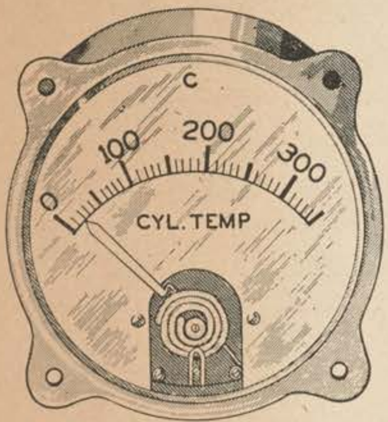


Figure 54. Indicating meter.

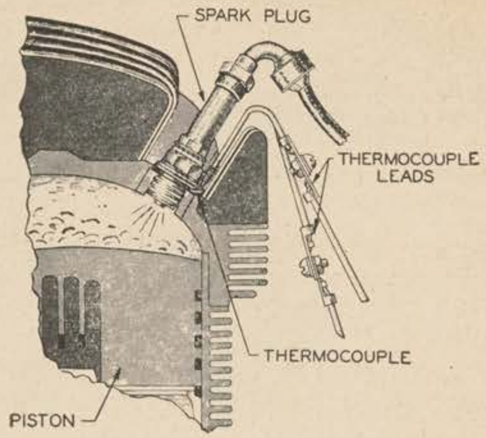


Figure 55. Thermocouple installed.

SECTION V

CONDENSERS

36. GENERAL. A condenser is a device used for temporary storage of electrical energy. It is used on aircraft as a voltage stabilizer in the generator circuit, radio noise eliminator or filter, etc. The use of the condenser in connection with the ignition system will be discussed in the section dealing with ignition systems.

37. CONSTRUCTION. a. A condenser may be constructed in many different shapes and from a variety of materials (fig. 56).

b. The parts of a condenser are 2 plates or 2 sets of plates, an insulator between the plates called a dielectric, and the connecting leads (fig. 57).

c. The capacity or effectiveness of the condenser depends upon the area of the plates, the distance between the plates, and the material used as the dielectric. To make a condenser of a high capacity, a large plate area and a thin, high-quality dielectric should be used. The plates are usually made of tin foil and the dielectric is made of wax paper or mica. One type of construction is the rolled condenser where the plates are insulated from each other and rolled into a roll (fig. 58). Another common type is the stacked condenser where plates are piled up with the dielectric between them (fig. 59). Alternate plates are connected together giving two sets of plates to which the terminals are connected.

38. OPERATION. a. In a d-c circuit a condenser will receive a charge from the circuit and will return most of the charge when the voltage of the circuit drops. It is in this respect that the condenser acts as a voltage stabilizer. However, the condenser will not permit a current to flow through it when a steady d-c voltage is applied to it. In the case where the applied voltage of

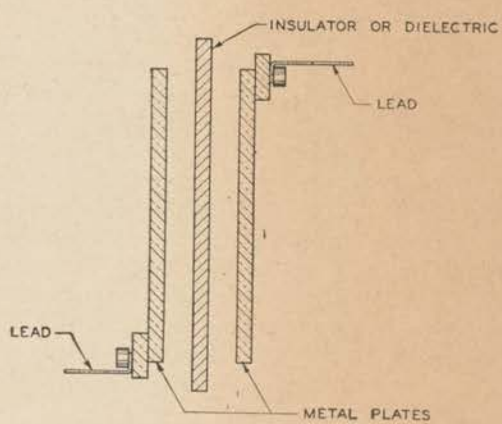


Figure 57. Parts of a condenser.

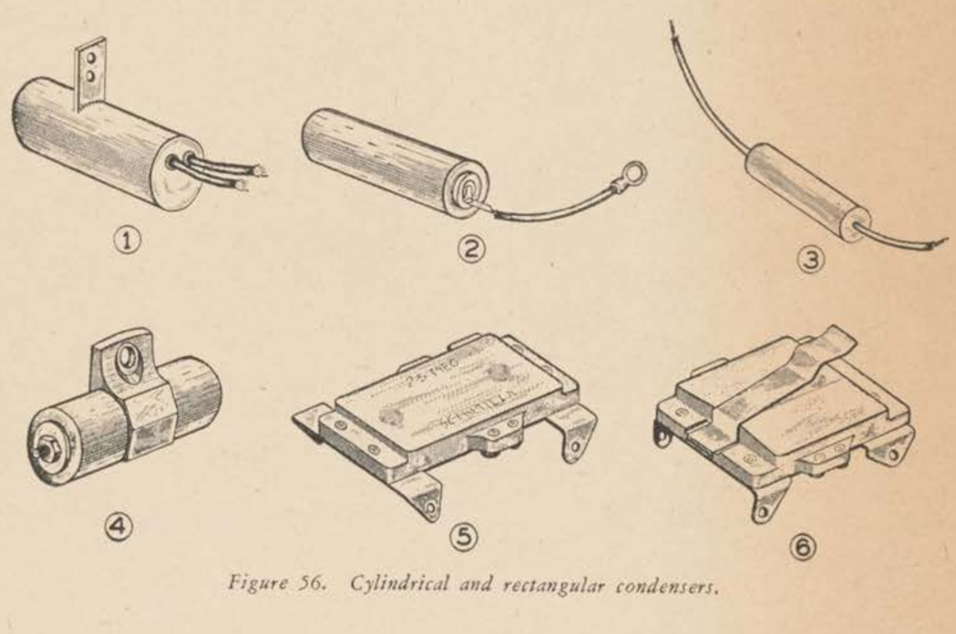


Figure 56. Cylindrical and rectangular condensers.

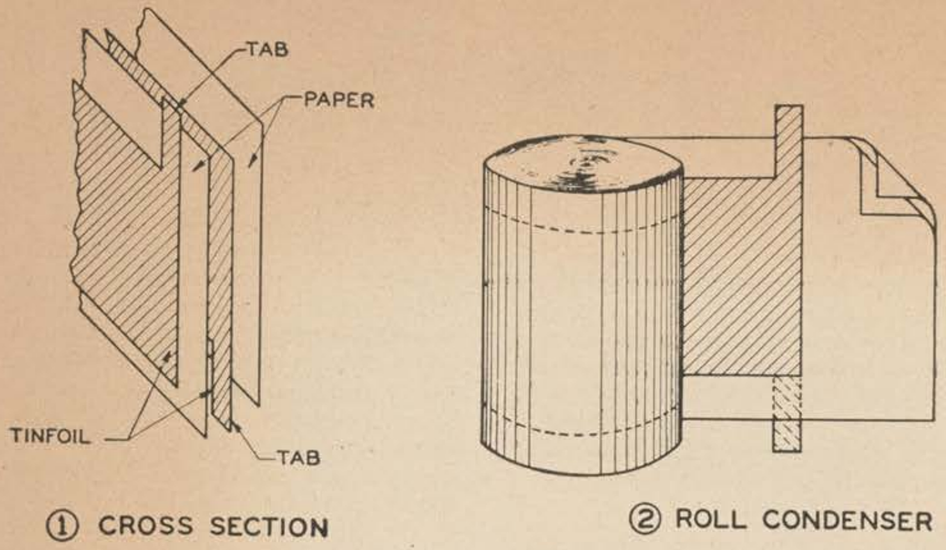


Figure 58. Rolled condenser.

the circuit is varying d-c or a-c voltage, a current will flow through the condenser. The condenser becomes a better conductor of electricity as the frequency of the applied voltage is increased. The action of the condenser can best be shown as a thin rubber diaphragm in a hydraulic analogy. As the piston on one side is moved toward the diaphragm, the diaphragm will be displaced, thereby moving the water on the other side. When the pressure on the piston is removed, the diaphragm will spring back causing the water to flow back to its original level. Only when the piston is in motion (when the force on the piston is changing) will the water move on the opposite side of the diphragm.

39. RATING A CONDENSER. a. A condenser is rated in a unit of capacity which indicates its ability to store electricity. The unit of capacity is the "farad." This unit is much too large for practical work so one millionth or a "microfarad" (mfd) is used.

b. The quantity of electricity that a condenser can store also depends upon the voltage at which the condenser is charged as well as the capacity of the condenser. However, not every condenser can be charged at a high voltage because the insulation will puncture under excessive voltage thereby shorting the plates. Therefore, a condenser is designed with an insulation or dielectric in each case sufficiently strong electrically to withstand the voltage to which it is to be subjected.

Figure 59. Stacked condenser.

GENERATION OF VOLTAGE BY INDUCTION

40. INDUCTION. Magnetic flux can be made to produce an electric current. Whenever a conductor is moved across lines of magnetic flux or magnetic flux cuts across a conductor, a voltage is set up or induced in the conductor (fig. 60). If the conductor is part of a closed circuit, a current will flow through that conductor. There are several types of induction all of which result in the generation of voltage. The type of induction depends upon the circuit or arrangement used. The three types of induction that will be discussed in this section are self, electromagnetic, and mutual induction.

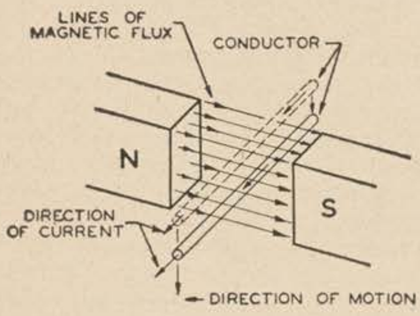


Figure 60. Induction.

41. SELF INDUCTION. a. Self induction is the electrical inertia action of a circuit, that is, the tendency of an inductive circuit to oppose any change in current flow. It is this action which produces the "fat spark," whenever a circuit containing inductance is opened. Self induction is used when the points of magneto open to produce a high voltage in the primary.

b. Any circuit which contains a coil of wire is said to be an inductive circuit. That is, the circuit possesses the property of self inductance. In a circuit containing inductance the current will build up gradually when the switch is closed. When the switch is opened, the field, in collapsing, will induce a voltage in the circuit which will keep the current flowing an instant after the switch is opened (fig. 61).

c. The value of the self-induced voltage existing at any instant in a coil depends upon how much magnetic flux was associated with the circuit, how fast the flux was changing, and how many turns of wire were cut by the flux. The "break-down" of the field surrounding a coil takes place in much less time than the "build-up;" therefore, the voltage induced on the "break" of the circuit is much greater than that induced on the "make."

d. The unit of measurement of inductance is the "henry." The value of inductance of any coil depends upon its design. The inductance of a coil increases with the number of turns of wire. The placing of an iron core in the coil will greatly increase the inductance of a coil because the flux is increased.

42. ELECTROMAGNETIC INDUCTION. a. Electromagnetic induction is the generation of a voltage by causing a conductor to cut lines of magnetic flux. This may be accomplished by mechanical movement of either

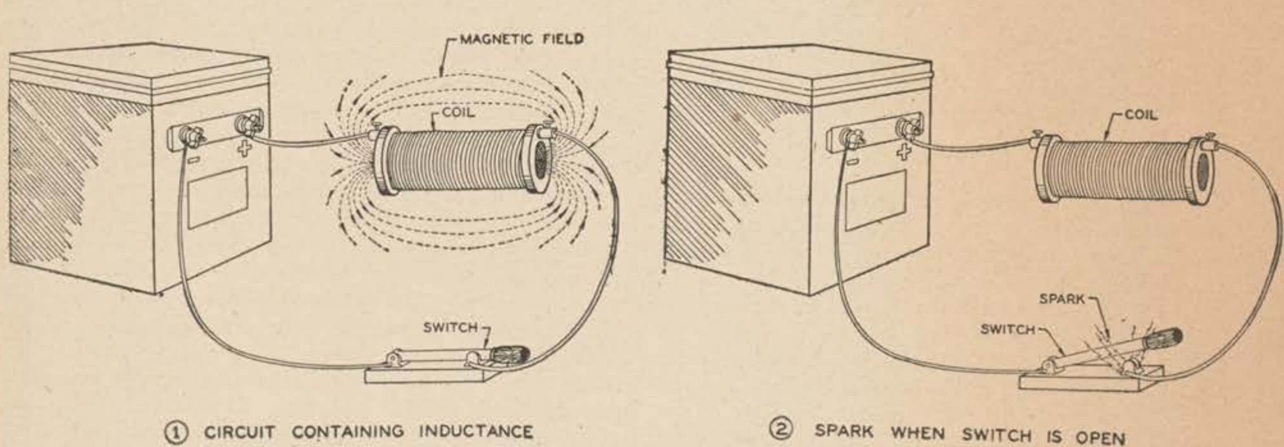


Figure 61. Self-induction.

the field or the conductor. The moving magnetic field of a magneto and the rotating armature in the generator are examples of electromagnetic induction.

b. A *generator* is a machine which converts mechanical energy into electrical energy by means of electromagnetic induction. An a-c generator (called an *alternator*) produces an alternating current at its terminals, while a d-c generator produces a direct current at its terminals. Every generator, regardless of type or construction, operates by the induction of alternating voltage in coils, produced by varying the amount and direction of magnetic flux threading through these coils. The variation in flux linkage may be accomplished by any one of a variety of methods, several of which will be discussed in the following paragraphs.

c. Generator rule. The direction of voltage induced in a conductor can be determined by the right-hand generator rule. This rule will also indicate the direction of current flow when the circuit is completed. In using this rule the direction of the field must be determined. If the poles are not definitely known they can be determined with a small pocket compass. The north pole of the compass will point to a south pole. The flux then flows from the north pole to the south pole. Use the right hand and extend the thumb, first finger, and middle finger so that they are at right angles to one another as shown in figure 62. Then turn the hand into such a position that the thumb points in the direction of the motion of the conductor and the first finger points in the direction of the magnetic flux. The middle finger will then point in the direction of the induced voltage. If the directions of any two of the factors are known, the direction of the other can be determined by applying this rule.

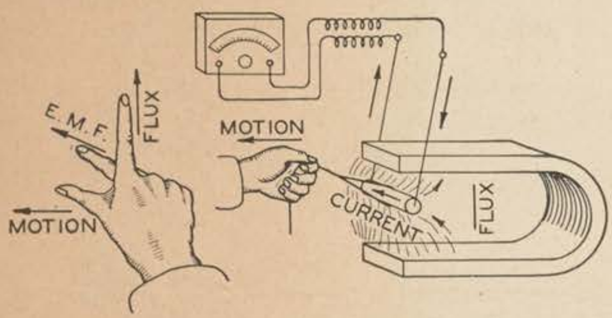


Figure 62. Generator right-hand rule.

d. Simple alternating-current generator. A method of generating voltage is shown in figure 63. As the loop of wire is rotated in the magnetic field, a voltage is induced in each side of the loop, and as the sides of the loop cut the flux in opposite directions, the voltages induced in the sides of the loop will be in opposite directions. This will cause the voltage appearing at the two ends of the loop to be the sum of the two induced voltages. *Voltage is the only quantity induced in the windings.* The amount of current flow in the windings will depend upon the load which is connected to the generator. The value of voltage will depend upon: number of turns in the rotating armature; speed of rotation; and strength of the magnetic field. The current flowing in the load attached to the loop will follow the pattern shown in figure 63. One complete turn of the loop will generate one cycle. The numbers of cycles per second is known as the frequency of the current.

e. Simple direct-current generator. The d-c generator has an automatic switching device which changes the alternating current in the armature to direct current for the external circuit. This automatic switching device is called a commutator. It consists of copper segments insulated from each other and mounted, by means of insulating rings, on the armature shaft. Each segment is connected to a coil end and, with a suitable brush arrangement, the coils can be connected (as the armature rotates) to the external circuit in such a way that the current will flow in only one direction (fig. 64).

43. PRACTICAL DIRECT—CURRENT GENERATOR.
a. The terminal voltage of a practical d-c generator is much more constant than the very unsteady voltage of the single-loop armature. This constant voltage is produced by using an armature consisting of a slotted soft iron cylinder and a number of uniformly spaced armature coils. Also the number of magnetic circuits, magnetized pole pieces, and commutator brushes are increased. The manufacturer may wire the armature coils together in any one of several ways and connect them to a commutator of many segments. The principles of operation, however, remain the same. There will be a slight variation in the value of the terminal voltage of the machine, known as *commutator ripple,* which may cause interference in the airplanes radio receiver. This interference may be reduced by stabilizing the terminal voltage with a filter condenser attached across the terminals of the generator. The condenser tends to lower the voltage peaks and build up the lows, thus smoothing out the voltage to a more steady value.

b. The magnetic fields in which the armature coils move are greatly strengthened, and consequently the induced voltage is increased, by the use of electromagnets instead of permanent magnets. All aircraft d-c generators have at least one shunt field coil shunted or connected across the brushes (fig. 65 ①). The magnetic flux of the field is therefore directly proportional to the voltage difference between the brushes, unless limited by a voltage regulator. A generator with only this type of field coil is called a *shunt-wound generator.* The terminal voltage of the shunt-wound generator (when used without a voltage regulator) will decrease as the load is increased. Figure 66 ① shows graphically the drop in terminal voltage which takes place as the load connected to a shunt generator is increased (that is, the resistance of the load decreased with the generator speed held constant). At no-load the terminal voltage is high and the load current is zero. As the load increases, the load current increases and the terminal voltage decreases as shown by the solid portion of the curve. With an increase of load, the voltage of the generator will drop to the place where the field will be reduced. This will

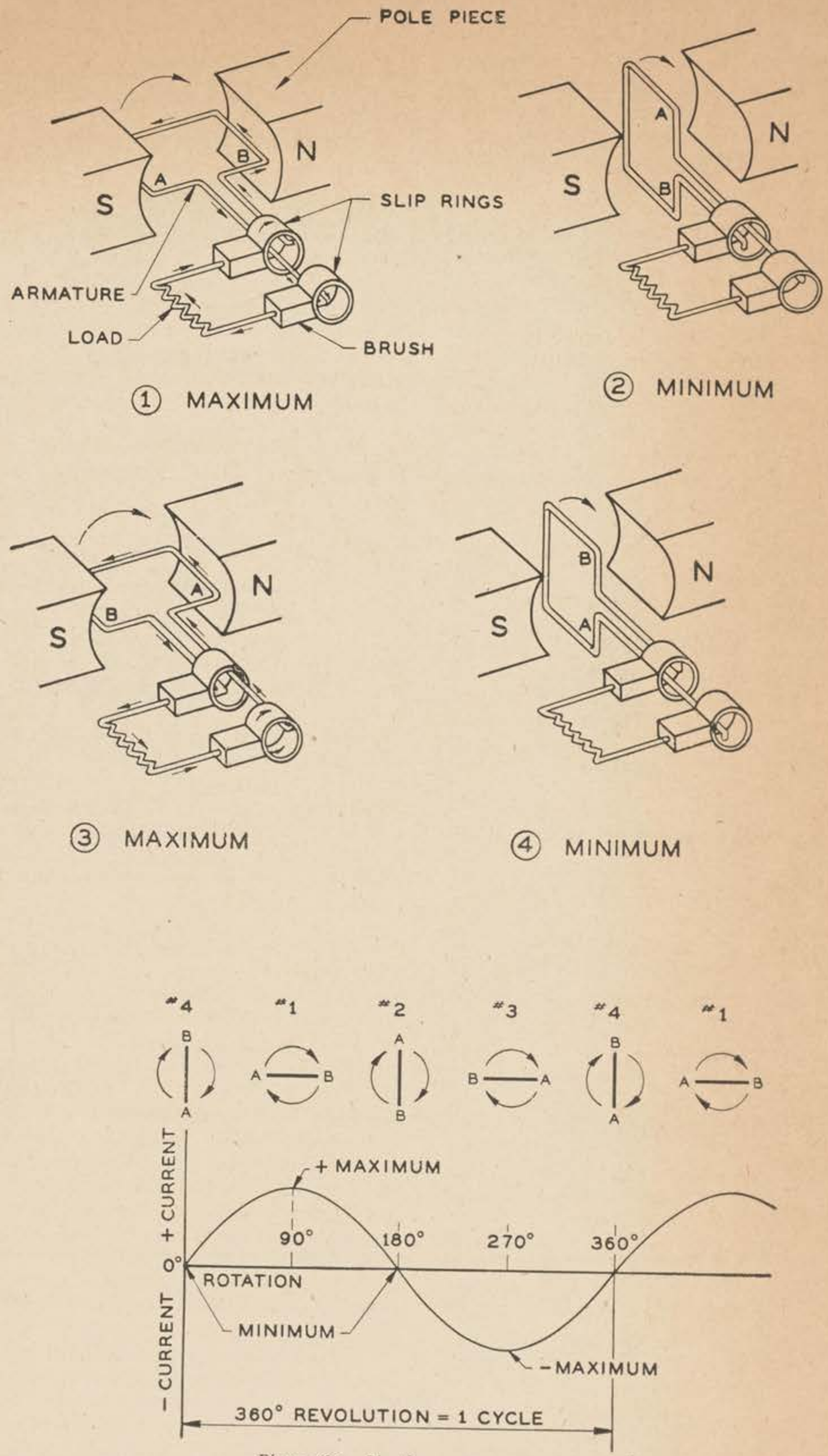


Figure 63. Simple a-c generator.

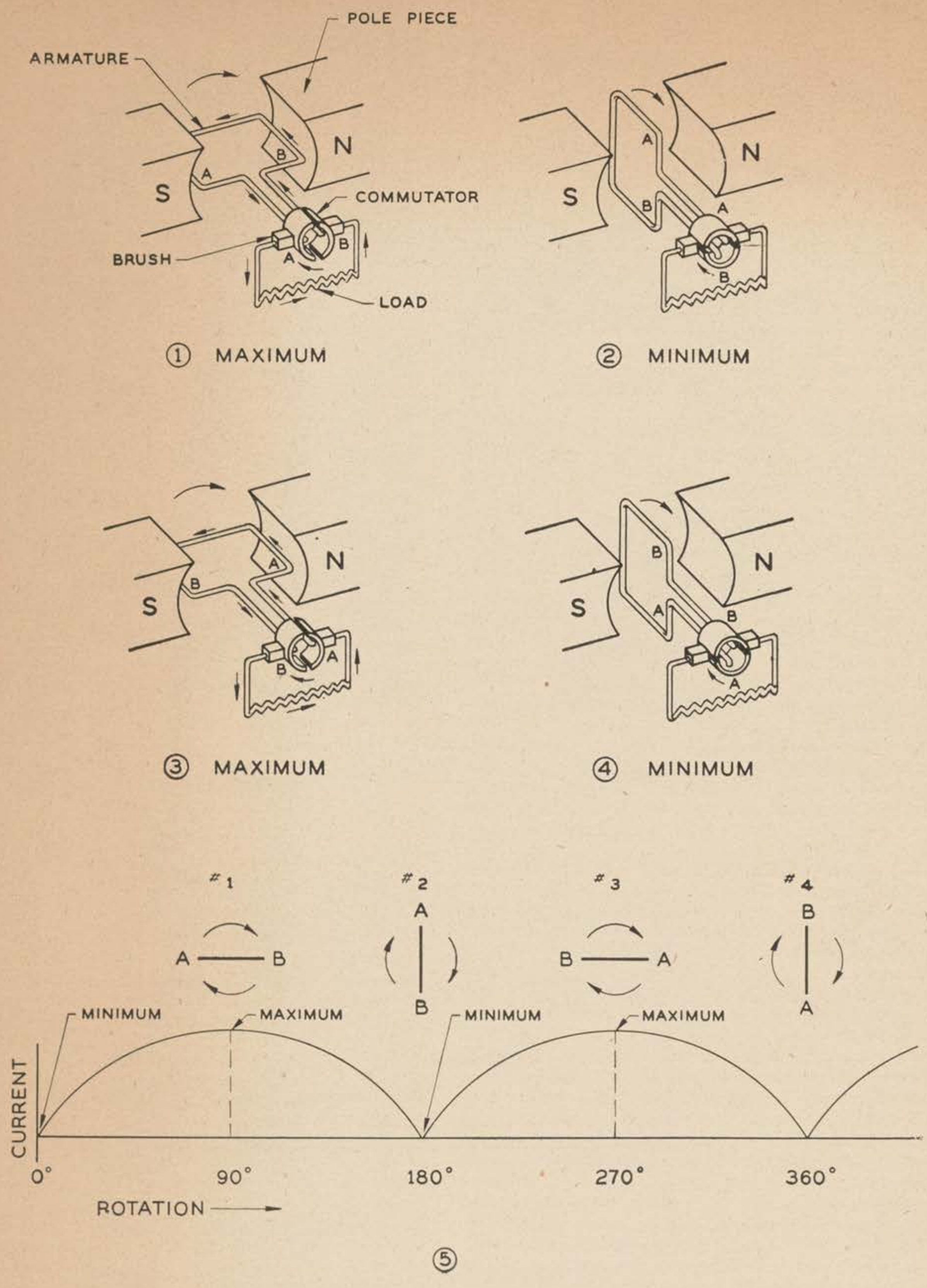


Figure 64. Simple d-c generator.

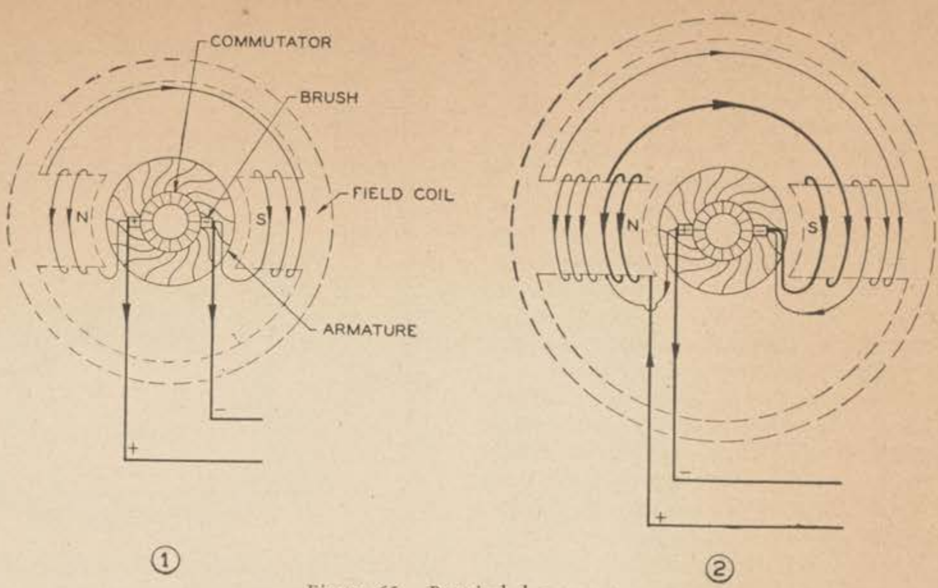


Figure 65. Practical d-c generator.

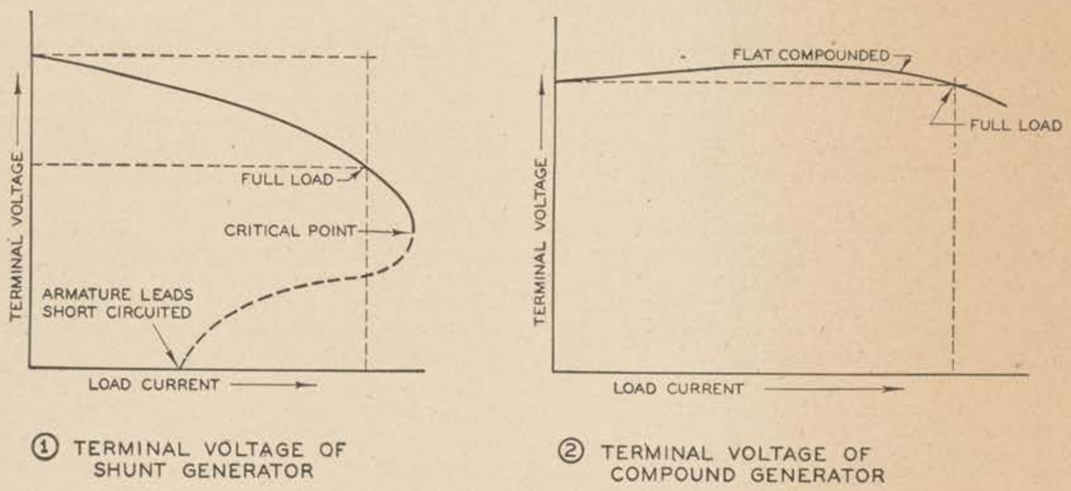


Figure 66. Characteristic curves of common aircraft d-c generators.

cause a further drop in voltage as the load is increased beyond a critical point.

c. The decrease in terminal voltage of a generator, as load is applied, is caused by several things. The armature has resistance, and as the current increases, the *IR* (voltage) drop in the armature subtracts from the terminal voltage. A decrease in terminal voltage also causes a decrease in field current. This causes a decrease in field flux and a further lowering of the induced voltage in the generator. Another factor which tends to decrease the voltage of a generator as load is applied is armature reaction. Armature reaction is the distorting of the generator field by the heavy armature current.

d. A generator may be *compounded* in order to stabilize its terminal voltage (fig. 65 ②). A *compound wound* generator has, in addition to its shunt field coils, a series field coil (consisting of a fraction of a turn to several turns) connected in series with the load circuit. The series field coils are wound on the pole pieces in such a manner that the flux they produce (which is proportional to the current in the load circuit) aids the flux produced by the shunt coils. Therefore, when the load increases, the flux in the generator field is increased. This will increase the induced voltage in the armature, but because of the losses in the generator which increase with increased load, the terminal voltage will remain about the same (fig. 66 ②). This machine has the advantage of requiring less regulation of the shunt field in that the machine automatically takes care of the load variations.

e. Because of the use of field coils (electromagnets instead of permanent magnets), the iron used in the generator is selected for its ability to become strongly magnetized by electromagnetic induction rather than for its ability to retain magnetism. However, a small amount of magnetism is retained by the pole pieces. It is the small amount of flux which these poles produce that starts generation. The voltage caused by this residual magnetism is only a few volts, but it will cause enough current in the field to start the voltage build-up. This process of building up the voltage takes only a few seconds. The polarity of the generator depends upon the polarity of the pole pieces. If the residual magnetism should be reversed, the polarity of the generator would be reversed.

44. GENERATION OF ALTERNATING VOLTAGE BY VARIATION IN FLUX IN A COIL.

a. If the amount of magnetic flux associated with a coil is varied by any means whatsoever, a voltage is induced in the coil. A simple method for producing a constant variation of flux in a magnetic circuit is shown in figure 67. A permanent magnet is mounted so that it may be rotated

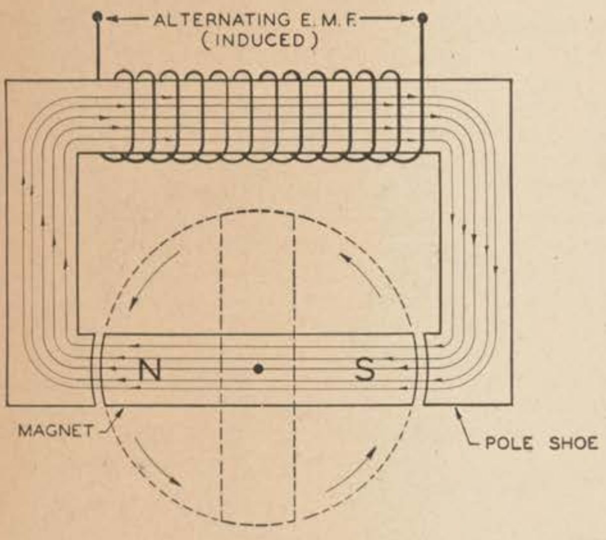


Figure 67. Induction of alternating voltage by rotation of a magnet.

within the gap of an unmagnetized iron yoke. The magnetic field of the magnet is then capable of producing flux in the magnetic circuit composed of the magnet and the yoke. With the magnet in the position shown, the flux is maximum, since the reluctance (magnetic resistance) of the circuit is minimum. As the magnet is rotated 90°, the reluctance increases and the effect of the magnet in the circuit decreases; both of these changes reduce the flux. At the 90-degree position, the flux decreases to 0, for in this position, the poles of the magnet are equally distant from each pole piece of the yoke, and the effect of one magnetic pole on the circuit is cancelled by that of the other. As rotation is continued, the yoke circuit becomes remagnetized with the flux lines reversed in direction. The flux reached a maximum value at 180° of rotation of the magnet from its original position. It again decreases to 0 at 270-degree position, and is re-established to the original value and direction when the original position is reached.

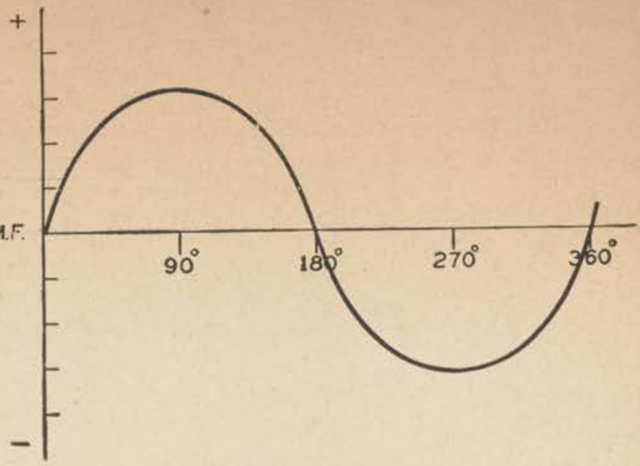


Figure 68. Voltage induced at successive positions of magnet rotating at uniform speed.

The flux, therefore, reverses direction twice per revolution (at the 90-degree and 270-degree positions).

b. If a coil is wound about the yoke as shown in figure 67, it is said to be *linked* with a magnetic circuit. Whenever a coil is linked with a magnetic circuit in which the flux rises, falls, or changes direction periodically, an alternating voltage is induced in the coil. A graphical representation of an alternating voltage is shown in figure 68. The important feature to be noted is that the induced voltage reaches a maximum, not when the flux linked with the coil is at maximum, but when the flux is at zero value and just reversing its direction. The two maximum values of voltage occur at 90-degree and 270-degree positions of the rotating magnet.

c. The value of induced voltage depends upon the rate of cutting a conductor with magnetic flux. This will depend upon:

(1) *Number of turns in a coil.* Regardless of the number of turns, the same value of voltage is induced in each turn. As the successive turns are in series, the total voltage is in proportion to the number of turns.

(2) *Speed of rotation.* The voltage depends on how quickly the flux cuts across the conductors. The faster the magnet is rotated, the more rapidly the flux disappears and appears again.

(3) The stronger the magnet, the greater will be the values of flux and consequently of the rate of change of flux.

(4) *Clearance between magnet and pole pieces.* The smaller the air gap, the less reluctance there will be in the magnetic circuit; hence, the greater will be the values of flux established by the magnet.

45. MUTUAL INDUCTION.

a. Mutual induction takes place when two coils or conductors (one of which is carrying a varying current) are placed near each other (fig. 69). A change in amount or direction of current in one coil will produce a change of flux in the system which will induce a voltage in the other coil. The transformer is an example of inducing a voltage in another coil (the secondary) by mutual induction.

b. All devices used on aircraft to generate high voltage for engine ignition operate on the principle of *mutual induction*. Strictly speaking, mutual induction is the induction of voltage in a coil (called a *secondary*) as the result of a change in the magnetism of another coil in its immediate vicinity (called a *primary*). In

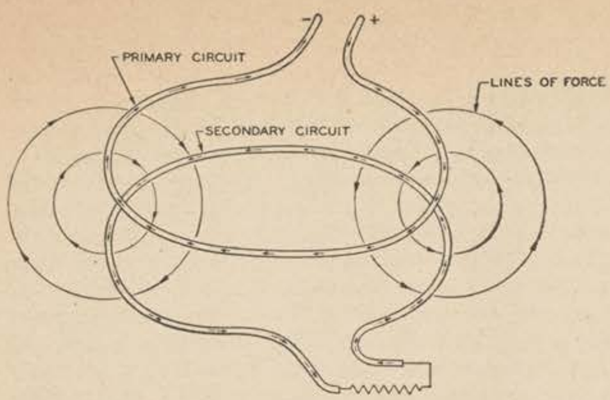


Figure 69. Mutual induction.

ignition equipment, however, the bulk of the voltage induced in the secondary is due to loss of magnetism of the core upon which both primary and secondary are wound.

46. BASIC PRINCIPLES OF ELECTRICAL IGNITION.

a. Electrical ignition will be explained with the aid of figure 70 which shows all of the essential parts in any common type of electrical ignition system. A *primary coil* (*P*) of about two hundred turns of insulated wire is wound around a laminated soft iron core, which is not a magnet (although it may possess some residual magnetism). The core is represented by the three straight lines between the primary and secondary coils. The *secondary coil* (*S*) of perhaps ten or twenty thousand turns of extremely fine insulated wire is wound over the primary coil. The secondary coil is well insulated from the primary coil. The center electrode of a spark plug is attached to one end of the secondary by means of a well-insulated wire. The outer electrodes of the spark plug are "grounded" and thus electrically connected with the other end of the secondary. The spark plug may be considered as a load unit attached to the secondary. The primary is in series with a switch, a battery, and a pair of "make" and "break" contact points. These points remain in contact, under spring tension, until pushed apart by a rotating cam timed to the engine. The primary circuit is therefore closed until the points are opened. The points are shunted by a condenser, known as the *primary condenser* (*C*). The condenser is normally "shorted" by the points, and cannot function until the points are opened.

b. When the switch is closed, current rises in the primary coil and circuit, reaching Ohm's law value in perhaps a few thousandths of a second. During this time, energy is stored in the primary and in the core. If the points are now pushed open, this breaks or opens the primary circuit. The resulting rapid collapse of the magnetic field induces a voltage in both primary and secondary, the total voltage induced in each coil being proportional in magnitude to its number of turns.

c. Under the influence of the induced voltage the free electrons in the primary tend to rush toward and rapidly accumulate on the first contact point will be drained of electrons. If the condenser were not present, the potential difference between the points would rise so rapidly that the points would be unable to separate without the occurrence of an arc between them. This arc would burn the surfaces of the points, and because of its conductivity, would prevent the sudden removal of battery voltage from the primary circuit. The condenser receives the electrons sent to the one contact point and

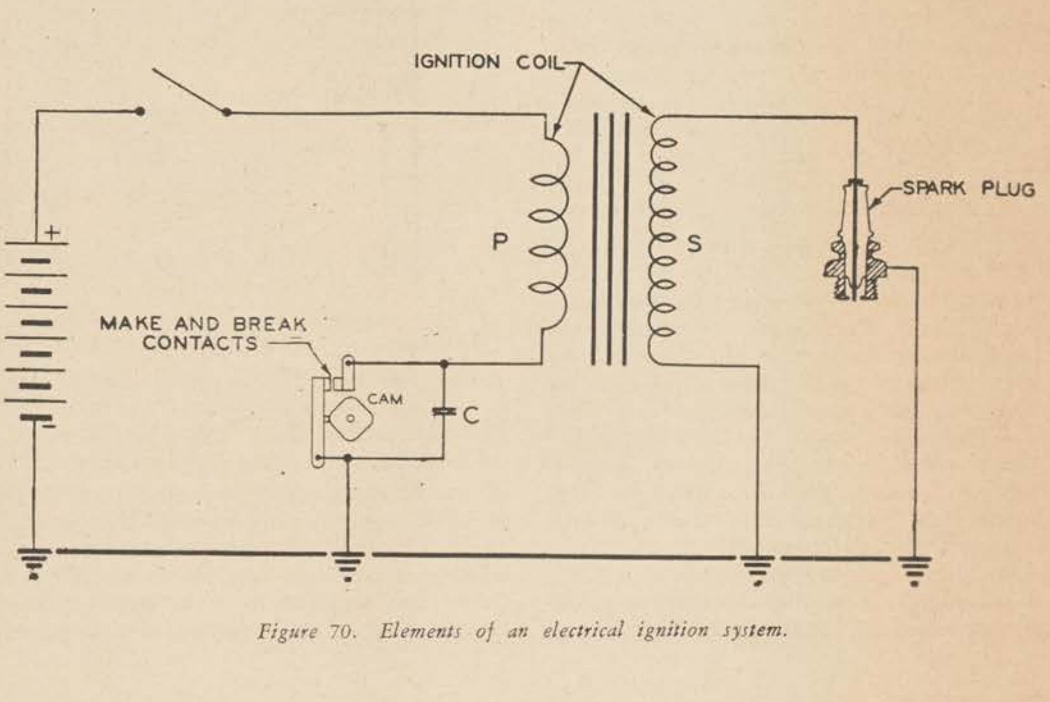


Figure 70. Elements of an electrical ignition system.

supplies the electrons demanded by the other point. A considerable quantity of electrons must flow before any considerable voltage difference between the terminals of the condenser can be established. Hence, the rise of potential difference between the points is retarded and suppressed. As soon as the value of the induced voltage in the primary has decreased to, and falls below the voltage to which the condenser has risen, the latter discharges back into the primary. The condenser thus returns to the coil some of the energy received from the coil. The condenser's discharge current reverses the flux of the primary and this reversed flux tends to remove the core's residual magnetism. The total change of magnetic flux is thus made greater. The primary condenser therefore accomplishes 3 desirable results:

(1) It lengthens the life of the points.

(2) It increases the total change in magnetism.

(3) It hastens the collapse of the magnetic fields.

The latter two of these results materially increase the value of voltage induced in the secondary. The value of the capacity of the condenser is important. If too large, the condenser's counter-voltage does not build up in time to be fully effective. If too small, the voltage rises to an excessively high value and arcing at the points results. The design engineer selects a condenser of the proper capacity to fit the appliance with which it is to be used. A shorted condenser will prevent the opening of the primary circuit and thus make the system inoperative. An open condenser results in arcing points and a low voltage output from the system.

d. The voltage induced in the secondary caused by the collapsing fields is many times greater than that in the primary because of the greater number of turns. The current flow may be either toward the center electrode of the spark plug, or toward its outer electrodes, in accordance with the direction in which the secondary is wound on the core. The voltage difference might reach 30 to 40 thousand volts were it not for the fact that a spark jumps across the electrodes (when the plug is in the engine cylinder) at approximately 20,000 volts. The spark is a conductor; it closes the secondary circuit and further rise in voltage is thus checked. Current flows in the secondary circuit as long as the collapsing fields have sufficient energy to maintain the spark discharge. When the voltage between the electrodes falls below the minimum value required for the electrical discharge, the spark "goes out" and the flow of charge ceases. All of this happens in a very small fraction of a second.

e. The two coils and core previously discussed make up the *ignition coil*. When such a coil includes a mechanical vibration for interruption (make and break) of the primary circuit, the coil is known as an *induction coil*, or in the Army Air Forces, as a *booster coil*. The booster coil is described in section X. The magneto, the theory of which is discussed in paragraph 47, also contains a primary, secondary, and core. Magnetic, self, and mutual induction are essential in sources of high voltage for aircraft electrical ignition. In each device energy is forced into a primary and core, and is transferred to a secondary. In each device the energy delivered from the secondary is at a very high voltage because of the high turns ratio between secondary and primary, and because of the rapidity of the collapse of magnetic flux.

47. THEORY OF MAGNETO.

a. The *magneto* is a special type of electrical generator which produces pulsations of high voltage. Flux is produced in the magneto by magnets and motion, rather than by means of a battery.

b. The essential parts of a simple magneto are shown schematically in figure 71. A 4-pole permanent magnet is arranged for rotation between the pole pieces of an unmagnetized soft iron yoke. The pole pieces of the yoke are so spaced that they always match two magnetically opposite poles of the rotating magnet. A primary coil (*P*) having perhaps 150 turns of wire, and a secondary (*S*) of many thousands of turns are wound upon the yoke. (These coils are shown on the sides of the yoke in order to simplify the illustration.) One end of the primary is permanently grounded. The other end is connected to a ground through a pair of contact points (*B*) known as "breaker" points, which are normally held together by spring tension. The primary is therefore shorted when the breaker points are closed. The breaker points are shunted with a primary condenser (*C*). One end of the secondary is grounded for simplicity in manufacture. This ground connection is attached to the terminal which is common to the primary coil, condenser, and one breaker point. When the breaker

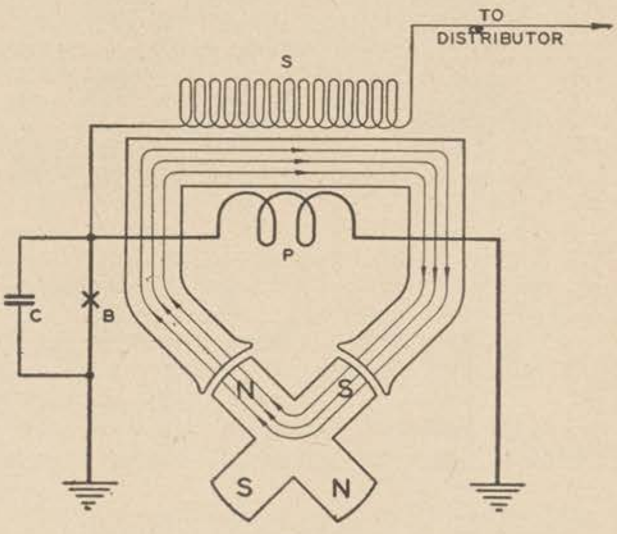


Figure 71. Essential parts of a magneto.

points are open, the secondary current easily reaches a ground through the primary coil because of the low resistance of the latter. The other end of the secondary is connected to the spark plugs through a distributor.

c. The operation of the magneto may be explained in several ways. A complete and detailed explanation is difficult because the circuits within the magneto are so closely linked with each other, electrically or magnetically, that an action in one is reflected (by induction) in the others. The following is a simple explanation.

When the poles of the magnet are in the position shown in figure 72, the m.m.f. applied to the yoke is maximum. The m.m.f. is in such a direction as to produce flux, directed to the right in the core of the coils. When the magnet is rotated, starting from the position shown, the magnetomotive force applied to the magnetic circuit (yoke and magnets) decreases to zero and reverses. The m.m.f. decreases to zero, increases to the maximum in the other direction, again falls to zero, and so on. There are four positions per revolution of the magnet in which the m.m.f. is zero, and four in which it is maximum (2 in each direction). This varying m.m.f. creates varying flux in the yoke and induces alternating e.m.f. in both the primary and secondary. The alternating voltage induced in the secondary by this flux change is too weak to break down the gaps in the spark plugs. The secondary circuit therefore remains open and no effective energy leaves the magneto as a direct result of the rotation of the magnets. The breaker points are opened and closed by a cam which is on the shaft of the rotating magnet. That is, the points are closed when a voltage is induced in the primary and opened when the current becomes a maximum. The opened points permit the collapse of the magnetic field about the core which induces a high voltage in the secondary. The collapse of the flux is hastened by the use of a condenser across the points. When the points open, the permanent magnet is in what is called the *E* gap position—that is, a few degrees past the 45-degree position as shown in figure 72. Hence, at *E* gap position the points open and the spark discharge takes place.

48. CHARACTERISTICS OF DIRECT-CURRENT MOTORS. **a.** The physical and electrical features of a d-c motor are the same as those of a d-c generator. Therefore, when a motor armature rotates, a voltage is induced in its coils. This induced voltage, known as back or counter e.m.f., vitally affects the electrical characteristics and the performance of the motor.

b. When a 12-volt battery is connected to a certain model of series-wound motor, current at first flows at the rate of perhaps three or four hundred amperes, because the resistance of the motor is a small fraction of an ohm. As the speed builds up, an increasing amount of back e.m.f. is generated. This increasing back e.m.f. reduces the net voltage in the circuit, and the current is therefore decreased to a value of about 100 amperes. At this speed, the back e.m.f. is only a few volts less than the applied voltage.

c. Suppose this battery-driven rotating motor is coupled to an engine which can cause the motor to rotate at still higher speeds. The self-induced (back) e.m.f. increase as the motor is forced to turn at speeds increasingly greater than that of its normal operation as a motor. As the induced voltage becomes equal to the battery voltage, the net voltage in the circuit, and consequently, the current flowing between battery and motor reach zero value. If this speed (which results in zero current) is exceeded, the induced voltage will exceed the voltage of the battery. The net voltage is now in the other direction and the current is therefore reversed. The motor has become a generator. It is converting mechanical energy into electrical energy and is sending it to the battery where it is converted into chemical energy. This is charging the battery.

d. Although the d-c motor and the d-c generator may be used interchangeably, this is seldom done in common practice. The structural and electrical features of a generator which efficiently fulfill a certain need on aircraft will not necessarily be the same as the corresponding features of a motor which efficiently fulfill a need, and vice versa.

e. If the load on a motor is increased, the motor will slow down. The reduction in speed reduces the back e.m.f., which in turn increases the net voltage, the current, and the developed torque. Since, in the series-wound motor, the field and armature circuits are in series, the magnetism of both is strengthened by the increase in current. However, in the shunt-wound motor, the current in the shunt circuit depends solely upon the terminal voltage of the machine. Therefore, loss of

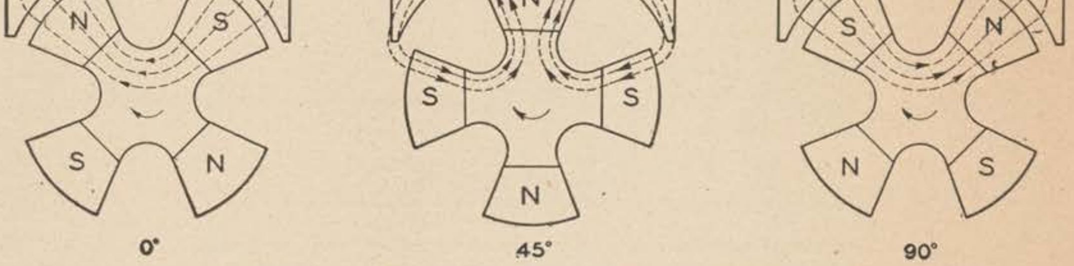


Figure 72. Magnetic flux at three positions of magnetic rotor.

speed does not affect the magnetism of the field coil; only the current in, and the magnetism of, the armature circuit are increased. The result is that it is much more difficult to stall a series motor than a shunt motor. Correspondingly, the torque of a series-wound motor at starting is many times greater than that of a shunt-wound motor of equal size. Therefore, in cases where an electric motor must start from rest under maximum load conditions, a series-wound motor is used. In cases where the load is light at starting and builds up with the speed (as in the case of an electric fan) the shunt-wound motor is very satisfactory. The shunt motor has the characteristics of constant speed under varying loads. One undesirable feature of a series motor is that if full voltage is applied with no load on the motor, so great a speed will be developed that the armature may fly apart as the result of centrifugal force. This fact should be kept in mind when bench-testing electric motors.

SECTION VII

FUNDAMENTALS OF ALTERNATING CURRENT

49. GENERAL. At the present time alternating current is used only on smaller aircraft units such as indicating instruments, remote compass, fluorescent lighting, automatic pilots, turbo regulators, gyroscopes, etc. However, with the increasing size of airplanes, the increasing power requirements, the higher altitude, a-c systems will become more popular. Direct-current motors and generators are limited in output at high altitudes by brush and commutator troubles. With alternating current no brushes are used in the power circuit, consequently, it has no advantage over direct current in this respect.

50. ALTERNATORS. a. General. In the alternating-current system the generator is called an alternator. In section VI the principles of voltage generation were explained. The common alternator is designed somewhat differently, but the principles of operation remain the same. In the common alternator, the voltage is induced in the stationary coils by a magnetic rotor (fig. 73). The fixed part is called the *stator* and the rotating magnet is called the *rotor*. In order to have a strong, controllable field, an electromagnet is used for the rotor. A direct-current is supplied to the rotor by means of slip rings mounted on the rotor shaft. The direct-current (exciting current) must be furnished by an auxiliary d-c generator which is usually mounted at the end of the alternator shaft or driven by an auxiliary engine (fig. 74).

The alternator should be driven at a constant speed, because the frequency of the voltage generated depends upon the speed at which the alternator is driven. A variation in frequency would cause faulty operation of some of the equipment connected to the alternator. The voltage output of the alternator is controlled by regulating the direct-current field (fig. 75).

Alternators are usually rated in voltage, amperage, power factor, and phases. Voltage and amperage are common to both d-c and a-c machinery but power factor and phases are used only in a-c equipment. The power factor is the relationship between the current and voltage at which the machine is intended to operate. The number of phases of an alternator or motor is the number of independent voltages it generates or to which it is connected. Single- 2- and 3-phase a-c equipment are the most comomn types used.

b. Single-phase alternator. The single-phase alternator generates a single a-c voltage. A simple machine

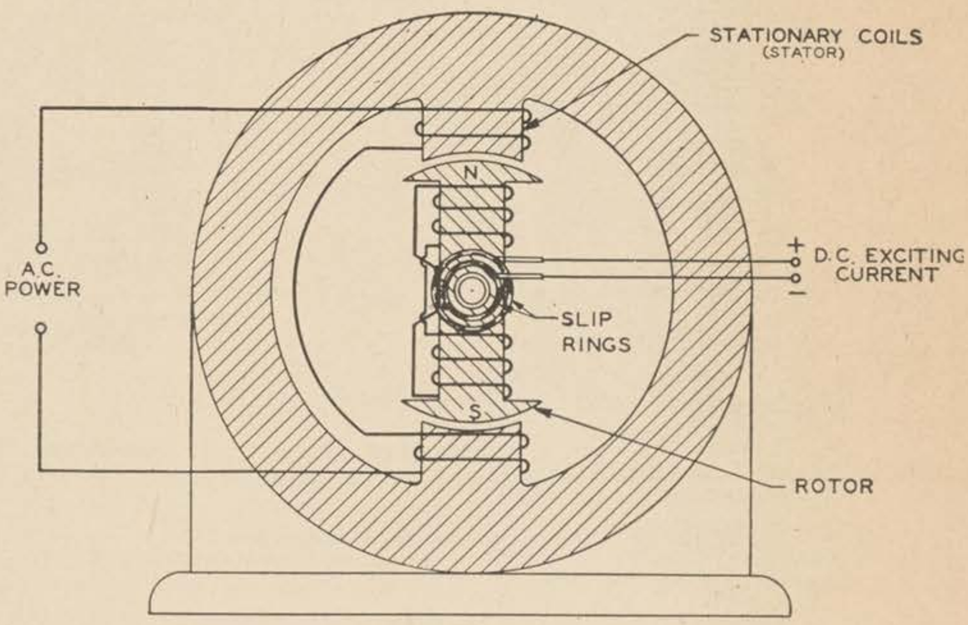


Figure 73. Simple alternator.

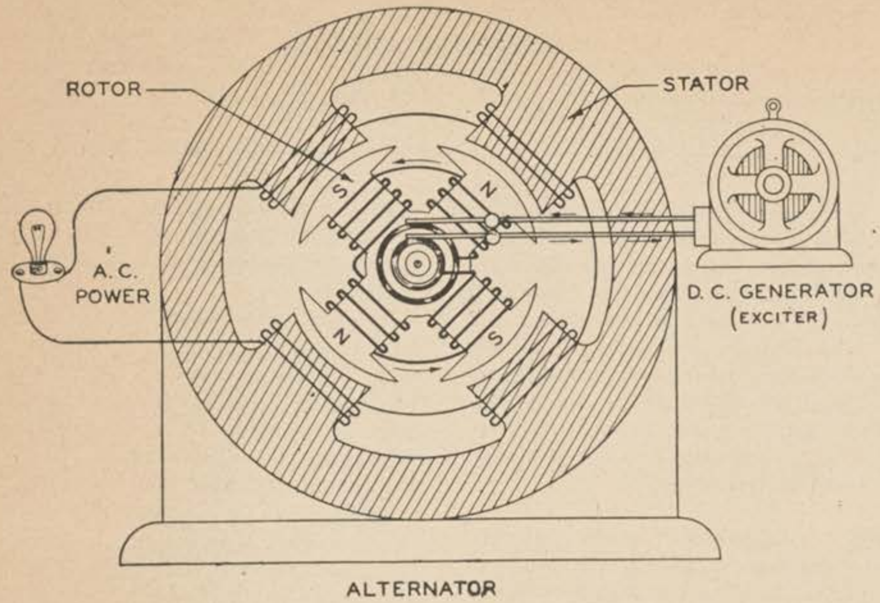


Figure 74. Alternator with field exciter.

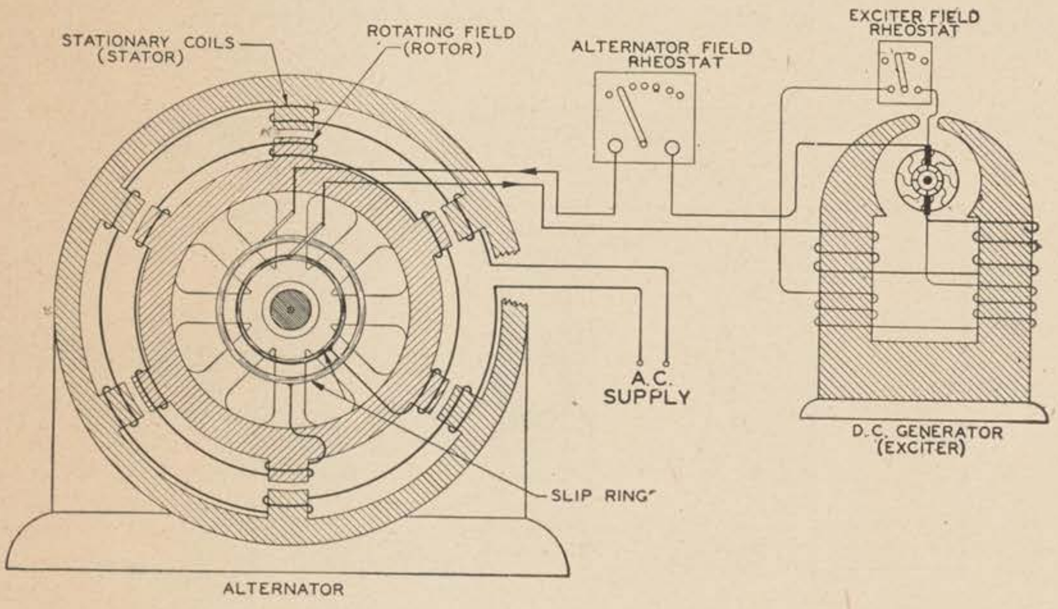


Figure 75. Voltage regulator on an alternator.

with a 2-pole rotating permanent magnet (rotor), and a 2-pole *stator* will be used to explain the operating principles of the single-phase alternator (fig. 76). As the magnetic rotor is rotated, the voltage induced in the stator windings sets up a current causing a flux which repels each approaching rotor pole and attracts each leaving rotor pole. The change in the direction of voltage takes place when the rotor poles line up with the stator poles. One complete revolution of the rotor will generate, in the stator, a voltage which is positive one-half of the revolution and negative the other half. One revolution in this case is called 1 cycle (fig. 77). The frequency (cycles per second) of the a-c voltage or current will depend upon the number of poles in the stator and the speed of the rotor. A simple rule to find frequency is to multiply the number of stator pole pairs (2 poles) by the number of revolutions of the rotor per second. If 4 poles are used, the rotor will have to rotate ½ as fast as the 2-pole alternator to generate a voltage of the same frequency.

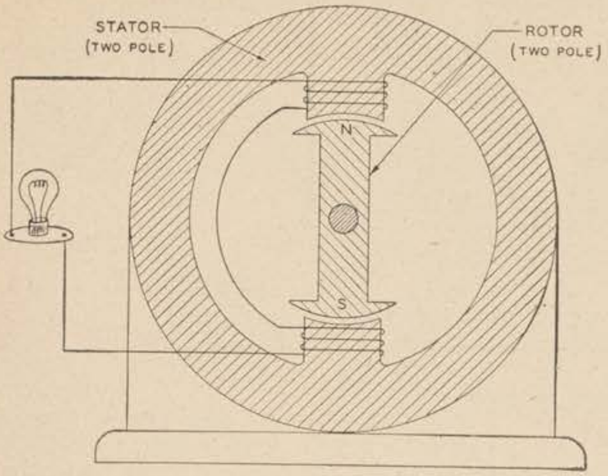


Figure 76. Single-phase alternator.

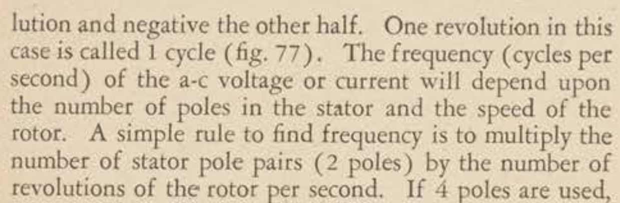


Figure 77. Single-phase voltage curve.

c. Two-phase alternator. The principles of operation and construction of the 2-phase alternators are the same as a single-phase alternator. However, a second set of coils is placed in the stator, independent of the first (fig. 78). Actually 2 voltages are generated instead of 1. The 2 are separated from each other by 90° or one-quarter of a revolution of the rotor in the simple 2-phase alternator as shown in figure 79. This relation of the voltages cannot change as the coils are permanently located in the stator. In figuring the frequency, the rule in *b* above can be used, counting only the poles of 1 phase. The 2-phase alternator is used very little because the 3-phase system is more economical.

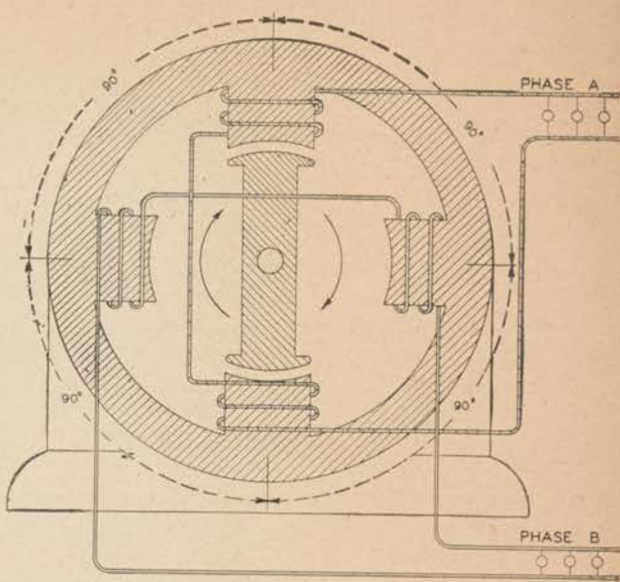


Figure 78. Two-phase alternator.

d. Three-phase alternator. The 3-phase alternator is a combination of 3 single-phase alternators in one unit. This is done by having 3 sets of stator windings equally spaced from each other (fig. 80). This machine will generate a voltage as shown in figure 81. In calculating the frequency of the 3-phase alternator, one-third of the pole pairs are used. The 3-phase alternator is by far the most popular type alternator, the reason for which will be discussed in a later paragraph.

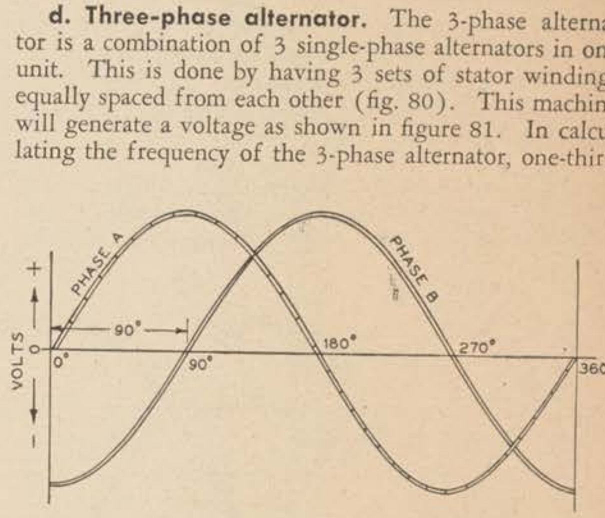


Figure 79. Two-phase voltage curve.

51. ALTERNATING CURRENT CIRCUITS.

a. General. Many of the ideas obtained from the study of d-c circuits must be changed or enlarged upon when studying a-c circuits. In the a-c circuit the voltage and current are never steady; they are constantly changing in value and direction.

b. Sine wave. The voltage and current in a-c circuits

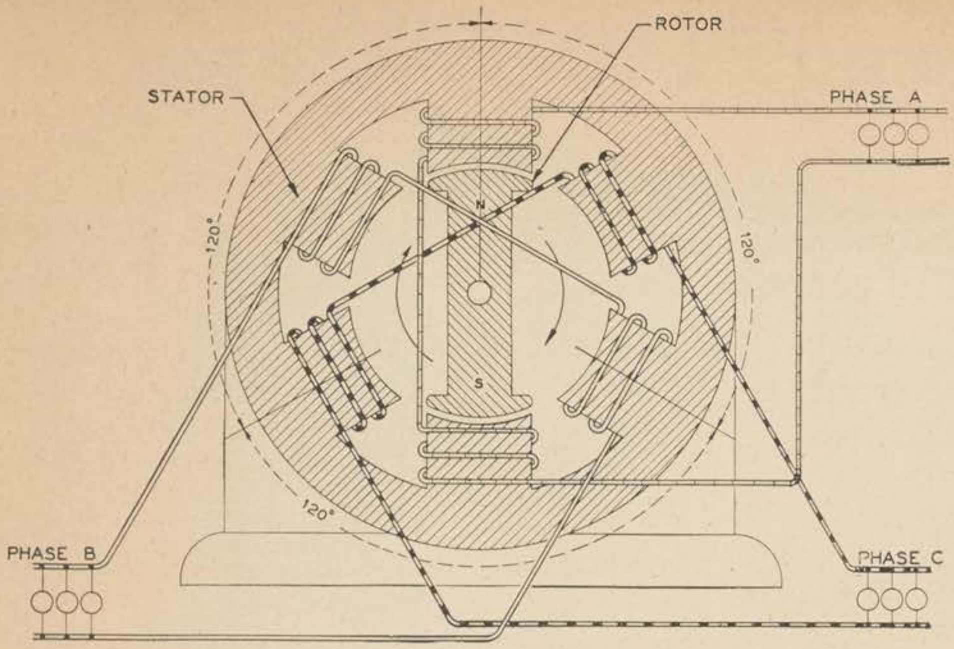


Figure 80. Three-phase alternator.

are said to follow a sine wave. Should a single loop of wire rotate one complete revolution in a magnetic field, the voltage would follow a path as shown in figure 82. More flux is cut when the conductors are traveling perpendicular to the flux than when they are traveling parallel with the flux.

c. Current in an a-c circuit. In a simple a-c circuit, the current will have the same frequency as the voltage. However, the current will not always be at the maximum value when the voltage is at a maximum. Current may be from 90° ahead of the voltage to 90° behind the voltage (fig. 83).

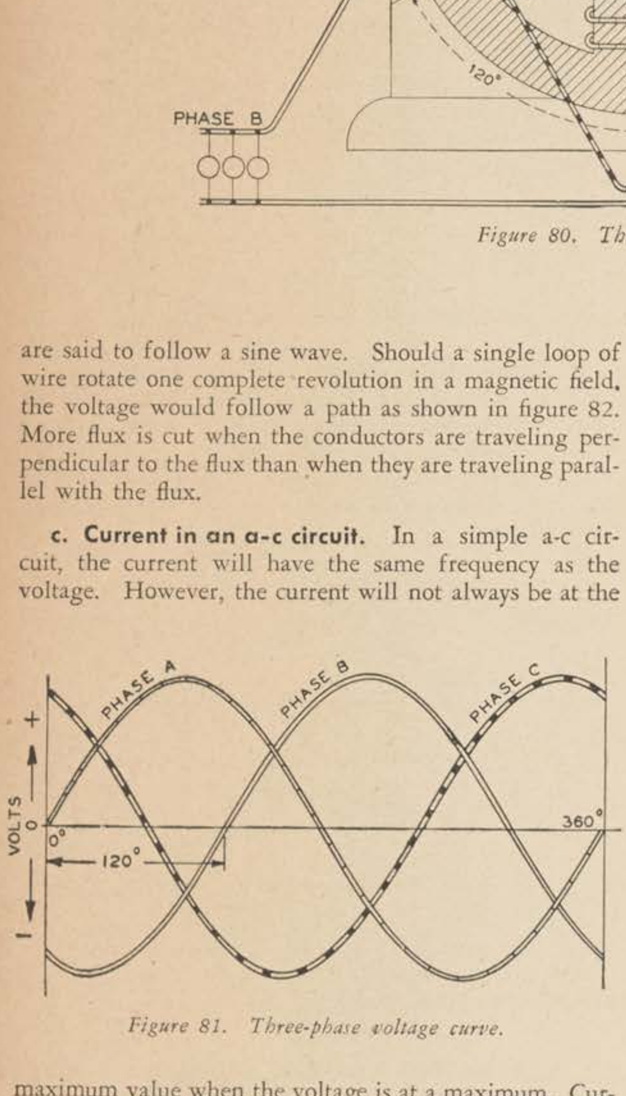


Figure 81. Three-phase voltage curve.

(1) If the load on an alternator is made up of resistors, lamps, and heaters, the current will be maximum when the voltage is maximum (fig. 84).

(2) When a motor, solenoid, or any unit having coils of wire is used, the current will be maximum after the voltage is maximum (fig. 85). Often an a-c voltage can

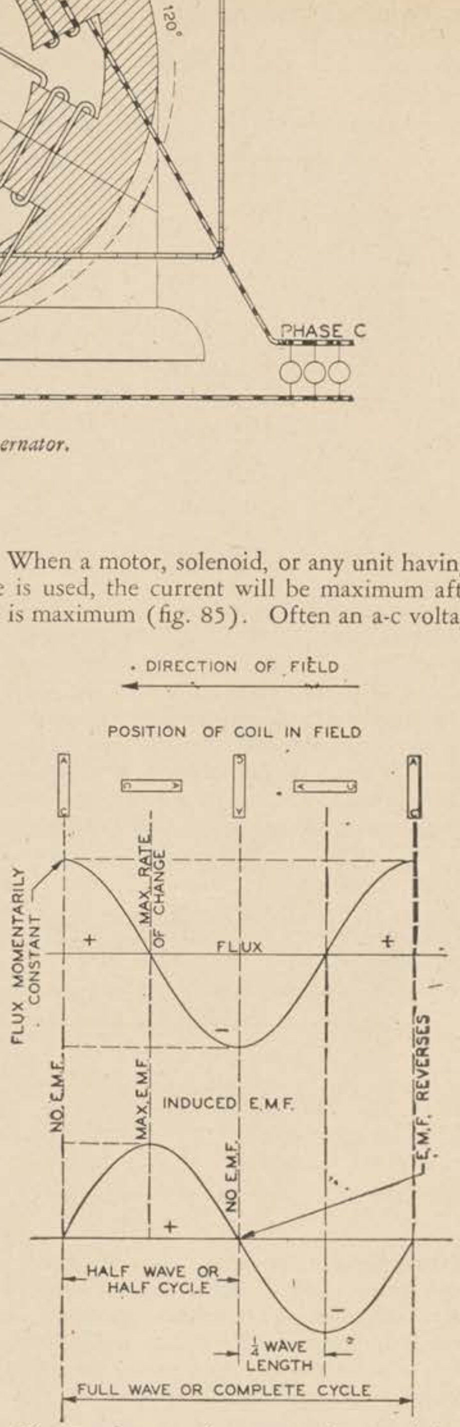


Figure 82. Development of current, voltage, and flux sine curves or waves.

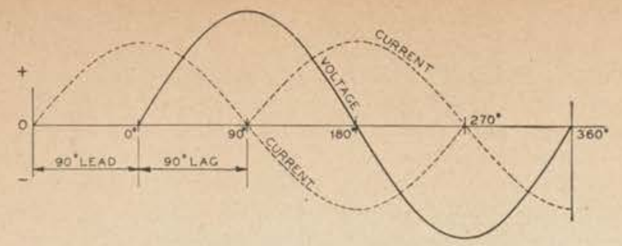


Figure 83. Maximum phase variations in current and voltage.

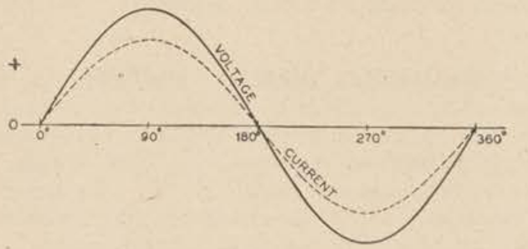


Figure 84. Current and voltage of a resistive load.

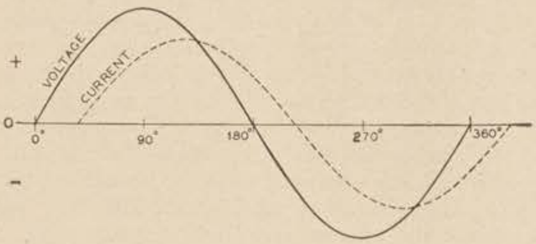


Figure 85. Current and voltage when a coil of wire is the load.

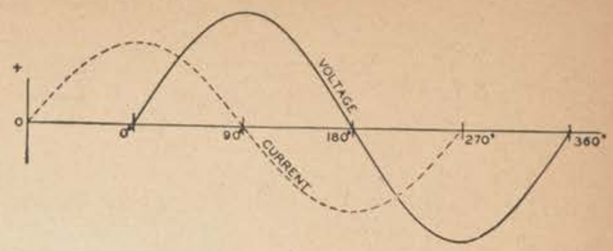


Figure 86. Current and voltage when a condenser is the load.

be applied to an inductive circuit resulting in very little current flow. However, if the same d-c voltage were applied, the current flow would be excessive and the unit would probably burn up.

(3) When a condenser is connected across a supply of a-c voltage, a current will flow through the condenser. This is one of the fundamentals of a-c which differs from d-c. The current and voltage relationship where the condenser makes up the load is very unusual; the current leads the voltage (fig. 86).

d. Power in an a-c circuit is not always found by multiplying voltage by amperage as in a d-c circuit. The d-c relationship is true in an a-c circuit only when the power is consumed by a lamp, heating device, or other resistors. Whenever the circuit contains capacity or inductance the current will lead or lag the voltage and a power factor (correction factor) must be used (watts = volts × amperes × power factor). The "power factor" is a number which may vary (depending on the total capacitance or inductance of the circuit) from 0 to 1 or from 0 to 100 percent and which is multiplied by the product of volts and amperes to get the actual power

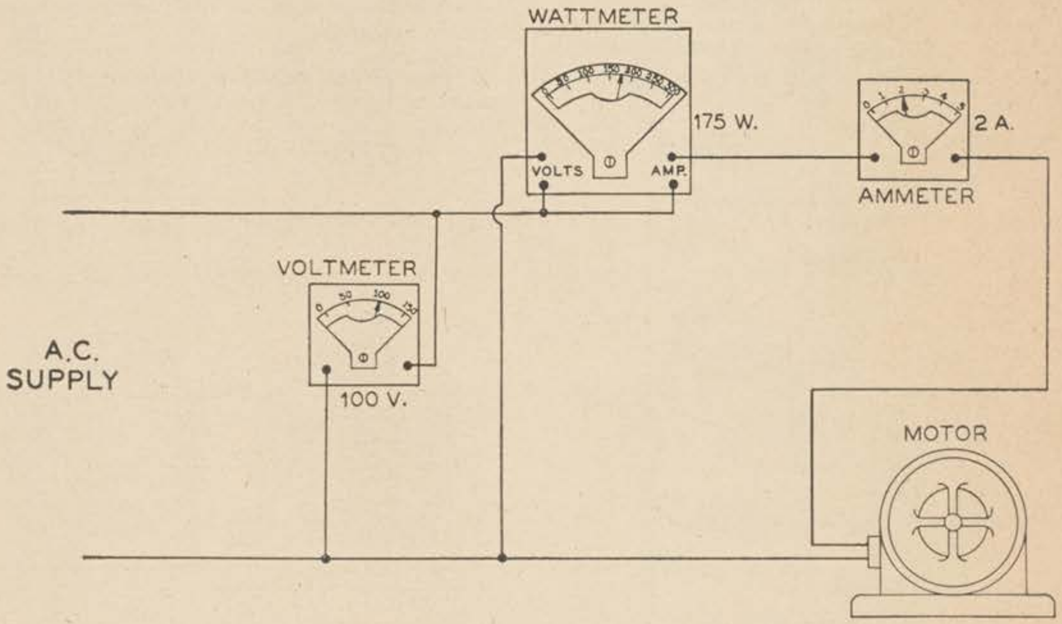


Figure 87. Method of measuring power factor.

consumed by the unit. To measure the power required by a unit a "wattmeter" is used. The wattmeter automatically takes care of the power factor. The important thing to remember is not to measure *power* in an a-c circuit with a voltmeter and an ammeter, but instead, use a wattmeter. To determine the *power factor* of a circuit use a voltmeter, ammeter, and wattmeter as shown in figure 87. To calculate the power factor use the formula:

$$\text{Power factor} = \frac{\text{watts}}{\text{volts} \times \text{amperes}}$$

To get the power factor (pf or P.F.) in percent, multiply by 100.

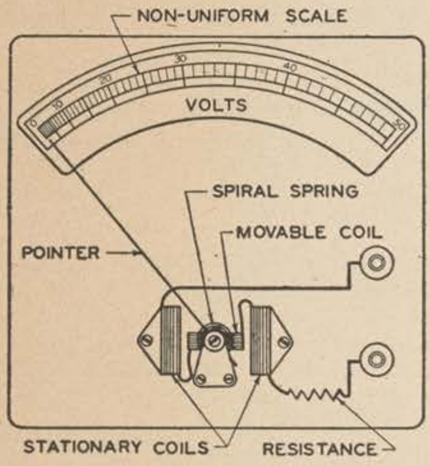


Figure 88. Dynamometer type of voltmeter.

52. ALTERNATING-CURRENT MEASUREMENTS. a. The common d-c voltmeter and ammeter will not work on a-c. The most popular movement used in a-c meters is the dynamometer movement (fig. 88). This movement uses two coils, one of which is a split fixed field coil and the other a movable coil, connected in series. Because the coils are connected in series, and the current is in the same direction in both coils, there is always an attraction between the coils.

b. In measuring a-c current and voltage, certain rules and standards must be accepted. All commercial meters show a reading which is called the *effective value* of current and voltage, not the maximum or peak value. The effective value is sometimes spoken of as R.M.S. (root-mean-square) value. This value is 0.707 of the maximum current or voltage. This effective value of a-c current or voltage corresponds to the same d-c current or voltage (fig. 89). In the case of the household 115-volt system, the voltage actually varies from 0 to approximately 162 volts. A current flow in a circuit which has a maximum value of 10 amperes has the value of 7.07 amperes as measured with an ammeter.

53. ALTERNATING-CURRENT MOTORS. a. General. The a-c motor most commonly used is the induction type. The 2- and 3-phase induction motors are simple in construction and have but 1 free moving part. Single-phase induction motors are not as practical nor as simple as 2- and 3-phase motors because a starting device must be used to start them. In this section 2- and 3-phase motors will be given particular attention.

b. Single-phase a-c motors. (1) A common single-phase motor is the universal (a-c, d-c) motor. It will operate on either a-c or d-c. It is a series motor and has operational characteristics similar to the common series motor as used on an aircraft starter. This motor will operate on a-c because the current changes its direction in both the field and armature at the same time. Thus the effect is the same as if the current were steady d-c. This motor is not very satisfactory for aircraft use because it uses a set of brushes which cause radio interference. The motor also requires considerable maintenance.

(2) Any one of several induction-type single-phase motors may be used where a small amount of power is required. However, they are not used in aircraft work because they require special starting devices which complicate the construction of the motor and require considerable maintenance.

c. Two-phase induction motors. In the 2-phase squirrel-cage induction motor, the rotor is made to rotate

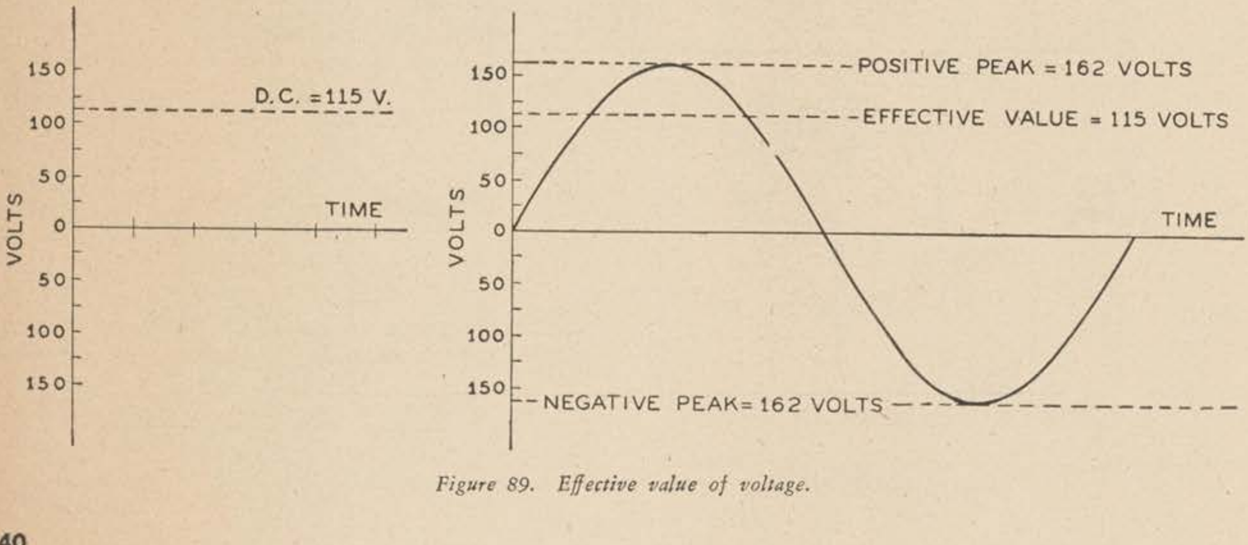
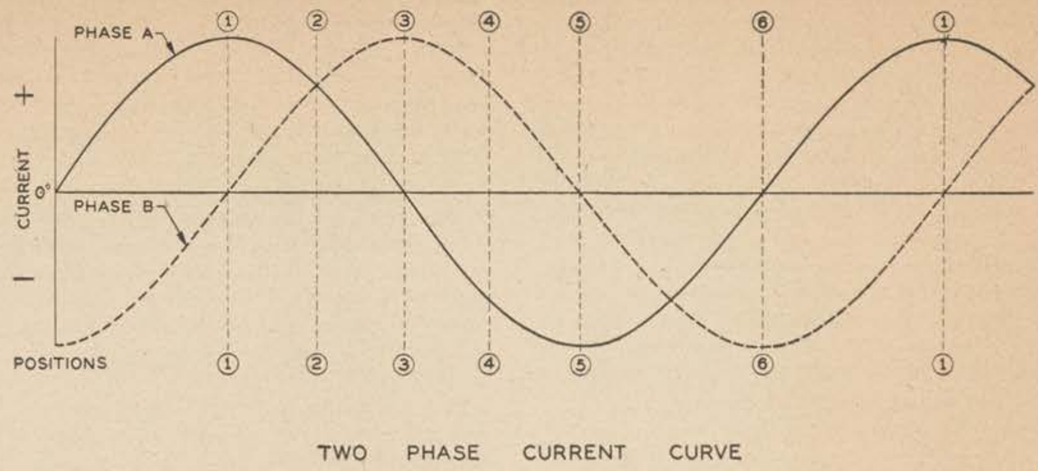


Figure 89. Effective value of voltage.



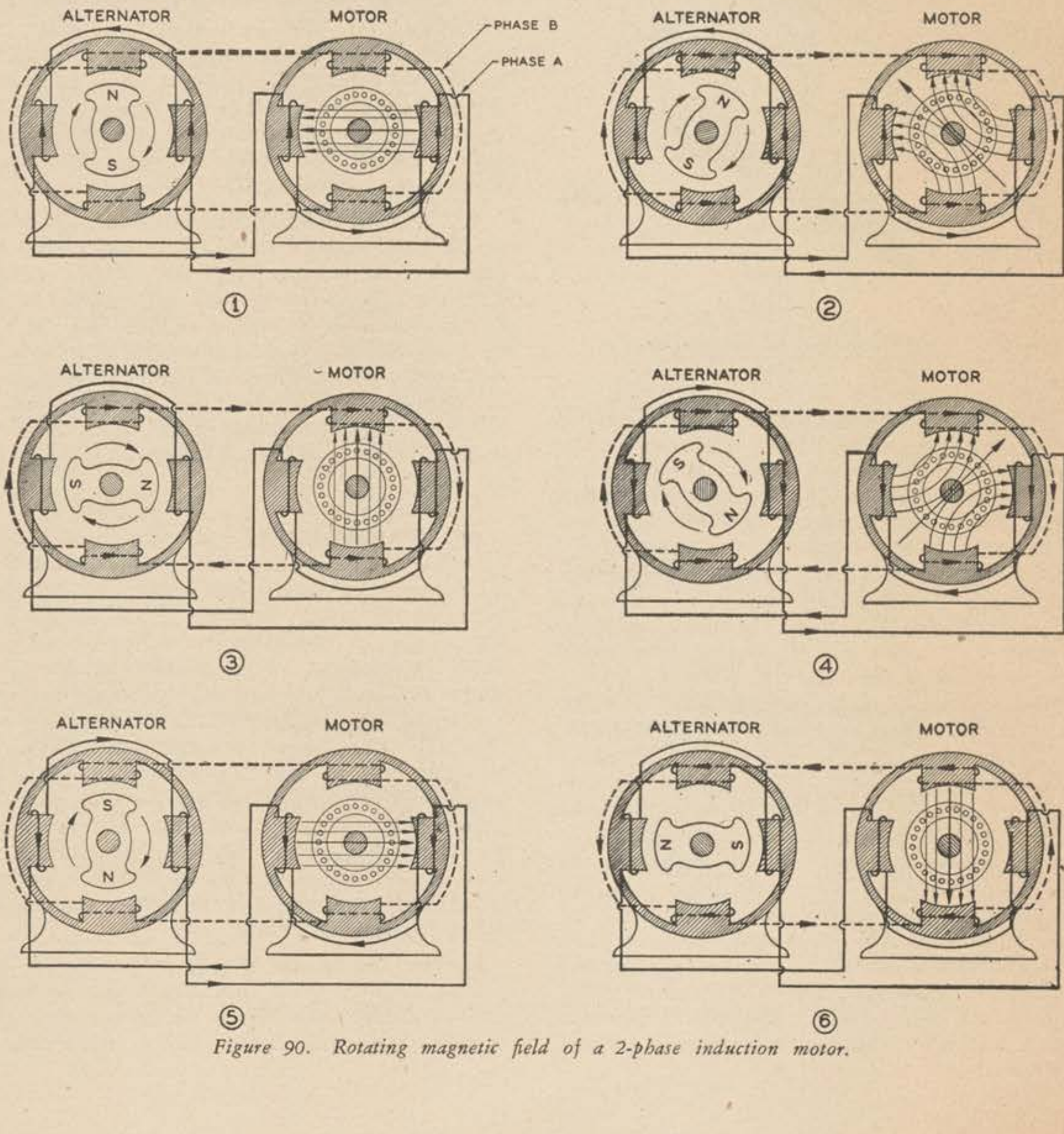


Figure 90. Rotating magnetic field of a 2-phase induction motor.

by a rotational magnetic field (fig. 90). A series of illustrations of the 2-phase alternator, 2-phase motor, and the generated voltages will explain the field's rotation. As this field cuts across the short circuited conductors of the rotor (fig. 91), the current set up in them will cause an opposing field. The rotating field will then drag the armature along with it and produce rotation. (The speed at which the field rotates is called the synchronous speed). The rotor will travel somewhat slower than the field to permit the field flux to cut the conductors in the armature. The percent of difference in speed of the magnetic field of the stator and the armature is called the slip. The slip varies with the load on the motor. However, it seldom exceeds 10 percent. In order to reverse the direction of rotation of the armature, the leads of one phase are reversed. The effect of reversing the leads of one phase reverses the direction of rotation of the field.

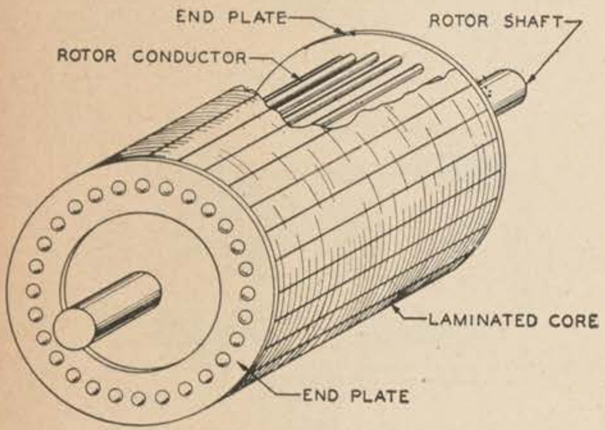


Figure 91. Squirrel-cage induction-motor rotor.

d. Three-phase induction motor. For simplicity the 3-phase induction motor will be explained in the same manner as the two-phase motor; however, only three leads are used to connect the alternator to the motor (fig. 92). Also it will be noticed that 2 of the phases work together to form the poles of the rotating field. The rotor is constructed of an iron cylinder wound with short-circuited turns of heavy copper bars. To reverse a three-phase motor, any two of the connecting leads are interchanged. This produces a reversed field which causes the reversing of the rotor.

e. Three-phase a-c circuit connections. (1) The 3-phase alternator can be represented by 3 coils equally spaced as in figure 93. From figure 93 ①, it can be seen that at the time when the instantaneous value of the voltage in phase "A" is 100 volts, that in phases "B" and "C" it is 50 volts. Similarly when the instantaneous value of the current in phase "A" is 10 amperes, the current in phases "B" and "C" is 5 amperes. The conductors to the inside connections can be dropped and the three points connected as shown by the dark line in figure 93 ②. This is known as a 3-phase, 4-wire generator and the wire shown by the dark line is referred to as the "common return" or "neutral." The ratio of the effective voltage between neutral and any phase of a 4-wire system to the effective voltage between any 2 phases is always as 1 is to 1.732. For example, if the effective voltage between any phase and neutral is 120 volts, the effective voltage between phases is 208 volts. The advantage of the 4-wire, 3-phase system is exemplified by the fact that in the case cited, 3-phase system, 208-volt equipment and single-phase, 120-volt equipment may be connected to the same circuit.

(2) With the instantaneous values of voltage shown in figure 93 ①, the current in the neutral wire, figure 93 ②, would be 10 amperes in one direction for phase "A" and a total of 10 amperes in the other direction for phases "B" and "C", it is obvious that the neutral wire carries no current and can be eliminated. Such a system is known as a 2-phase, 3-wire system and the generator as a 3-phase, 3-wire generator. As the 3-phase, 3-wire system is the one in most comomn use, it is frequently referred to merely as 3-phase (3-wire being understood). As compared with the single-phase, 2-phase, and 3-phase, 4-wire systems, the 3-phase, 3-wire system has the advantages of simplicity, symmetry, and a somewhat smaller copper requirement for conductors. For most purposes it is also more practical than the other alternating-current systems.

(3) In connecting a motor or generator to a 3-phase circuit, each lead must be properly connected as reversing two leads on a motor will cause a reversal in direction of rotation. The wrong connection of a coil in one phase of an alternator will produce an unbalanced voltage condition in the system (fig. 94).

f. "Y" and delta (△) connections. The coils of an alternator may be connected in either "Y" or delta (fig. 95). In the case where the coils are connected in △ (delta) the voltage between any 2 of the 3 leads will be the same as the voltage of an individual coil. When the coils are connected in Y, the voltage between any two of the three leads will be 1.732 times the voltage of the individual phase coils. To make sure that all the coils are connected correctly, make certain that voltmeter readings between all possible combinations of phases are the same.

54. TRANSFORMERS. a. The transformer is used to connect 2 a-c circuits (which usually operate at different voltages). Power is transferred from one circuit to the other by mutual induction. The voltage is raised with a "step-up" transformer, or is lowered with a "step-down" transformer. A transformer consists fundamentally of two coils (primary and secondary) wound upon, and electrically insulated from, a closed magnetic core (fig. 96). The coils are thus linked with the same magnetic circuit. The secondary or output coil of a step-up transformer has more turns than the primary. The secondary of a step-down transformer has fewer turns than the primary. The two voltages are proportional to their turns ratio. The current varies inversely as the turns ratio. The power output is the same as the power input except for some small heat losses.

b. The core consists usually of laminations (layers) of soft iron. If solid iron were used, electrical *eddy currents* would be set up in the core during operation of the transformer. Eddy currents create heat which

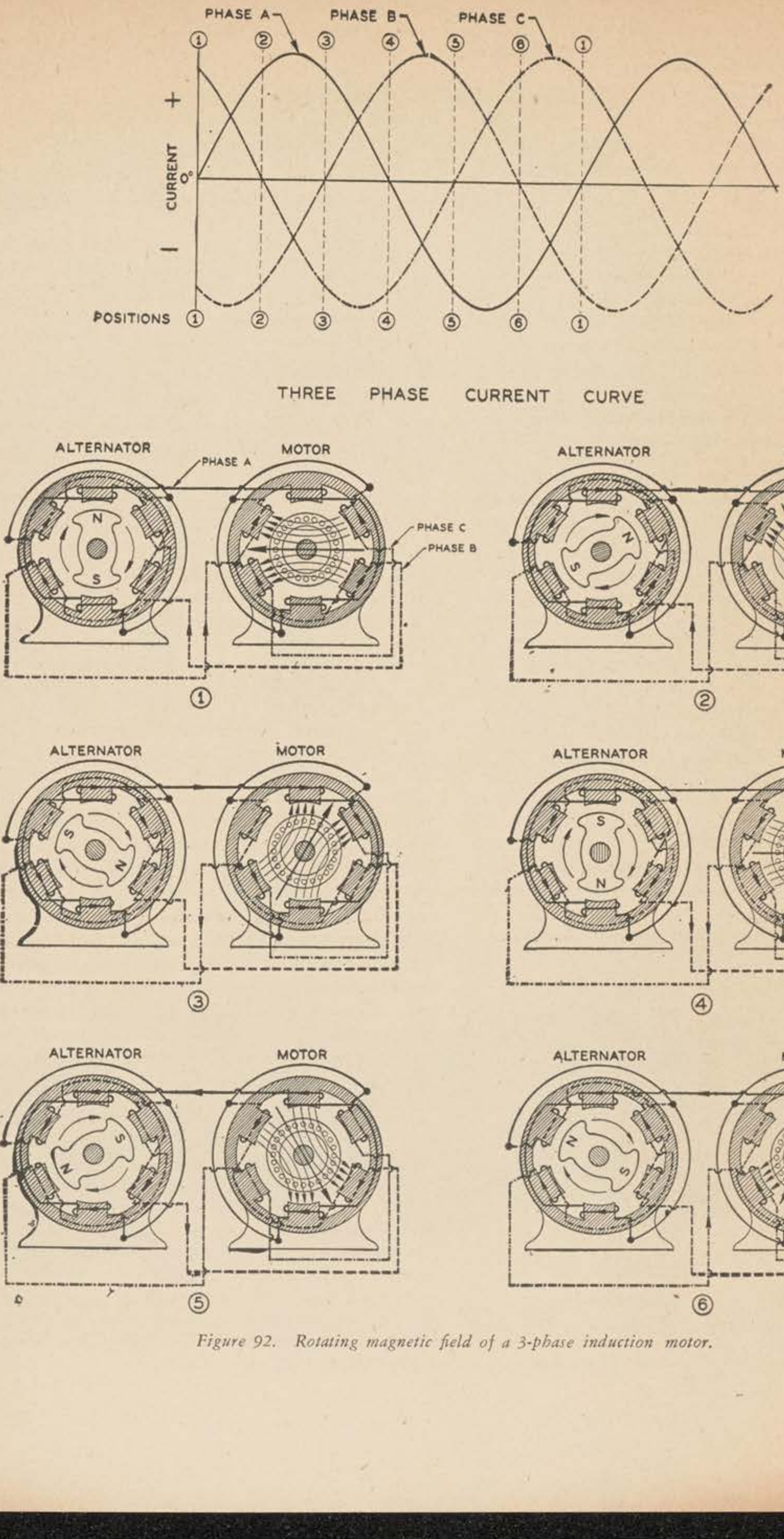


Figure 92. Rotating magnetic field of a 3-phase induction motor.

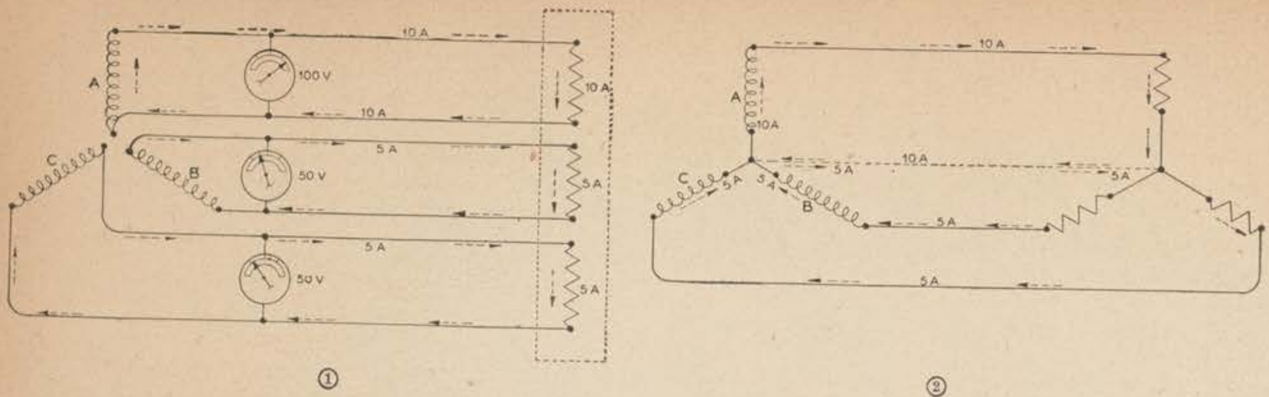


Figure 93. Instantaneous currents and voltages when a phase voltage is a maximum of 100 volts.

would lower the efficiency of the transformer. Oxide films or nonconducting coatings on the laminations tend to prevent or to reduce eddy currents without interfering with the magnetic operation of the core.

c. When the primary of a transformer is connected to a source of alternating current, it tends to magnetize the core first in one direction, then in the other. Power from

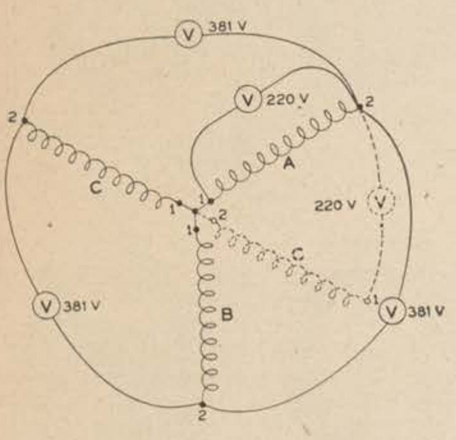


Figure 94. Method of checking phase connections.

the a-c source is stored in the core during each flux build-up. When the secondary is without a load, the voltage induced in the primary coil by the rising and falling flux is almost as great as the voltage of the power source, so

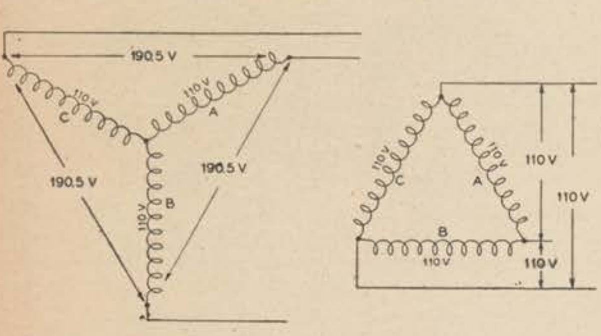


Figure 95. "Y" and "delta" alternator connections.

that the difference of the voltages is almost zero. Consequently, the alternating current in the primary is very small. Transformers may therefore be left connected to the high voltage feeders at all times with very little waste of power. As long as the secondary circuit is open, the a-c voltage induced between the secondary terminals does not do any work and, so far as the magnetic core is

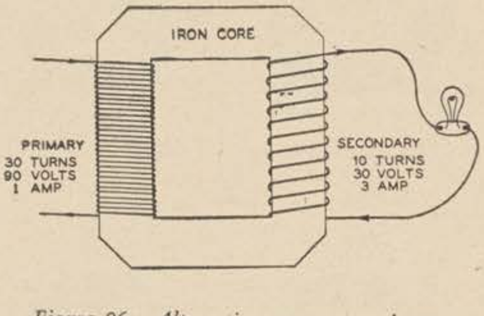


Figure 96. Alternating-current transformer.

concerned, the secondary is not on the core. But when the secondary circuit is closed (as, for example, by switching on the lights in the circuit), the resultant flow of alternating current in the secondary circuit periodically removes some of the power placed in the magnetic circuit by the primary. Therefore, the back voltage of the primary is reduced; and the net voltage in the primary circuit is increased; and the primary current rises. A well-designed transformer, therefore, draws current from the line in proportion to the demand of the connected load.

d. It has been found more satisfactory to use d-c equipment on aircraft for a number of reasons, the primary reason being that a-c electrical energy cannot be stored. However, where certain devices require a-c, a special source of a-c power must be provided, with which the transformer finds application. In larger aircraft where a power plant is necessary, the use of a-c on a large scale may be found practicable. In such event, the aircraft may be relieved of considerable weight in copper by use of transformers and the transmission of energy at high voltages over small wires.

AIRCRAFT STORAGE BATTERIES

55. GENERAL. **a.** The purpose of the aircraft storage battery is to provide a reserve source of electrical energy for operating the various units of aircraft electrical equipment. During normal engine operation, the engine-driven generator serves as the primary source of electrical energy for operating the various units of aircraft electrical equipment. The most common types of aircraft batteries are shown in figure 97. The battery supplies the electrical energy to start an engine and to operate electrical equipment during low engine speeds and when the generator or engine fails.

b. A storage battery has a number of cells in series (fig. 98). During discharge chemical energy in these cells is transformed into electrical energy. This chemical energy is later replaced as explained in the following paragraph.

c. A storage battery is kept charged by sending a current back into the battery. When a current from an external source is sent through the storage cell, a reverse chemical change of the plates and electrolyte occurs. This process is known as "charging." The usefulness of a storage cell lies in its ability to be "discharged" and "charged" many times before it eventually becomes permanently deteriorated. In an aircraft installation the battery is required on various occasions (especially during starting) to furnish a very heavy current for a short time. During flight the generator replaces this energy which has been drained from battery, at a much lower rate, but over a longer period of time. A storage cell does not actually "store" electricity; during discharge, chemical energy is changed into electrical energy and during charge electrical energy is changed into chemical energy.

d. There are two types of storage cells in common use, namely the Edison (alkaline) cell and the lead-acid cell. The Edison-cell storage battery is not used in aircraft.

56. PRINCIPLES OF LEAD-ACID CELLS. **a.** A lead-acid cell contains positive plates coated with lead peroxide (PbO_2); negative plates made of lead (Pb); and a liquid known as an electrolyte, consisting of a mixture of sulfuric acid (H_2SO_4) and water (H_2O).

b. During discharge of the lead-acid cell, lead sulfate ($PbSO_4$) is formed on both the positive and negative plates; the acid content of the electrolyte is decreased and water content is increased. As a result of the loss of heavy acid molecules from the solution and because of the formation of comparatively light water molecules, the electrolyte gradually becomes more dilute and less dense as the battery is discharged.

c. It is not the dilution of the electrolyte nor the loss of acid molecules, but the formation of the lead sulfate on the plates which causes the battery to become "run down." When the sulfate coatings become so thick that the electrolyte cannot effectively reach the active materials (lead and lead peroxide), some chemical reaction is prevented. In practice, the cell is not permitted to be discharged to this extent. Thin coatings of lead sulfate are easily removed by recharging the battery, but thick coat-

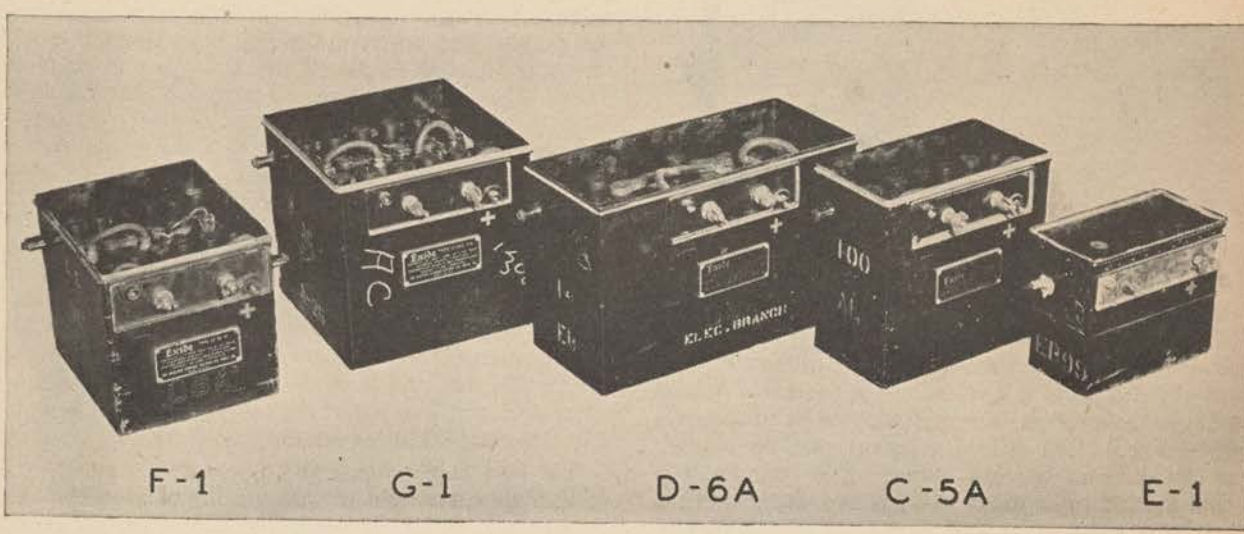


Figure 97. Types of batteries.

ings are difficult to remove. Also, a cell is not very useful when approaching a state of total discharge because of the high internal resistance caused by the sulfate coatings on the plates. This resistance would be introduced into any circuit to which the cell is applied, and would reduce the current to a value too low for practical use.

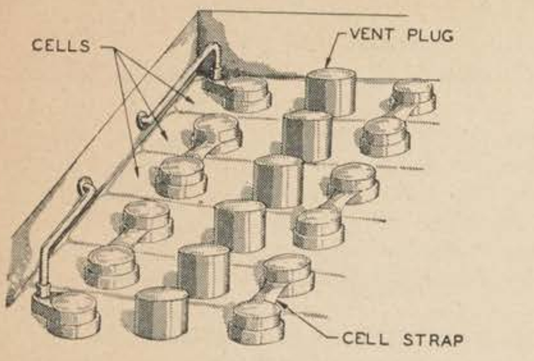


Figure 98. A storage battery has a number of cells in series.

d. When the cell is placed on charge, lead sulfate is removed from both the positive and negative plates, and acid is formed. The water content of the electrolyte is decreased in the process. Consequently, the density of the electrolyte increases as the cell is charged.

e. The *open circuit* voltage, figure 99, of a lead-acid cell is approximately 2.2 volts. The e.m.f. of the cell is dependent only upon the character, and not upon the quantity of its active materials. This voltage is the same for all lead-acid cells regardless of their plate size. The open circuit voltage or e.m.f. of a lead-acid cell remains close to 2.2 volts, regardless of the state of discharge of the cell, until the cell is practically "dead." It then begins to drop rapidly (fig. 106).

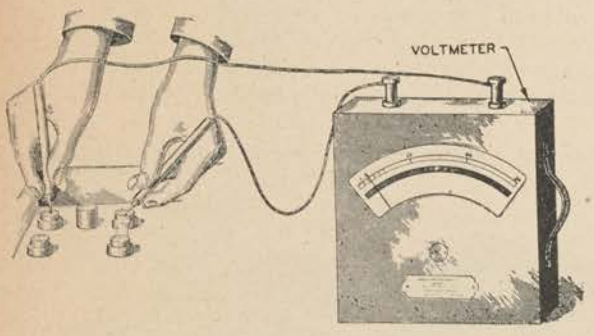


Figure 99. Open-circuit voltage.

f. The terminal voltage of a cell while under load decreases gradually as the cell continues to be discharged. The gradual decrease in terminal voltage is due to a gradual increase in the internal resistance of the cell. The internal resistance of a lead-acid cell at the end of normal discharge increases to more than double its value when fully charged. The difference between the open-circuit and closed-circuit terminal voltages (the voltage drop within the cell while under load) is an indication of the energy lost while under load, as a result of the internal resistance of the cell (fig. 100).

g. To obtain a high discharge current and a high terminal voltage under load, low internal resistance is necessary. Low internal resistance is achieved mainly through the use of large plate area. The internal resistance of a cell depends on its total plate area. The greater the number or area of its plates, the less the internal resistance of a cell. All the positive plates of a cell are connected by

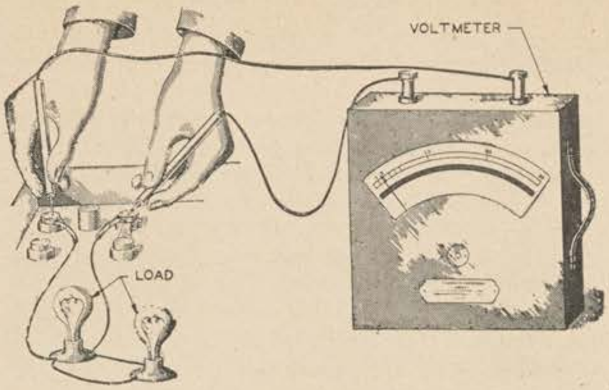


Figure 100. Measuring the terminal voltage of a cell under load.

one common connecting bar, and all the negative plates are connected to another connecting bar. The value of the e.m.f. of this assembly is the same as that of a single pair of plates of the same materials.

57. AIRCRAFT STORAGE-BATTERY CONSTRUCTION. **a.** In order to have a 12- or 24-volt system, 6 or 12 cells are connected in series. The open-circuit voltage (terminal voltage) is the voltage of the battery when it is not undergoing discharge. A sectional view of an aircraft battery is shown in figure 102.

b. A plate of a lead-acid cell consists of a framework called the grid to which the active material is attached. The positive and negative plates are assembled with a positive plate placed between two negative plates, having a negative plate at each end of the cell. Separators are used to prevent plates from contacting. The separators are porous; they are vertically ribbed on the side facing the positive plate to permit the electrolyte to circulate freely around the plates and to provide a path for sediment to settle on the bottom of the cell (fig. 102). The bottom of the battery jar on which the plates rest is ribbed. These ribs form channels into which the sediment may settle without shorting the plates.

c. The hard rubber cover of the cell is sealed with a special sealing compound. The cover provides a base for the installation of a non-spill vent plug and terminal posts. The vent plug provides access for testing and adjusting strength of electrolyte, provides a means for the escape of gases, and is so designed that a minimum of electrolyte will leak out of the cell regardless of any position the aircraft might assume (fig. 103).

The lead weight, figure 103, is actuated by gravity. In level flight the weight permits venting of gases through a small hole; in inverted flight this hole is covered by the lead weight.

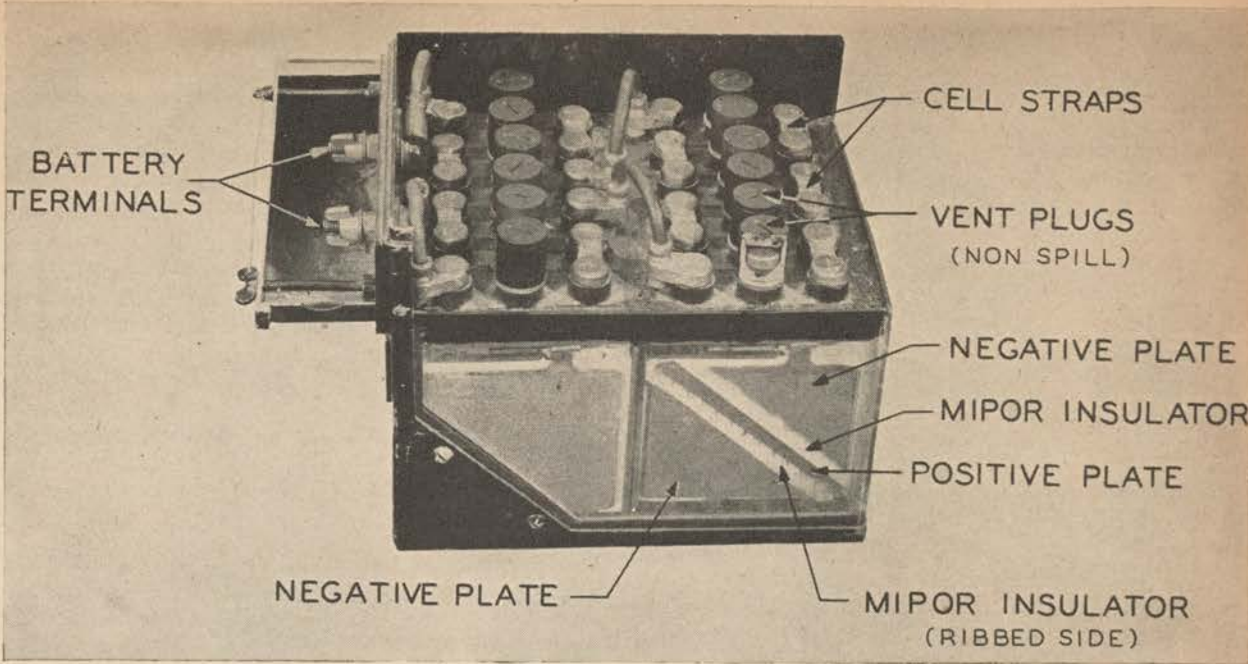


Figure 101. Sectional view of an aircraft battery.

d. In the modern aircraft battery the containers for the individual cells are constructed of hard rubber composition material (fig. 104). The cell assembly is enclosed within an acid-resisting lined metal container (battery box) which is used for electrical shielding and mechanical protection. The battery box has a removable top, held in place by hold-down rods. It also has a vent-tube nipple at each end of the box for the attachment of flexible tubing. These tubes lead out of the airplane, one directed upward, the other downward. This arrangement serves to clear the battery container of gases and any spilled electrolyte. The terminals of each cell are connected permanently to each other in the plus to minus order (series) by means of heavy lead straps. The two end terminals are connected to their respective battery terminal posts which are provided with washers and wing nuts for attachment of cable leads. A removable terminal-box cover permits access to the battery terminal posts (fig. 105).

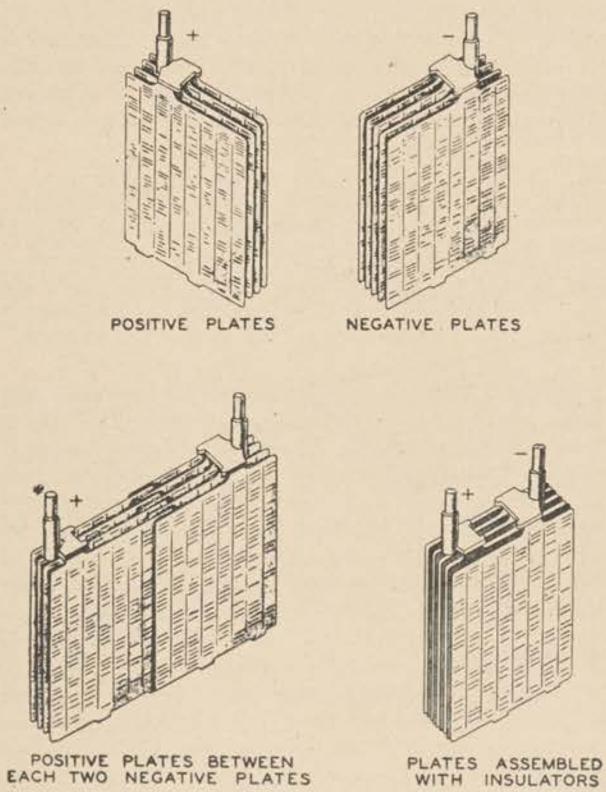


Figure 102. Positive and negative plates as arranged in a cell.

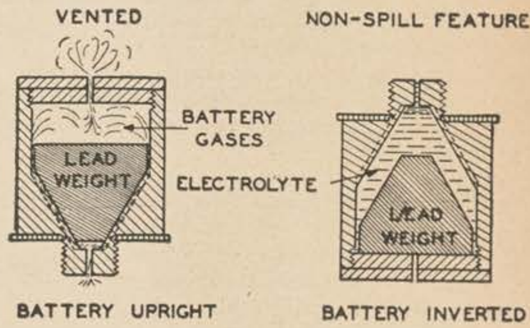


Figure 103. Non-spill vent plug.

58. RATINGS OF STORAGE BATTERIES. **a.** A lead-acid cell is rated at 2 volts. Therefore, a 6-cell battery is rated at 12 volts; and a 12-cell battery is rated at 24 volts.

b. (1) Storage-battery capacity is rated in ampere-hours. This rating indicates how long a battery may be used at a given rate before it becomes exhausted. An ampere-hour is 1 ampere flowing from a battery for 1 hour. Theoretically, a 100 ampere-hour battery will furnish 100 amperes for 1 hour, or 50 amperes for 2 hours, or 20 amperes for 5 hours, etc. Actually, the ampere-hour output of a particular battery is dependent upon the rate at which it is discharged. Heavy discharge currents heat the battery and decrease the efficiency and

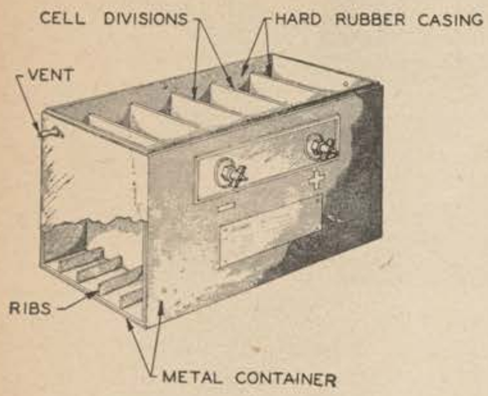


Figure 104. Battery Box.

ampere-hour output. For aircraft batteries, a period of 5 hours has been established as the discharge time in rating of battery capacity. This time of 5 hours does not necessarily mean the length of time which the battery is expected to furnish current. Under actual service conditions the battery can be completely discharged within a few minutes or it may never be discharged if the generator provides sufficient charge.

(2) Figure 106 shows a discharge curve based on values obtained during tests made on a 68 ampere-hour battery. The load current was held at 13.6 amperes for 6 hours (except during momentary opening of the circuit at the end of each hour to obtain open-circuit voltage). It is to be observed that the open-circuit voltage remained almost constant during the first 5 hours of discharge, whereas the voltage while under the load decreased gradually. After the rated capacity of the battery (68 (that is, 13.5 x 5) ampere-hours) was exceeded, both voltages decreased rapidly as the discharge was continued.

c. The temperature of a storage battery is one factor which determines the output of the battery (fig. 107). An acid battery will not deliver as much power as a warm battery. In cold climates a storage battery is of little use.

d. The more common models of aircraft storage batteries are rated as follows:

Volts	*Capacity in ampere-hours*
12	68
12	34
24	17

The ampere-hour capacity of a cell depends upon the total effective plate area. Cells connected in parallel have a net capacity equal to the sum of the individual cell capacities. A battery of identical cells connected in series has the same ampere-hour capacity as one individual cell. In multi-engine aircraft, where more than one battery is used, the batteries are connected in parallel. The voltage is thus equal to that of one battery but the ampere-hour capacity is increased. The total capacity is the sum of the ampere-hour ratings for the individual batteries.

59. BATTERY DETERIORATION.

a. Various factors aid deterioration of a battery and will make its service life short. *Excess sulfation* of plates causes a permanent increase in the resistance of a cell. Increased internal resistance transforms the electrical energy of a battery into useless and harmful heat within the battery, which

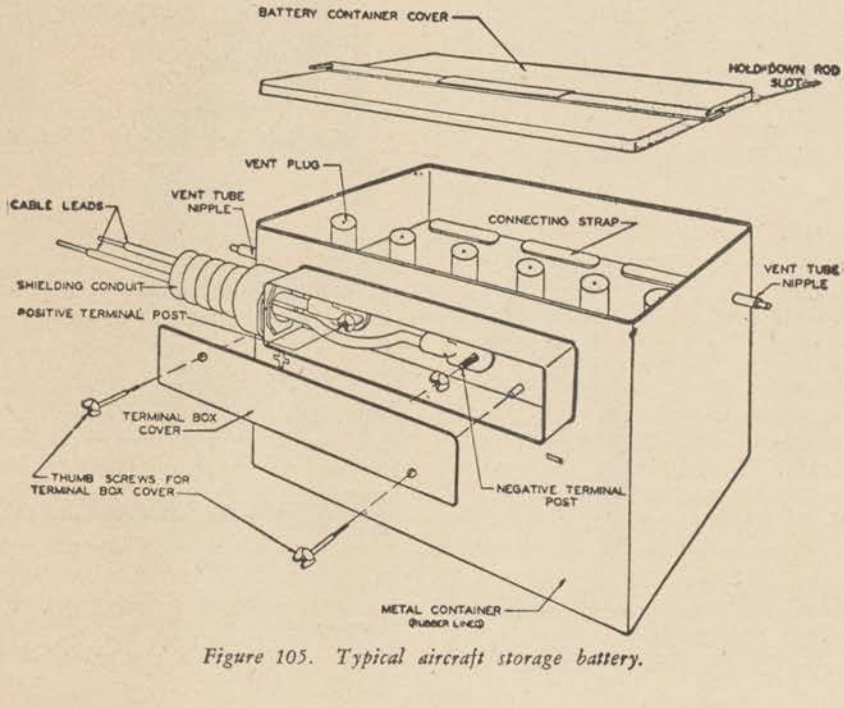


Figure 105. Typical aircraft storage battery.

could have been used on the external circuit. Internal resistance also results in an increase in temperature within the cell while the cell is being charged. Excessive heat results in expansion and buckling of plates and shedding of active material. During the normal life of a battery, approximately 20 percent of its active material may be shed. The pores of material not shed may become clogged with sulfate or other impurities, or the material may corrode. Under any of these conditions the battery capacity is decreased. In addition, accumulation of shed material may cause shorting of the plates and result in internal discharge. Internal discharge may also result by reason of "local action" between portions of the active material and metallic impurities on the same plate.

b. The state of charge of a storage battery should not go below a specific gravity of 1.200. (See following paragraph.) A battery may be permanently injured if it remains in a low or discharged condition.

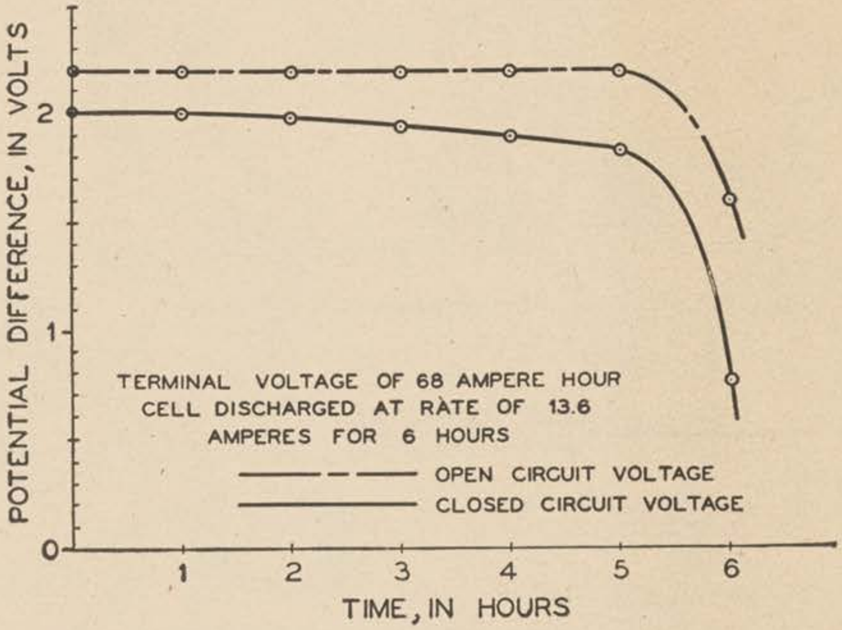


Figure 106. Discharge characteristics of typical aircraft storage battery.

60. TESTING METHODS. **a.** The state of charge of a storage cell depends upon the condition of its active materials, primarily the plates. It is difficult or impractical, however, to find out the plate condition or degree of sulfation by visual inspection. Therefore, an indirect method (hydrometer test) is used to determine the state of charge of a lead-acid cell of a storage battery. In order to find a cell's fitness for use, which condition cannot be obtained by a hydrometer test, the high-rate discharge test is used.

b. The specific gravity or hydrometer test is made periodically on a storage battery installed in aircraft, as a part of established inspection procedure, to determine if the state of charge is adequate. The hydrometer test determines the state of charge of a cell by measuring the degree of concentration of electrolyte.

(1) Pure sulfuric acid is 1.835 times as heavy as an equal volume of pure water. A new, fully charged aircraft storage-battery cell is filled with a mixture of approximately 30 percent acid and 70 percent water (by volume). This mixture, or solution, is 1.300 times as heavy as pure water. During discharge the solution (electrolyte) becomes less dense and its "specific gravity" (weight as compared with water) drops below 1.300. Thus, by determining the specific gravity of the electrolyte, a reliable indication of the state of charge of the cell is obtained. The concentration of the electrolyte is not the cause of the particular state of charge of a cell; it is rather a normal incidental effect. Thus, if a cell has a low specific gravity reading, the adding of some sulfuric acid will increase the concentration and raise the specific gravity of the electrolyte, but the state of charge of the cell will remain as before, inasmuch as the sulfation of the plates remains the same. Even if the electrolyte were replaced with fresh electrolyte having a specific gravity of 1.300, the condition of the plates, and hence the state of charge, would remain the same. Therefore, the specific gravity test of a cell is reliable only if nothing has been added to the electrolyte except occasional small amounts of distilled water to replace the quantity lost as a result of normal evaporation.

(2) The hydrometer commonly used to determine the specific gravity of battery electrolyte is shown in figure 108. It consists of a small sealed glass tube weighted at its lower end so as to cause it to float upright. A paper scale is enclosed within the narrow stem of the tube. The scale is marked from 1.100 to 1.300 with intermediate graduations. The hydrometer is generally inclosed (for convenience) in the glass tube of a syringe. With this arrangement sufficient electrolyte may be withdrawn from a cell, by suction, to float the hydrometer. The more dense the electrolyte, the higher the hydrometer will float. The higher number (1.300) will, therefore, be at

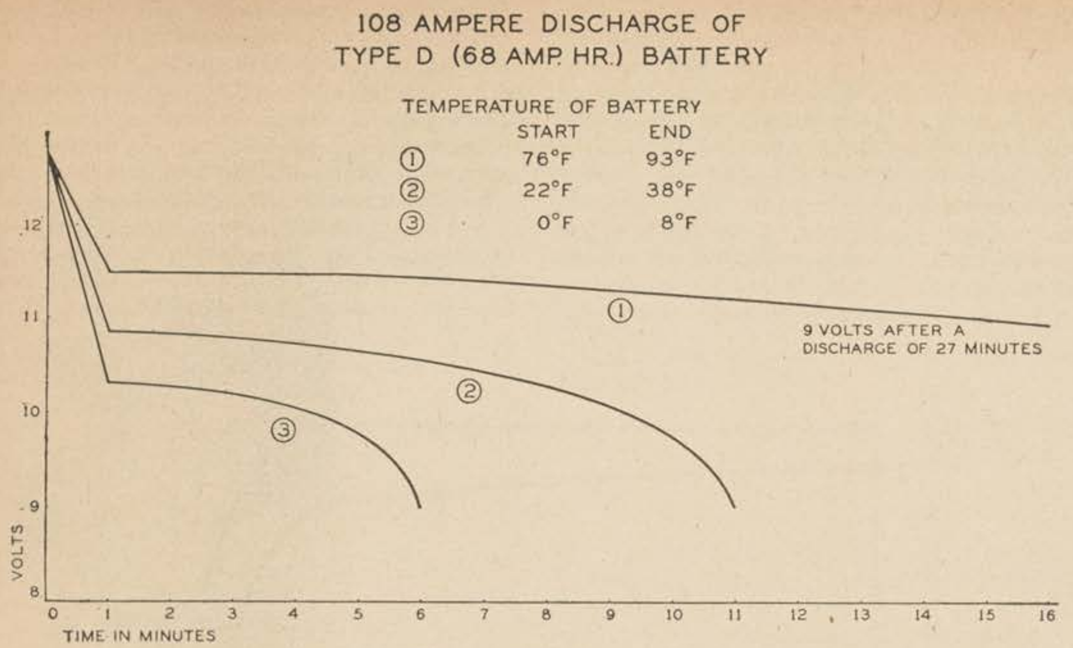


Figure 107. Effect of temperature on storage battery.

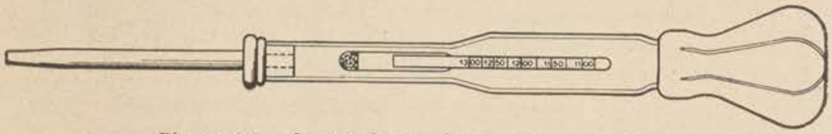


Figure 108. Storage battery hydrometer and syringe.

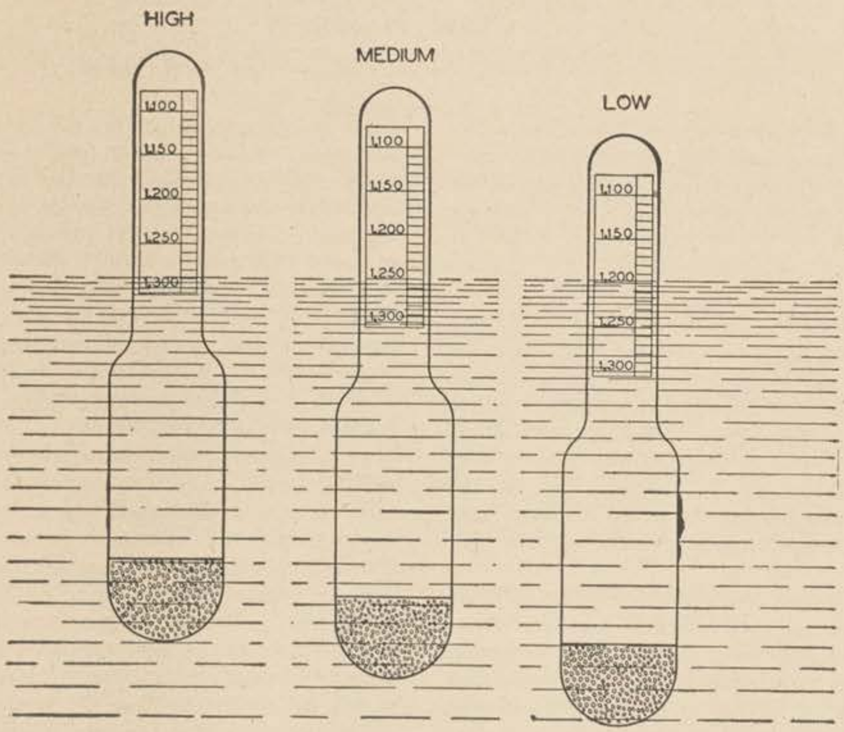


Figure 109. Specific gravity indications of hydrometer.

the lower end of the hydrometer scale. The scale value indicated at the level of the electrolyte is the specific gravity.

(3) Aircraft batteries are generally of small capacity but are subject to heavy loads. The values specified for state of charge are therefore rather high. An aircraft battery in a so-called "low" state of charge may have perhaps 50 percent charge remaining, but the charge is nevertheless considered low in anticipation of heavy demands which would soon exhaust it. A battery in such state of charge is considered in need of immediate recharging. With present aircraft storage battery specifications, a specific gravity reading between 1.275 and 1.300 indicates a high state of charge; of 1.250 a medium state of charge; and of 1.200 or below, a low state of charge (see figure 109).

Figure 110. Be careful when using acid.

(4) Hydrometer readings should not be taken immediately after, but before, adding distilled water to electrolyte. This precaution is necessary for the reason that some time is required for the water to mix thoroughly with the electrolyte; the hydrometer syringe might thus suck up a sample of electrolyte which is not representative of the electrolyte as a whole.

(5) Following testing, the sample of electrolyte should be returned to the particular cell from which it was drawn.

(6) Be careful when taking the hydrometer test of a lead-acid cell, inasmuch as sulfuric acid has a burning effect on clothing and skin (fig. 110). First aid treatment consists of thoroughly flushing with water. Bicarbonate of soda may be applied, but only after thorough washing with water.

c. (1) The high-rate discharge tester is used in bench testing to measure the terminal voltage of a cell while it is under load, (which is test under operating condition). The tester (fig. 111) consists of two heavy prongs (with handle) which are bridged by a thick nichrome shunt of low resistance. A voltmeter, mounted on the tester, is connected to the ends of the shunt so as to measure any potential difference created between them. The voltmeter is a zero-at-center instrument with a range of 2.5 volts in either direction, so that either tester prong may be placed on either terminal posts of a cell. When the ends of the prongs are pushed into the terminal posts of a cell, the resultant heavy current which passes through the nichrome shunt resembles an operating condition. The prongs are held in firm contact with the cell terminals for approximately 15 seconds. During this time the observed voltage should remain almost constant.

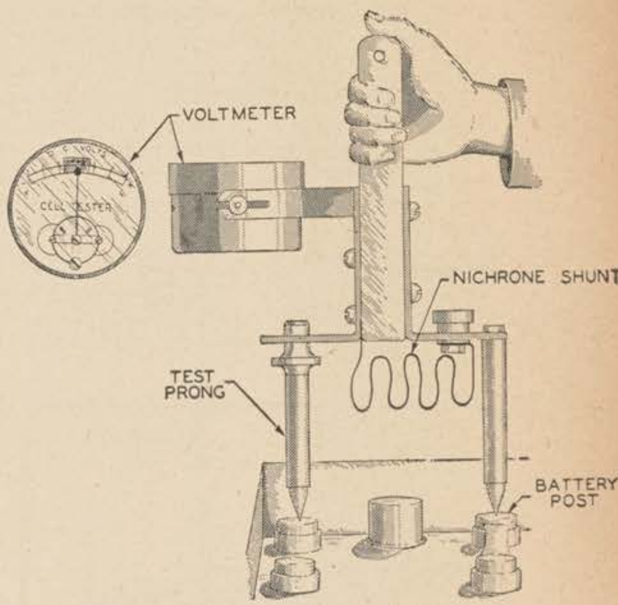


Figure 111. High-rate discharge tester.

(2) It must be remembered that the high-rate discharge test is strictly a comparative test. Since the voltage reading is affected by both the resistance of the shunt and the internal resistance of a cell, the test consists solely of a comparison between the performances of cells of equal ampere-hour capacity when checked with the same tester. In order that the test may accurately indicate the condition of a cell, the latter must be fully charged before the test is made. The observed voltage should then be compared with the average of the readings of a number of cells in good condition, fully charged, and each equal in capacity to the cell under test. If any cell of a battery shows a voltage which is more than approximately 0.2 volt below the average of the readings of the good cells of similar capacity, the cell may be considered to be internally deteriorated. In border-line cases, the general physical condition and history of the battery should be considered in deciding whether or not the battery should be discarded. For this reason, the high-rate discharge test is usually performed only by experienced persons.

(3) An alternate method of determining the condition of the individual cells is by loading the battery and measuring the voltage of the individual cell (fig. 112).

A cell whose reading is different from the rest indicates a poor cell.

61. BATTERY CHARGING. **a.** A storage battery may be charged by passing a direct current through the battery in a direction opposite to that of the discharge current.

b. (1) The voltage of the external charging source must be greater than the voltage of the battery. The e.m.f. of a 6-cell lead-acid battery is approximately 15.2 volts. When, however, a charging current flows through the battery, its voltage soon rises to a value of approximately 14.2 volts, known as the "gassing voltage." The

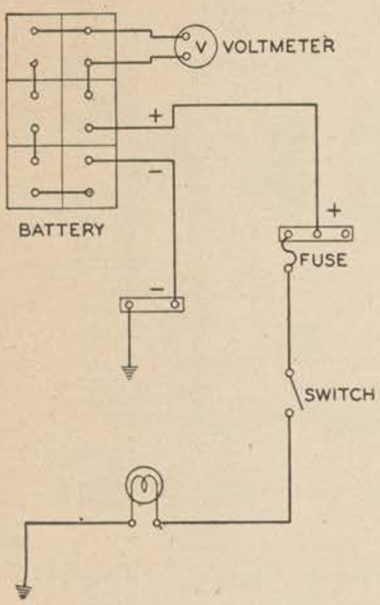


Figure 112. Battery load test.

explanation for this rise of 1 volt need not be given here, but its existence must be recognized. Therefore, to charge a battery normally rated at 12 volts, an external voltage of more than 14.2 volts is required.

(2) The value of the charging current depends on the net voltage in the circuit, which voltage is the amount by which the external voltage exceeds the battery e.m.f. If the two are equal, no current flows. To maintain a heavy charging current, the value of the external voltage need be only a fraction of a volt higher than the voltage of the battery because of the low internal resistance of the charging circuit.

(3) The charging current must always flow in the same direction. Hence, only d-c (and not a-c) may be used in the charging process. The respective terminals of the charging source must be connected to the like terminals of the battery. If incorrectly connected (if the value of the external voltage is below that of the battery) the battery would discharge through the intended charging source at a fast rate.

(4) The charging current, in amperes, should be adjusted to the ampere-hour capacity of the battery and to its state of charge. A battery with large heavy plates may be charged, without risk of damage to its plates, with a higher current than that which could safely be used with a battery having small thin plates. A battery in a low state of charge may be charged at a high beginning rate, and, as it approaches a fully charged state, the charging rate should be induced. If a battery in a low state of charge is charged at a slow rate, time is wasted. After a battery has reached a high state of charge, the continued application of a high charging current heats the cells and, further, causes the liberation of oxygen and hydrogen. (These gases form an explosive mixture). During charging, a small amount of "gassing" normally occurs. When the electrolyte violently gases, it is a sign of charging at an excessive rate, or completion of the process. During charging the temperature of the electrolyte should not be permitted to exceed 100° F.

(5) A battery is permitted to remain on charge until the specific gravity of electrolyte reaches normal value (1.275 to 1.300) and no increase in specific gravity is noted at three successive readings taken at 30-minute intervals.

c. Batteries are charged in battery rooms by either of two methods. By use of a motor-generator set (constant voltage), it is possible to start the process with a high current which automatically tapers off, reaching a value of approximately 1 ampere when a state of full charge is reached. When a tungar rectifier outfit (constant current) is used, the battery usually cannot be charged at a rate higher than 5 to 7 amperes. The current remains almost constant during the entire charging process. The constant-voltage method requires less time, and does not require much supervision. The constant-current method requires a longer time to charge a battery fully, and toward the end of the process care should be taken to avoid overcharging.

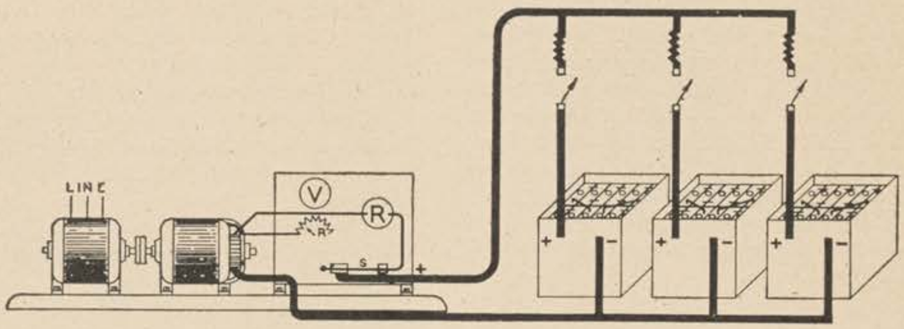
(1) The constant-voltage method uses a generator driven by an electric motor (fig. 113) or a gasoline engine (fig. 114). The output leads of the generator are connected to large copper bus bars, across which the batteries to be charged are shunted. The batteries are therefore connected to each other in parallel, and must have the same voltage rating. The potential difference between the bus bars is adjusted by means of a field rheostat to a value of 14.25 volts or slightly higher. Each battery automatically draws a current suited to its own ampere-hour capacity and in accordance with its state of charge. A battery of high ampere-hour capacity has a lower resistance than a battery of low capacity. A battery of high capacity draws a heavier charging current than a low capacity battery in an equal state of charge when both are subjected to the same charging e.m.f. As the state of charge of any battery increases, its voltage increases, the net voltage decreases, and the charging rate of the battery decreases. The initial charging current furnished to a battery in a low state of charge may be 30 to 50 amperes. The value of the charging current of any battery may be found readily at any time by switching an ammeter, provided for the purpose, into the battery circuit. When a battery reaches a fully charged state it may be permitted to remain connected to the bus bars without harm, for the charging current is then approximately 1 ampere.

(2) When the available electrical source is a-c, a tungar rectifier outfit may be used for battery charging

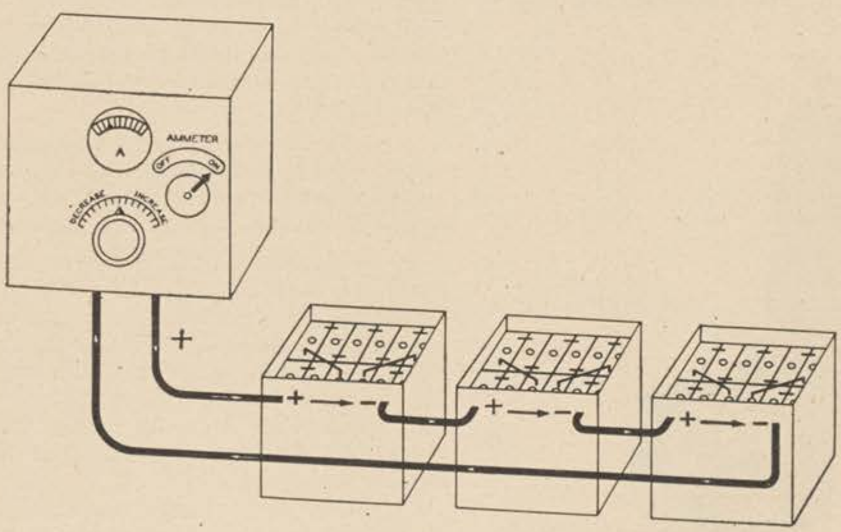
(fig. 113). This equipment includes a transformer to step down the line voltage and a tungar rectifier bulb, which converts the a-c into d-c, required for battery charging. The rectifier outfit may include two independent charging circuits, each separately controlled by transformer tap switches. Only batteries of equal ampere-hour capacity should be charged in one circuit at one time; whether they are 12- or 24-volt batteries is immaterial. As many batteries as desired may be connected in series (plus to minus) up to a total voltage not in excess of 84 volts (with most charging outfits) in one charging circuit. The charging rate (5 to 7 amperes) does not decrease to any great extent as the charging process goes on. The resistance in the charging apparatus is much greater than that of the batteries under charge. The voltage applied to the charging circuit must therefore be, from the start, some few volts above the voltage of the batteries in order to overcome this resistance. Therefore, the small increase in battery voltage as the batteries become charged produces little change in the net voltage in the circuit; and likewise, the decrease in internal resistance of the batteries produces little change in the total resistance of the circuit. As a result, the charging current remains substantially constant. The specific gravity of the batteries must be checked frequently, for some batteries will reach full charge sooner than others, and may be damaged as a result of overcharging if left in the circuit.

d. A storage battery in service in aircraft is charged by a constant-potential system, the voltage of the engine-driven generator being held constant by use of a voltage regulator. The generator voltage is predetermined and adjusted in accordance with the voltage of the particular storage battery to be used; the varying charging requirements of the battery are automatically satisfied.

62. MAINTENANCE. **a.** Aircraft storage batteries are of relatively low capacities to save weight. It is impracticable to repair an aircraft battery; therefore, it is replaced when it becomes unfit for further service. In an emergency, however, a defective cell may be replaced with a cell taken from another battery. To remove a cell, the connectors must first be removed. This is done by drilling into each end of the connector at the terminal post; use a drill slightly larger than the terminal post. The connectors can then be removed by prying between the connector and terminal nut with a suitable tool. The cell can be pulled after the sealing compound has been removed from the cell cover and cell jar. The plate



CONSTANT POTENTIAL CHARGING CIRCUIT



CONSTANT CURRENT CHARGING CIRCUIT

Figure 113. Two systems of storage-battery charging.

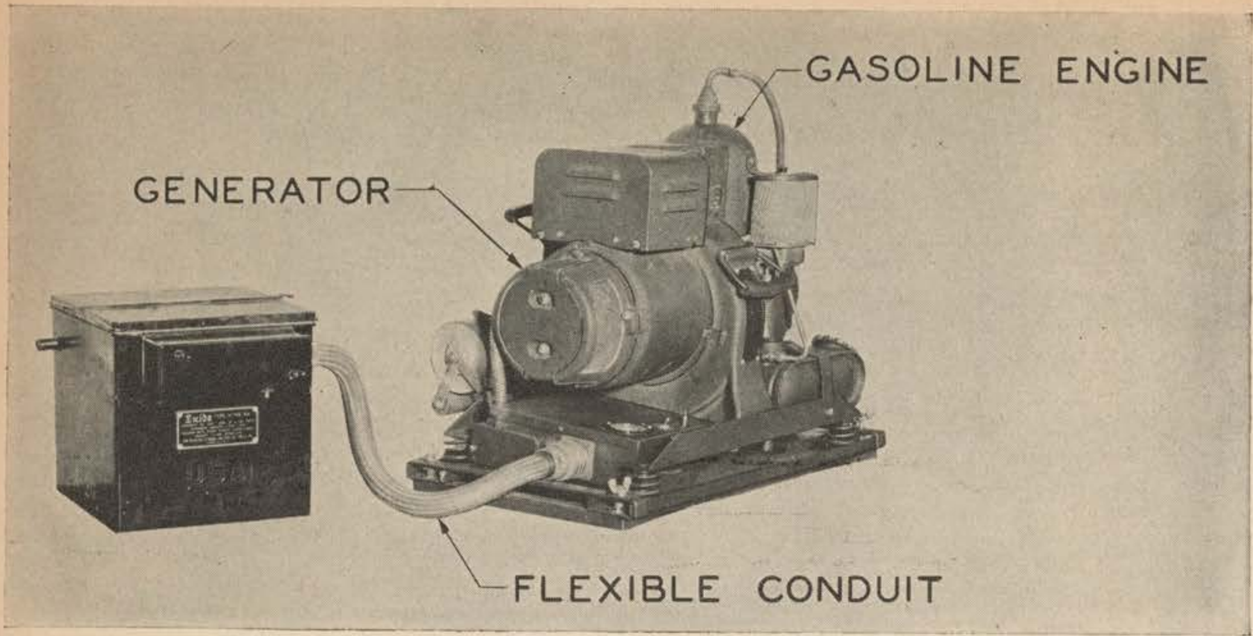


Figure 114. Constant-voltage method of battery charging using gasoline-engine-driven generator.

groups can then be separated by removing each terminal nut and pulling the positive and negative plates apart. When reassembling be sure to place a separator, grooved side toward the positive plate, between each positive and negative plate. In placing the cell back in the jar, the cell covers must be sealed by running hot sealing compound between the cell and jar (fig. 115). The terminals and connector can be reconnected by using a small torch to run the metal together. (***Caution:*** Whenever a flame is to be used near the battery, remove all explosive gases with an air blast.)

b. (1) Check the vent tubing and note the condition of the metal tubing that is used for protection of the rubber tubing; make a rigid inspection at bends where there is danger of pinching. The downward tubing outlet should be located where there is no danger of the vented electrolyte coming in contact with any part of the aircraft. Check the outlet to see that the slip-stream has not damaged the protruding tube-end. The vent tubing must be clear of obstructions; otherwise there might be dangerous accumulations of spilled electrolyte or battery gases. Battery cell-vent plug *holes* should be unobstructed.

Figure 115. Sealing a cell.

(2) Check the condition of asphalt-varnish coating whenever it has been applied to protect aircraft or engine surfaces from spilled electrolyte.

(3) If any electrolyte has been spilled on external parts of the battery or on nearby surfaces, corrosive effects may be neutralized by applying baking soda mixed with water to the consistency of a thin cream. Fresh applications should be repeated until all bubbling action has ceased. Following this, wash the battery with clear water and dry. The soda solution must not be permitted to enter any of the cells.

c. Check the security of terminal connections. The plain washer should be under the wing nut and the lock washer under the plain washer. Less corrosion results when the terminals are kept clean and tight.

d. At specified periods, check the state of charge of the battery with a hydrometer. Test each cell; if the specific gravity is 1.200 or below and all the cells are approximately the same, a normal discharged condition is indicated and the battery should be replaced. Regardless of state of charge, if the specific gravity of any cell differs appreciably from that of the remaining cells of the battery, a defective condition is indicated which requires battery replacement.

(1) After the hydrometer test, check the level of the electrolyte in each cell and add distilled water if necessary. The electrolyte level should be approximately 3/8 inch above the baffle plate.

(2) All cells in a battery should require about the same amount of water; if one cell requires much more than the others, examine the battery for leakage.

(3) Acid is never added to a cell to increase the specific gravity. Leakage may occur around the base of a vent plug which is not tight or may result from the addition of too much water.

(4) Regardless of hydrometer readings, if a battery does not hold its charge under normal service conditions or otherwise fails to function normally, it should be replaced.

e. (1) During low temperatures, it is absolutely necessary that the batteries be kept well charged or the electrolyte will freeze. Temperatures at which mixtures of sulfuric acid and water will freeze are as follows:

Specific gravity of electrolyte	*Freezing point (Fahrenheit)*
1.000 (pure water)	+32°
1.030	+26°
1.100	+19°
1.150	+5°
1.200	—16°
1.250	—62°
1.275	—85°
1.300	—96°

(2) If water is added to the battery during freezing weather, the battery should immediately be put on charge to mix the electrolyte. The water, being lighter than the electrolyte, will stay on top and freeze at a much higher temperature than the electrolyte.

f. When an aircraft is to remain idle for more than one week, the battery should be removed and returned to the battery room for proper maintenance.

GENERATORS AND REGULATOR SYSTEMS

63. GENERAL. In modern aircraft the generator is mounted on the engine and driven by the engine (fig. 116). The purpose of the generator is to supply the power for all the units of the electrical system. The generator also supplies the power to keep the battery fully charged. The electrical system of most aircraft is d-c in order that a battery can be used as a source of emergency power. The electrical systems of all earlier type and small aircraft is 12 volts. A new high-output system which maintains its voltage at 28 volts is known as a 24-volt system. Each system has its individual types of generators and control equipment. Table II gives the types of equipment used in each system. In this section particular attention is given to the latest equipment of 24-volt systems.

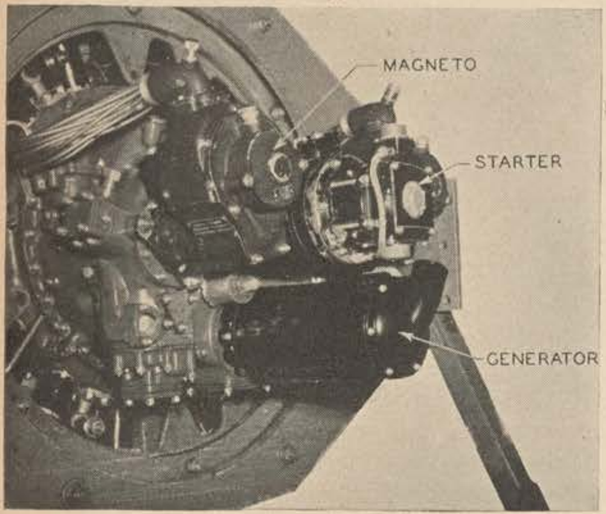


Figure 116. Generator mounted on engine.

64. CONSTRUCTION FEATURES OF AIRCRAFT DIRECT-CURRENT GENERATOR. Figures 117 and 118 show cross section views of generators used on 12 and 24-volt aircraft systems. The main features of the aircraft generators will be discussed in detail in the following paragraphs. Due to the fact that several manufacturers build generators for the Army Air Forces the designs vary somewhat. However, the general construction features are the same.

a. Armature assembly. The armature is made up of a steel shaft on which is mounted a laminated soft iron core, armature coils or windings, and a commutator (fig. 119).

(1) The armature core is made by stacking soft iron stampings on the armature shaft. The core is laminated to reduce eddy currents which produce undesirable heat (fig. 120). The laminations are placed side by side in such a manner that the slots line up. The slots are lined with insulating fish paper to protect the armature windings.

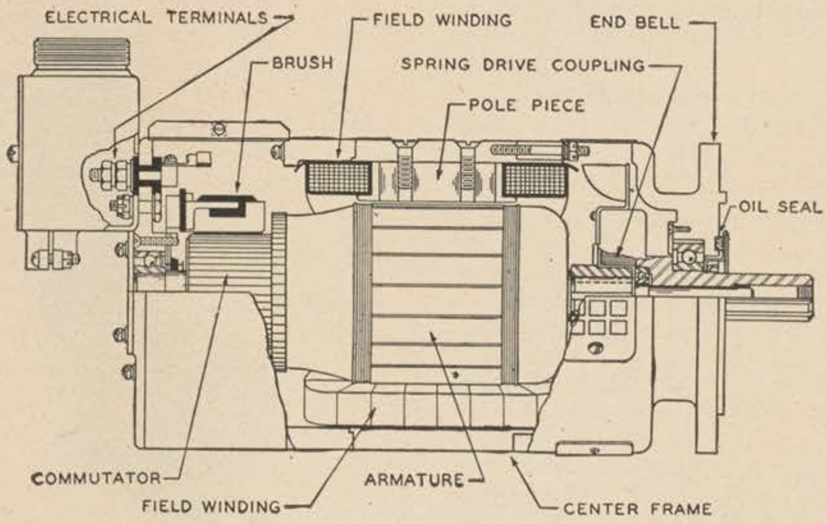


Figure 117. Sectional view of typical 12-volt or early model of 24-volt aircraft d-c generator.

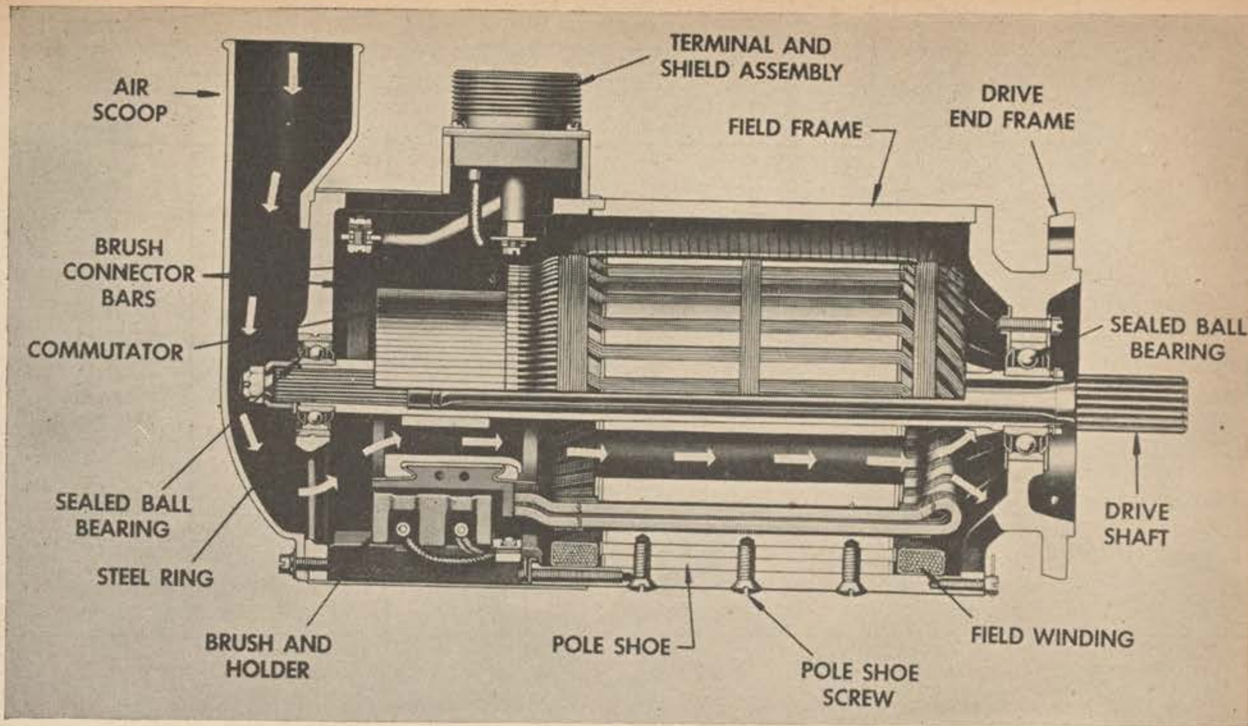


Figure 118. Sectional view of typical high-output 24-volt aircraft generator. (Courtesy of Delco-Remy Division, General Motors Corp.)

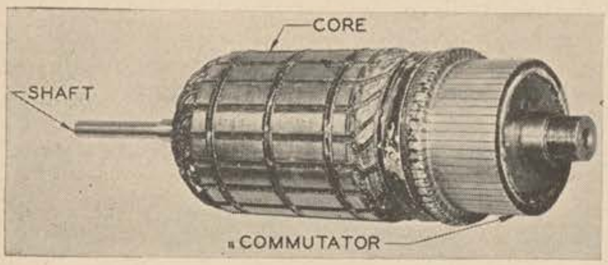


Figure 119. Generator armature.

(2) The armature windings are made of insulated copper wire and are wound in the slots of the armature core. The ends of the windings are brought out at the commutator end and connected to the commutator segments. Wedges, and in some models, steel-wire bands are used to keep the windings from flying out of the slots when the armature is driven at high speeds.

(3) The commutator consists of copper segments insulated from each other and the armature shaft with mica and held firmly in place with insulated wedge rings. The leads from the armature coils are soldered or otherwise secured into slots or risers of the commutator located next to the windings.

(4) The generator armature is coupled to the engine through a suitable splined shaft. In order to eliminate the violent twisting motions caused by the vibration of the engine, a shock-absorbing coupling is placed between the drive shaft and armature. In older styles, and in some recent types, a rubber or spring coupling is used. Some new high-output machines use a hollow armature shaft with an inter-shaft which drives the armature from the commutator end. The inter-shaft is small and takes up the shocks and vibrations by twisting.

b. Field-frame assembly. (1) The cylindrical steel or iron field frame serves as a mechanical support for the generator and also forms a part of the magnetic circuit connecting the poles (fig. 121).

(2) The *pole pieces* are rectangular in cross section and are fastened to the field frame. Figure 122 shows

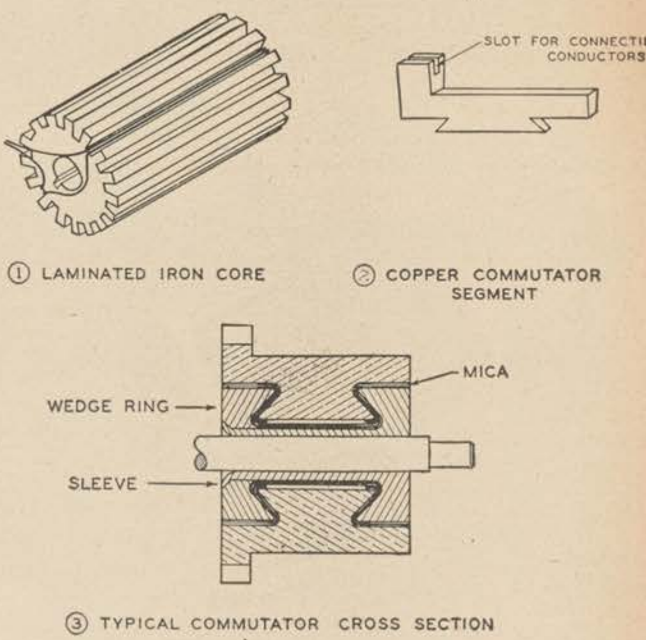


Figure 120. Armature and commutator construction.

Table II. Generator types

Type	Volts	Amps.	Flange Bolts	Speed Range r.p.m.	Control Equipment: Relay Volts[2]/Amperes	Control Equipment: Regulator[3] Volts	Control Equipment: Panel
E–5A	12	50	4	2,500/4,500	—	—	A–1
E–8	12	100	6	2,600/4,500	—	—	A–2a
E–10	12	100	4	2,600/4,500	—	—	A–2a A–2
L–1	24	25	6	2,600/5,000	—	—	B–1a B–1b
L–2	24	25	4	2,500/4,500	—	—	B–1a B–1b
L–3[1]	24	25	4	2,500/4,500	—	—	B–1a B–1b
M–1	24	50	6	2,600/4,500	—	—	B–1a B–1b
M–2	24	50	6	2,500/4,500	28/200	28	—
M–3	24	50	4	2,500/4,500	28/200	28	—
O–1	24	100	6	2,500/4,500	28/200	28	—
O–2	24	100	6	5,000/10,000	28/200	28	—
O–3	24	100	4	2,500/4,500	28/200	28	—
O–4	24	100	6	5,000/10,000	28/200	28	—
P–1	24	200	6	2,500/4,500	28/200	28	—
P–2	24	200	6	5,000/10,000	28/200	28	—
P–3	24	200	4	2,500/4,500	28/200	28	—
R–1	24	300	6	5,000/10,000	28/300	28	—

[1] Right hand rotation.
[2] Specification 94–32278.
[3] Specification 94–32276.

the magnetic circuit of a 4-pole generator. The complete magnetic circuit is made up of the armature core, pole, pieces, and field frame.

(3) Generators used on aircraft have either shunt or compound-wound fields. The shunt field winding is made of many turns of small wire. The compound generator has both a shunt field and a series field. The shunt field of a compound generator is wound similar to the shunt field of a shunt generator. The series field winding is made up of a fraction of a turn to a few turns of heavy wire on each field pole. The voltage of a compound generator is regulated by varying the shunt-field current. The series field is connected in series with the load and aids the shunt field in proportion to the load on the generator.

(4) Interpoles, which are used in some of the recent models of generators, are small poles placed between the main poles. The windings on these poles are connected in series with the load and must carry the entire generator current. The purpose of the interpoles is to improve commutation. They will be discussed in a later paragraph.

c. Brush assembly. (1) Generator brushes are usually small blocks of graphitic carbon which will give minimum wear of the commutator and yet be sufficiently hard to give long service. Each brush is provided with a flexible lead and terminal to permit a good electrical connection with the brush.

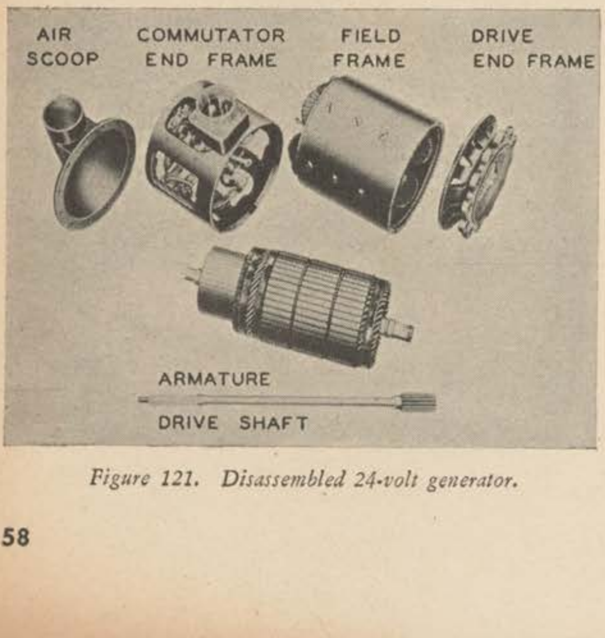


Figure 121. Disassembled 24-volt generator.

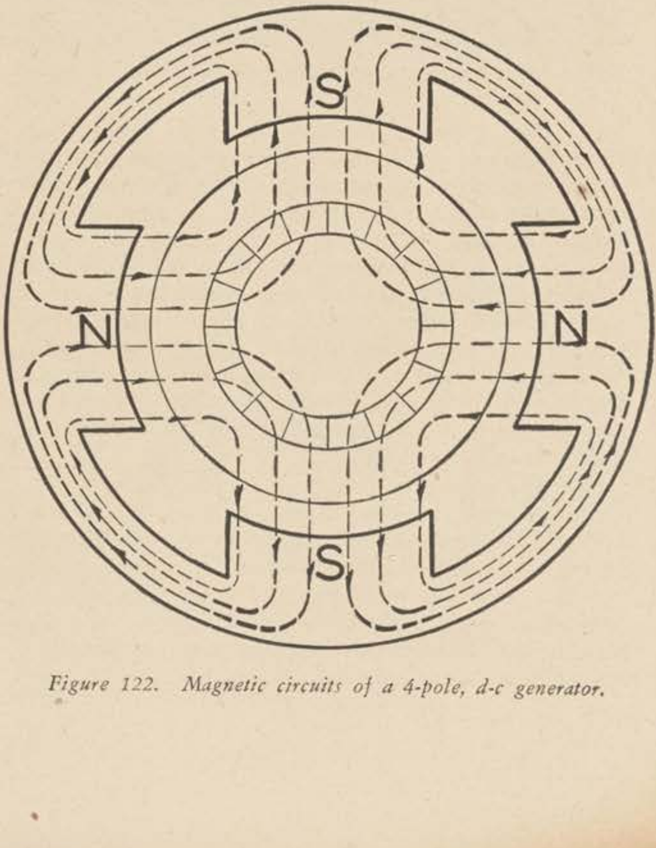


Figure 122. Magnetic circuits of a 4-pole, d-c generator.

(2) The brush slides freely in its holder to allow it to follow irregularities in the surface of the commutator and to permit it to make good contact with the commutator as the brush wears (fig. 123). A spring provides a constant pressure on the brushes to hold them against the commutator. The brush pressure should usually be approximately 6 pounds per square inch of contact area —see Technical Order covering the individual generator.

d. End-frame assembly. (1) The supporting frame at either end of the field frame (sometimes called field ring) is called an end frame.* The end frames contain the armature bearings, thus supporting the armature. On the commutator end, the end frame also forms a support for the brush holder. The terminal bolts on the 12-volt and early 24-volt models and the connector plug on the newer 24-volt models are mounted on the commutator end (fig. 124). The end frame is flanged on the drive-shaft end to permit mounting on the engine.

(2) The end frames are held in place with bolts extending through the field frame, or by studs screwed into the field frame. These bolts must be tightened securely or the bearings will be thrown out of alignment, permitting the armature core to drag on the pole pieces.

(3) The armature is mounted on ball bearings to give long life at high speeds and good performance under temperature extremes. These bearings are packed with grease at the factory and should not be lubricated between overhauls. They should be replaced at overhauls.

(4) The engine is equipped with an oil seal. Holes are provided in the mounting flange to allow oil leakage to escape without creeping into the generator.

* Manufacturers do not all use the same nomenclature when referring to sub-assemblies. The terms end shields, front housing, rear housing, commutator-end housing, etc., are used by some in referring to end frames.

65. ELECTRICAL FEATURES OF AIRCRAFT DIRECT-CURRENT GENERATORS. The generation of voltage by electromagnetic induction, residual magnetism, voltage build up, and the characteristics of different generators have been discussed in a preceding section. However, there are several other electrical characteristics which will be discussed in this paragraph.

a. Rating generators. (1) A generator is rated in power output (watts), that is, the number of amperes that the generator can safely supply at a specified voltage. The number of amperes that a generator can safely supply depends upon the amount of heat it can dissipate or radiate; therefore, to make possible high outputs, cooling ventilation is used as described in the following subparagraph.

(2) The most popular of ventilation or cooling devices are the air scoop, figure 121, and the forced-draft fan, figure 125, the air scoop being the most effective. It consists of a connecting tube from the air scoop to the generator armature, the generator being cooled by the air current created by the motion of the airplane. The forced-draft fan used on some generators may be mounted at either end of the armature shaft and forces cooling air through the generator (fig. 125).

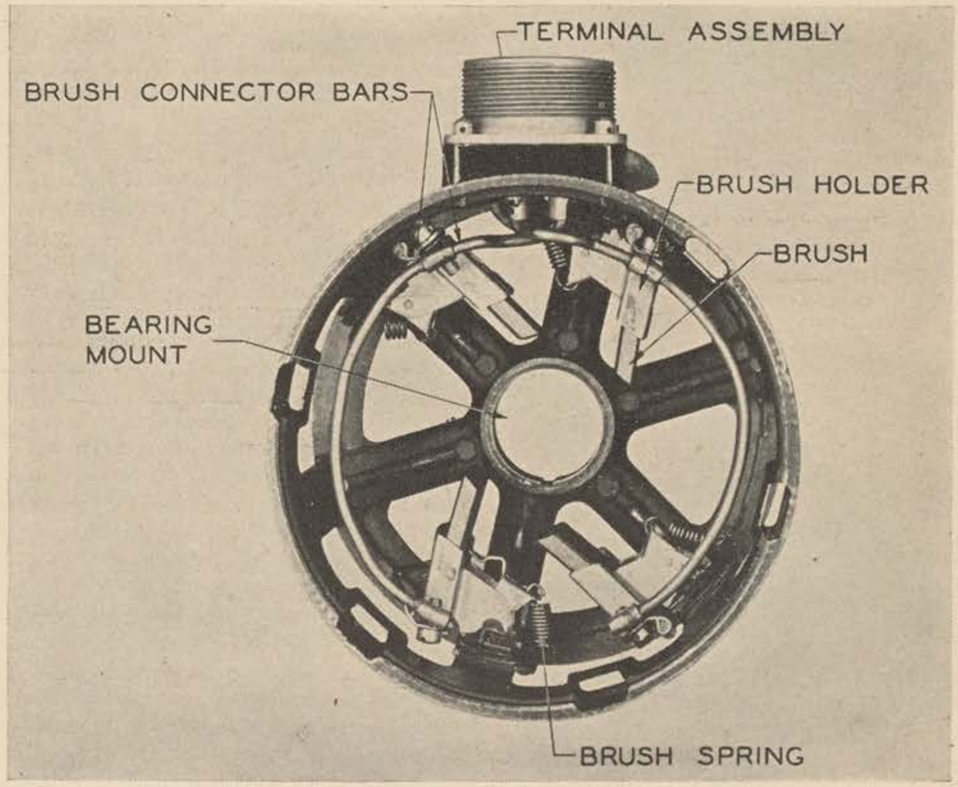


Figure 123. Generator end frame with brushes.

b. Types of armature windings. Armature coils are wound in a number of different arrangements. The two general types of windings are lap and wave windings. However, for all practical purposes the mechanic is not interested in the type of winding used. The procedure for testing and servicing the armature is the same in both cases.

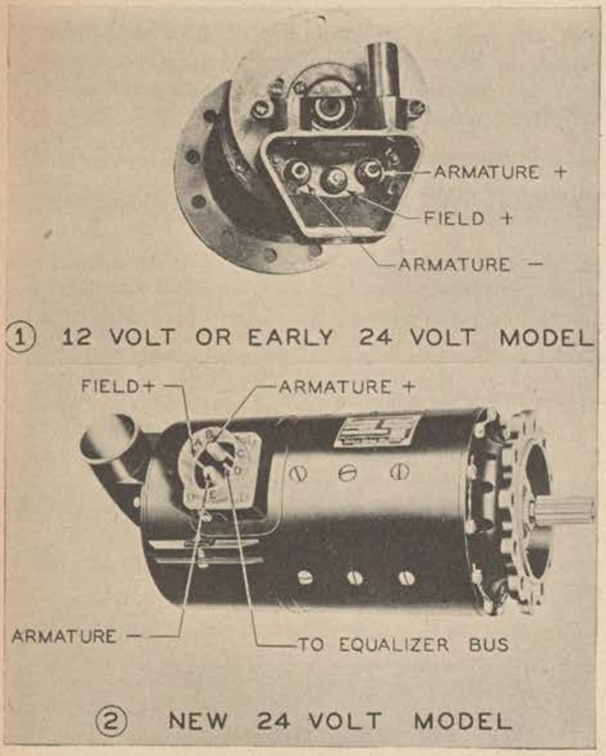


Figure 124. Terminal connections of 12- and 24-volt generators.

c. Brush location. The number and location of brushes will depend upon the number of poles in the field. In small low-output generators with 4 poles, 2 brushes, located 90° apart, are used. In higher output generators with four poles, 4 brushes are used, 2 positive

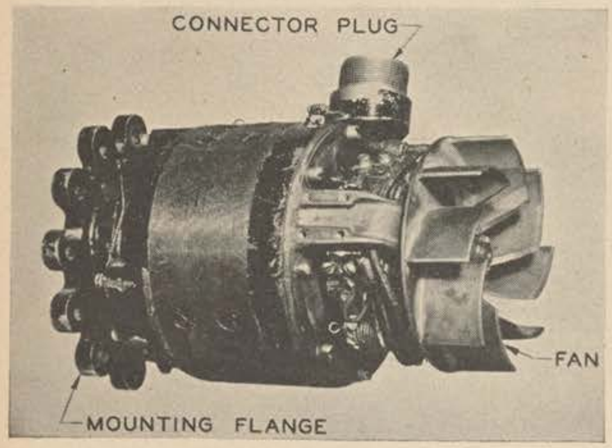


Figure 125. Generator showing cooling fan.

and 2 negative. In 6-pole generators, 4 or 6 brushes are used, located as shown in figure 126.

d. Field windings. (1) In the aircraft generator used on the 12-volt system, and on small 24-volt systems there are three terminal posts marked *A*+, and *A*—, and *F*+ (fig. 127). These letters stand for armature positive (*A*+), armature negative (*A*—) and field

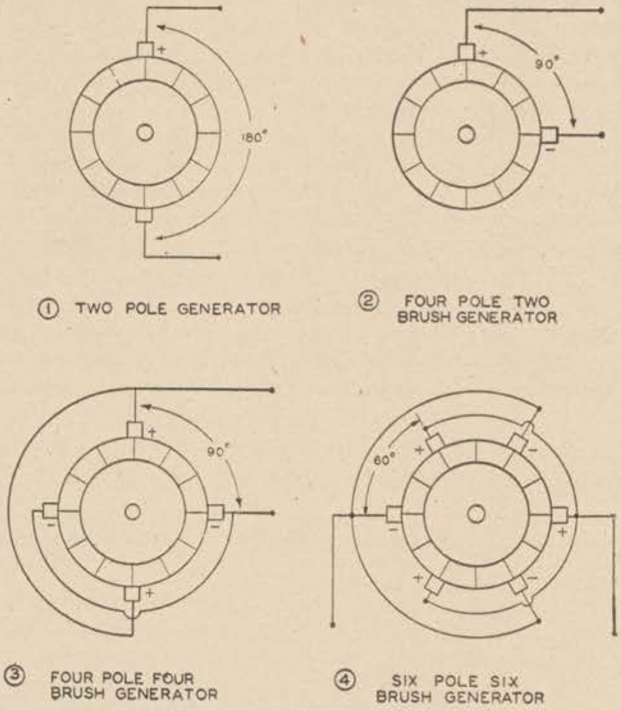


Figure 126. Brush arrangement on d-c generators.

positive (*F*+). The shunt field terminal *F*+ obtains its current from terminal *A*+ through a voltage regulator; the current then passes through the shunt-field coils and back to the armature through the negative brushes. In addition to this field current there is also the load current which leaves the armature through the positive brushes, passes through the series field coils (shown in heavy lines) to terminal *A*+ and after passing through the load returns to the generator armature through the *A*— terminal and the negative brushes. The current generated in the armature is accordingly the sum of the shunt current and the load current. The two field coils (shunt and series) wound on each pole carry current in the same direction and aid each other. If no series field were used, the positive brushes would be connected directly, through flexible leads, to terminal *A*+.

(2) In some large 24-volt generators, a connector plug has been used instead of connecting terminal (fig. 124), but connector terminals will be provided on future generators. The internal construction of small and large generators are similar, but different letters are used for the connections. Terminals *B*, *A*, and *E* in the large 24-volt generators correspond to terminals *A*+, *F*+ and *A*— in the 12-volt generator and types *L* and *M*—1, 24-volt generators. In addition to terminals *B*, *A*, and *E*,

two other terminals *D* and *C* are used. Terminal *D* is connected to *E* inside the generator and is used in the paralleling of two or more generators. However, in some of the early generators this connection was omitted and it became necessary to connect *D* to *E* inside the plug. Terminal *C* is used at the present in one generator, as a second field connection.

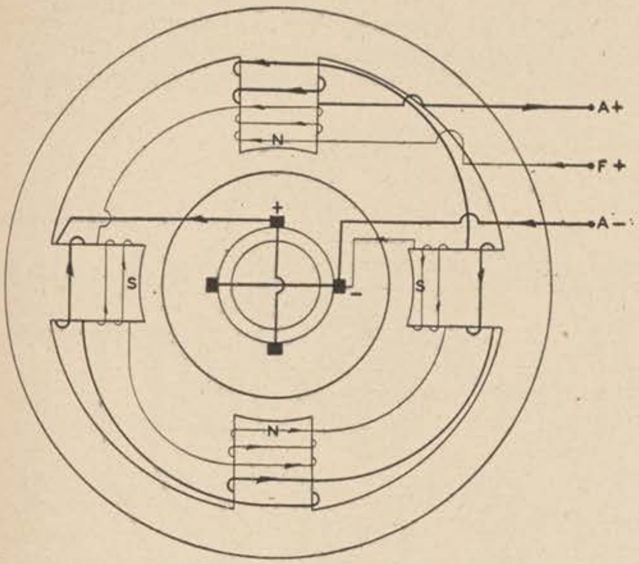


Figure 127. Compound-wound generator.

e. Distortion of magnetic field. (1) When the generator is in operation, the load and armature circuit are connected in series; thus all the current must pass through the armature. The armature conductors, therefore, are surrounded by electromagnetic fields, the strength of which varies with the load current. These added fields tend to distort the magnetic field furnished by the main field poles. This distortion becomes greater as the armature current increases (fig. 128).

(2) Because of field distortion, a voltage induced in the coils shorted by the brushes would result in sparking between the brushes and commutator segments, pitting of the commutator, and excessive brush wear. Thus, the output of the generator would be reduced. To correct this condition, the brushes must be set at such a position that the plane of the coils which are shorted by the brushes is perpendicular to the distorted magnetic field. Therefore, the brushes are moved forward in the direction of rotation. This is referred to as shifting the brushes to the neutral plane or plane of commutation. On some generators, the brushes may be shifted manually as desired. On non-adjustable generators the manufacturer sets the brushes for minimum sparking at $2/3$ to $3/4$ full load (fig. 129).

(3) Interpoles may be used to counteract some of the effects of field distortion, as shifting the brushes in inconvenient and unsatisfactory, especially when the generator speed and load are changing constantly. The magnetic strength (and therefore the corrective influence) of the interpoles varies with the load on the generator. This is ideal, because the field distortion varies with the load. In the generator the polarity of the interpole should be the same as that of the next main pole in the direction of rotation. The interpole is so located that the flux produced causes the current in the armature to change direction as the conductors pass under it. This fixes the neutral plane in one position for all loads on the generator. By the use of interpoles, the efficiency, output, and service life of the brushes and commutator are improved (fig. 130).

66. REGULATION OF GENERATOR VOLTAGE.

a. General. Since most electrical circuits are designed to operate within a definite range of voltage, it is important to keep the voltage constant. In aircraft, the generator is operated at variable speeds and variable loads. In order to maintain the voltage constant under these conditions, automatic voltage regulators have been devised.

b. Principle of field regulation. (1) The voltage output of a generator depends upon three factors:

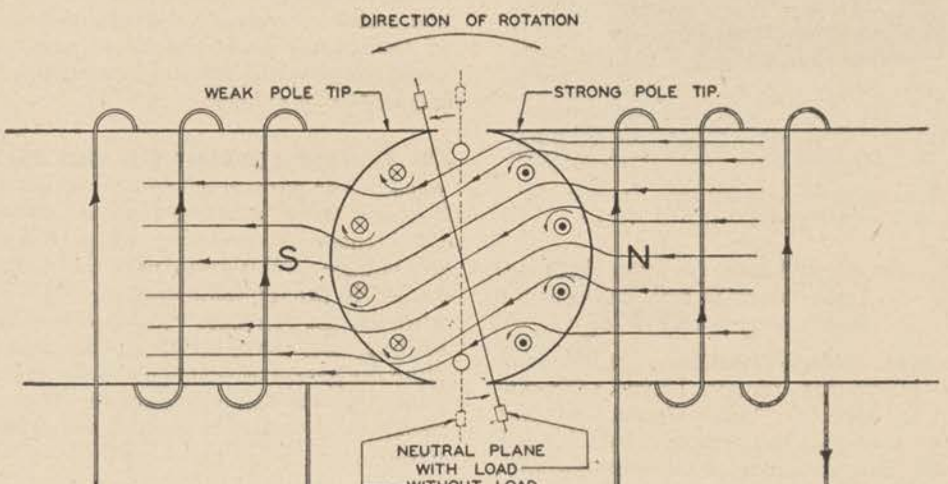


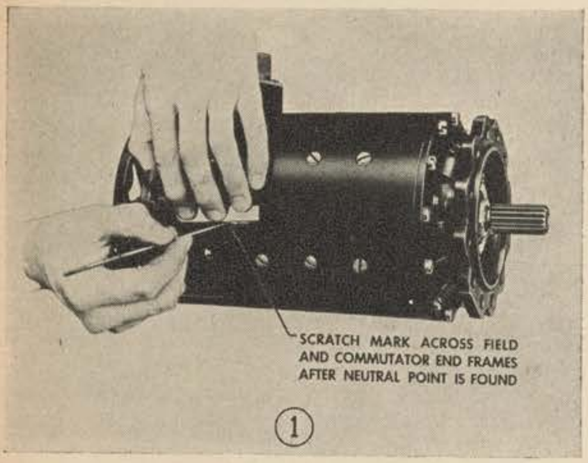
Figure 128. Magnetic field distortion and rotation of neutral plane.

(*a*) The number of armature conductors connected in series.

(*b*) The speed of the rotating armature.

(*c*) The strength of the magnetic field. The strength of the magnetic field depends upon the number of ampere-turns (ampere × turns) of the field windings, and since the number of turns of wire in the field is fixed, the current sent through the windings is regulated to control the terminal voltage of the generator.

(2) Figure 131 is a simple diagram which illustrates the principles involved in voltage regulation. If the



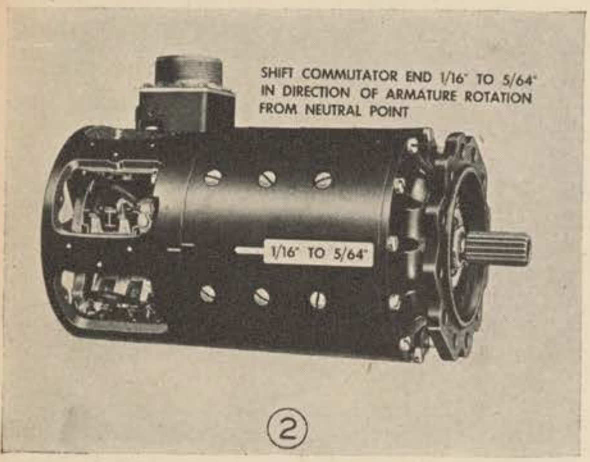


Figure 129.—Delco-Remy brush adjustment. (Courtesy of Delco-Remy Division, General Motors Corp.)

field-circuit resistance is increased (as by a rheostat), the field current decreases, which in turn decreases the field strength and lowers the generated voltage.

c. Vibrator-type voltage regulator. (1) A simplified vibrator-type voltage regulator (figure 132) consists of a coil of fine wire (*V*) wound around a soft iron core; two contacts (*C*), one mounted on a movable soft iron arm and the other stationary; a helical spring (*S*); and a resistor (*R*). The voltage winding (*V*) is connected across (in parallel with) the generator terminals, *A*+ and *A*— and the resistor is connected across the contact points.

(2) When the generator is not operating, the spring holds the contact points closed. As the generator comes up to speed, current flows directly from the *A*+ terminal to the *F*+ terminal through the closed contact points. As the voltage rises, the current through *V* increases, and its iron core becomes more strongly magnetized. When the magnetic attraction on the movable arm becomes strong enough to overcome the spring tension, the contact points are separated. The field current must now flow through the resistor, and because of the resistance added to the field circuit, the current in the field circuit

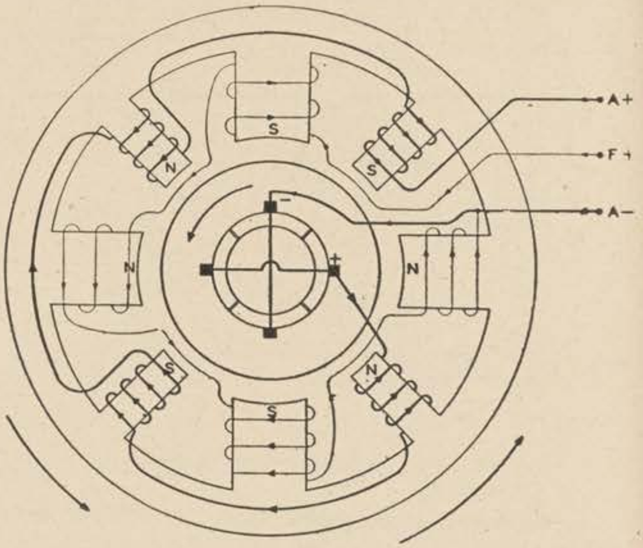


Figure 130. Generator with interpoles.

decreases. The magnetic field of the generator therefore is weakened and the pull of the magnetized core decreases, and the spring closes the contacts. As a result, the field strength and the generated voltage rise again. This cycle of events occurs over and over again, the points opening and closing many times per second. The terminal voltage of the generator rapidly varies above and below an average value determined by the tension of the spring, which may be adjusted. The vibrating voltage regulator is used on 12-volt systems and on low-output 24-volt systems.

67. REVERSE-CURRENT CUT-OUT RELAY. a. Purpose. The purpose of the reverse-current cut-out relay is to disconnect the battery automatically from the generator whenever the generator voltage is less than the battery voltage. If this device were not used in the generator circuit, the battery would discharge through the generator whenever the generator was not operating. This would tend to make the generator operate as a motor, but because the generator is coupled to the engine it could not rotate. Under this condition the generator, generator wiring, or both may be severely damaged and a fire may result.

b. Construction. In figure 133 a reverse-current cut-out relay is shown as a part of a simple generator-battery system. There are two windings on the soft iron core. The current winding *CW*, which is in series with the line and must carry the entire generated current, consists of a few turns on heavy wire. The voltage winding *VW* consists of a large number of turns of relatively fine wire, and is shunted across the generator leads. The two coils are wound on the core in the same direction. The movable arm carries a pair of contact points *C* which normally are held open by a spring *S*.

c. Operation. When the generator is not operating, the relay contact points are open so that the battery does not discharge into the generator even if the main line switch is left closed. As the generator voltage builds up, the voltage winding of the cut-out relay magnetizes the iron core. When the generated voltage produces sufficient magnetism in the iron core, it attracts the movable arm, thus closing the contacts *C*, and the generator begins to charge the battery. The coil spring is so adjusted that the voltage winding will not close the contact points until the voltage of the generator is at a value such as to be in excess of the normal voltage of the battery. The charging current passing through the current winding of the cut-out relay aids the voltage winding in holding the points tightly closed. When the generator

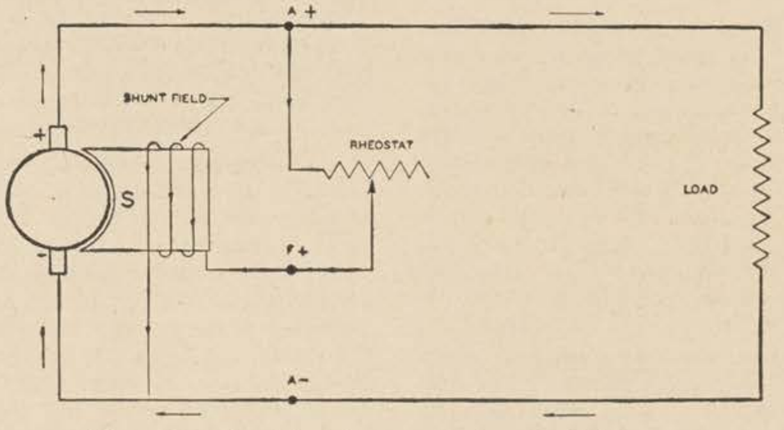


Figure 131. Regulation of generator voltage by field rheostat.

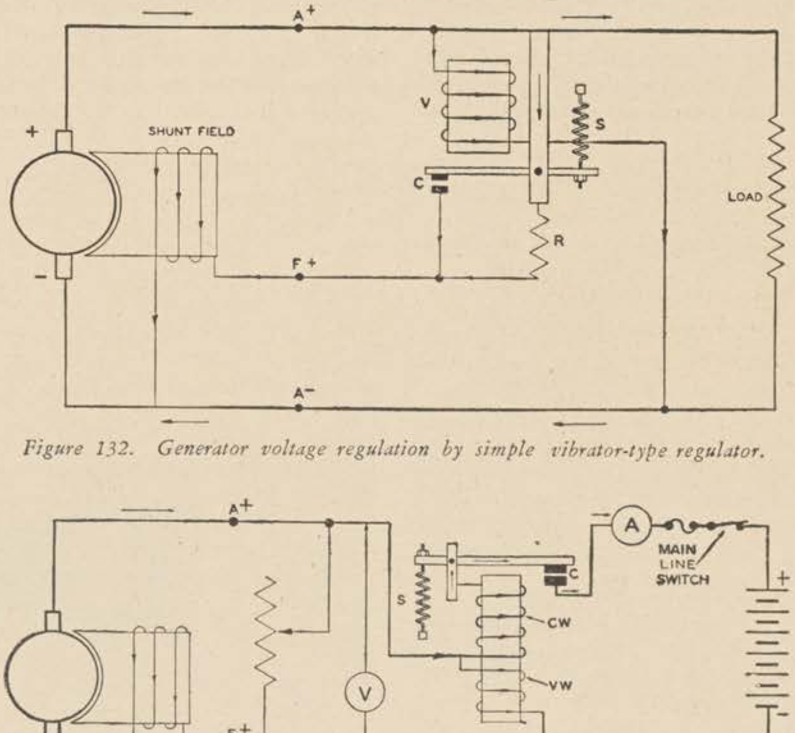


Figure 132. Generator voltage regulation by simple vibrator-type regulator.

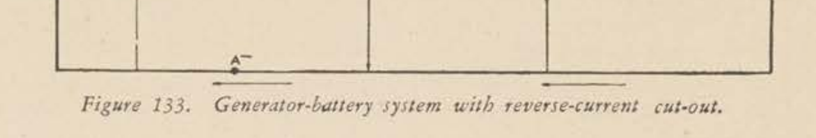


Figure 133. Generator-battery system with reverse-current cut-out.

slows down, or for any other cause the generator voltage decreases below that of the battery, the current from the battery flows through the current winding in such a way as to tend to produce magnetism of opposite polarity. This tends to counteract the magnetizing influence of the voltage winding, reducing the magnetism of the core. Therefore, the contacts are opened by the spring, and the circuit between the battery and the generator is broken. During normal operation, the contact points do not open until the reverse current has reached a value of 5 to 10 amperes.

68. GENERATOR 12- AND 24-VOLT CONTROL PANELS. **a.** Generator control panels are usually referred to as two-unit or three-unit control panels. A two-unit control panel may consist of a vibrating-type voltage regulator and a reverse-current cut-out mounted on the same panel. Figure 134 is a top view of a 12-volt, two-unit control panel. A simplified diagram of a single-engine generator circuit with a two-unit control panel is shown in (fig. 134 ②). A simple wiring diagram for use in circuit analysis (fig. 134 ③). This panel is adjusted to regulate the voltage at 14.25 volts and to connect the generator to the battery at 13.5 volts.

b. Early 24-volt systems also used a two-unit control panel with L type and M–1 type generators. The operating principle of the 24-volt vibrating voltage regulator is similar to that of the 12-volt system; however, some refinements have been added. The Leece-Neville 24-volt panel has an extra set of points. These points short out the field when a very low average value of field current is required to maintain the voltage constant. Figure 135 shows a typical 24-volt vibrating regulator, type B–1A. Type B–1B, 24-volt, control panel has a carbon-pile voltage regulator element. (See paragraph 70b (2) for principle of operation.)

69. VIBRATOR-TYPE CURRENT LIMITER. **a. Purpose.** The purpose of the vibrator current limiter is to limit the current of the generator automatically to its maximum rated output. This device will protect the generators.

b. Construction. The construction of the current limiter is similar to that of the voltage regulator except that the actuating coil is in series with the main line. Thus, the amount of current flowing in the line is the determining factor in the operation of the limiter, instead of the voltage across the line, as in the case of the voltage regulator. The coil consists of several turns of large wire, since it carries the entire line current.

c. Operation. In figure 136 a vibrator-type current limiter is shown as part of a simplified wiring diagram of a three-unit control panel. The spring S_2 holds the contact points C_2 together until the current through the main line and series winding *SW* becomes excessive, magnetizing its iron core to such an extent that the magnetic pull on the movable arm overcomes the tension of the spring, and opens the contact points. This inserts resistor R_2 into the field circuit of the generator, decreasing the field current, the strength of the magnetic field, and the generated voltage. With decreased voltage the generator current is reduced. The iron-core regulator is therefore partly demagnetized, and the spring closes the contact points. This causes the generator voltage and current to rise, until the current reaches a value sufficient to start the cycle again. The spring may be adjusted to limit the current to any desired value

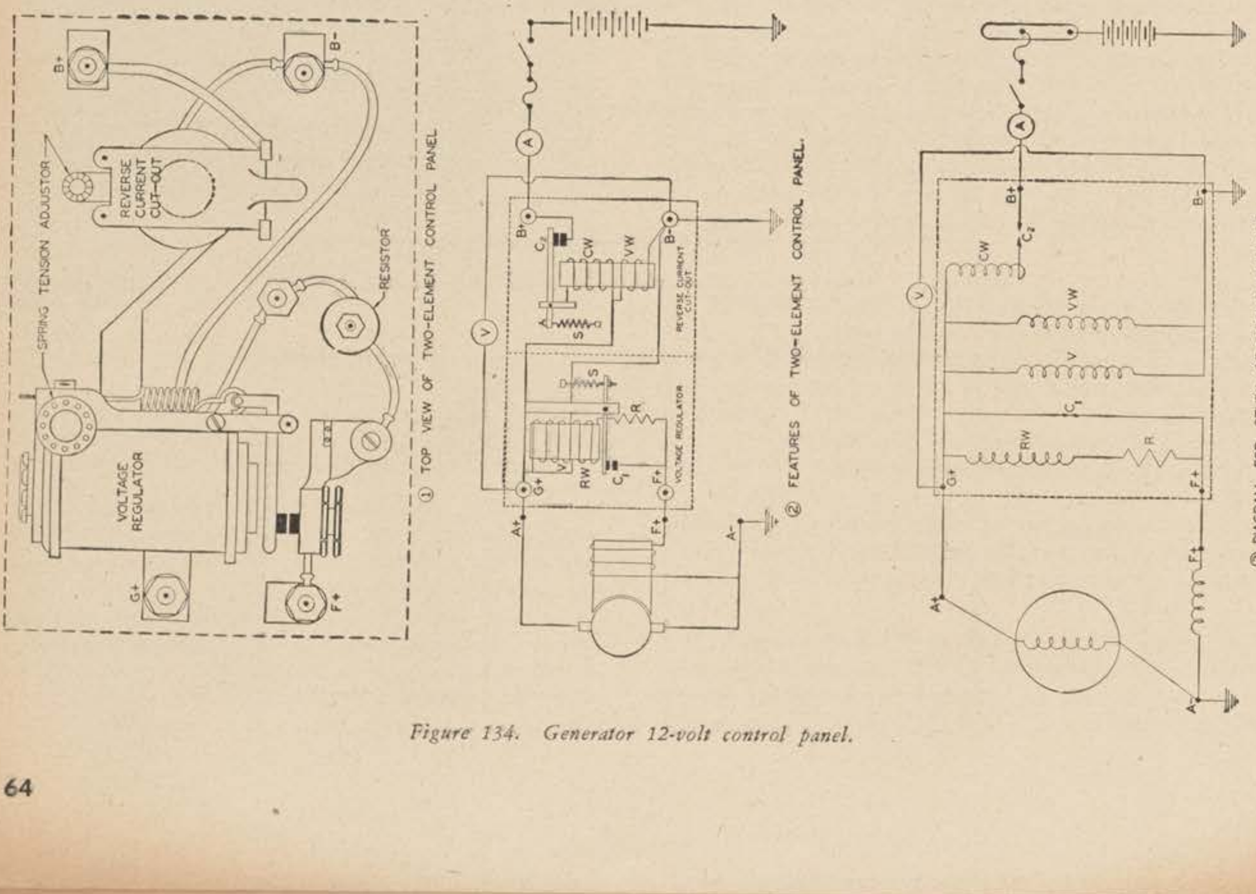


Figure 134. Generator 12-volt control panel.

within the rating of the limiter. In other respects, the three-element control panel is similar to the two-element panel.

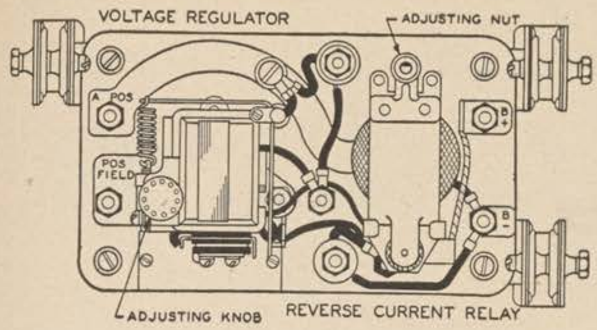


Figure 135. Generator 24-volt control panel (B–1A).

70. PLUG-IN MODELS OF 24-VOLT VOLTAGE REGULATORS. a. General. In late models of aircraft using the high-output 24-volt system, the voltage regulator and generator reverse-current relay switch are installed as separate units. The voltage regulator plugs into a standard panel socket or sub-base, so that it may be easily removed for inspection or replacement. The plug-in models are designed to control the voltage of generators with an output of several hundred amperes at 28 volts, and to provide regulation over a wide range of generator speed and load (fig. 137).

b. Operating principles of field-rheostat voltage regulator. The automatic field-rheostat type voltage regulator does not use the vibrating contacts as discussed in paragraph 66. One type of field-rheostat regulator works on the principle of shorting out portions of a tipped resistor (fig. 138). The General Electric and

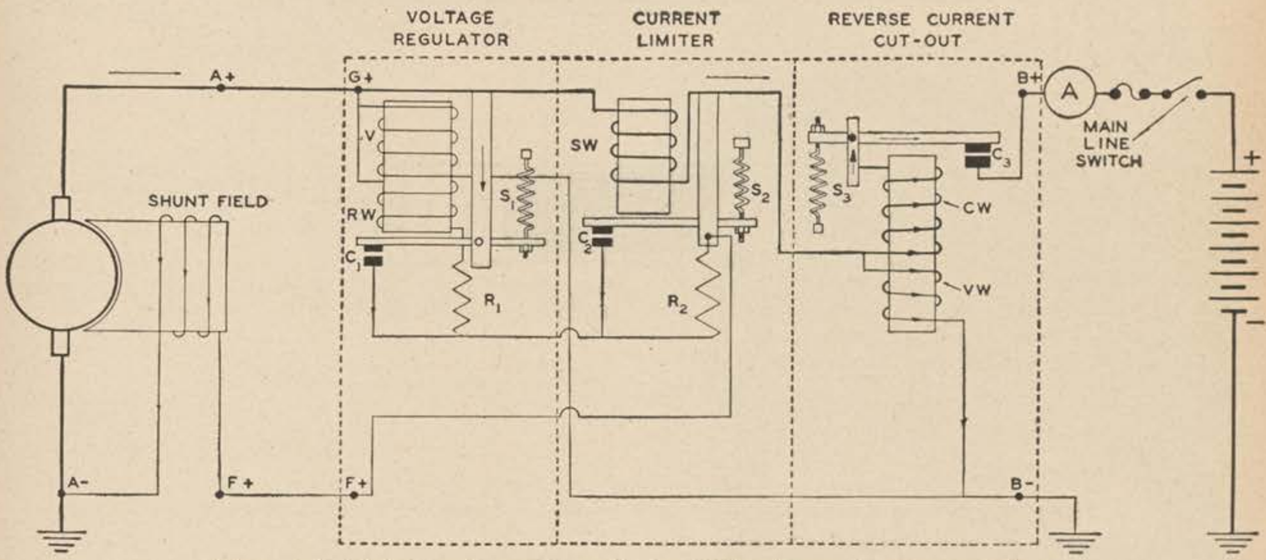


Figure 136. Typical 3-unit control panel using both voltage and current regulation.

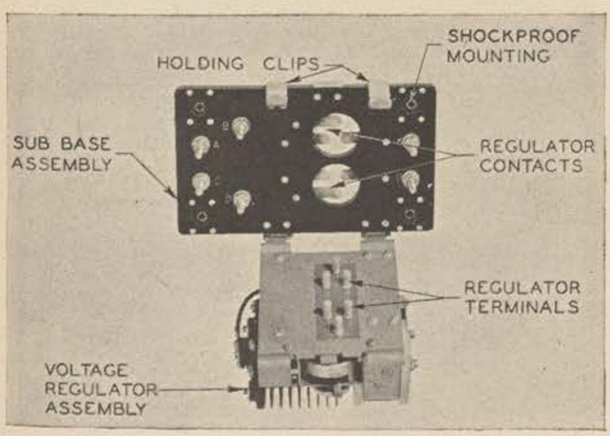


Figure 137. Voltage-regulator sub-base with regulator partially removed.

Westinghouse regulators operate on this principle. Another popular type regulator uses the variable resistance of a carbon pile. A stack of carbon disks have a resistance which varies with the mechanical pressure forcing them together. The greater the pressure the less the resistance (fig. 139).

(1) *Tapped resistor voltage regulator.* Two makes of tapped resistor regulators are used by the Army Air Forces, Westinghouse and General Electric (figs. 140 and 141). The principal difference between the two is in the arrangement of the contacts. Both have the voltage of the generator applied to an electromagnet which is fitted with a movable regulating arm and balanced by a calibrated spring. Whenever the generator voltage is below normal, the resistance of the resistor is short circuited through the contact leaves or fingers. As the voltage rises to normal, the electromagnet causes the movable armature to open some of the contacts thus adding resis-

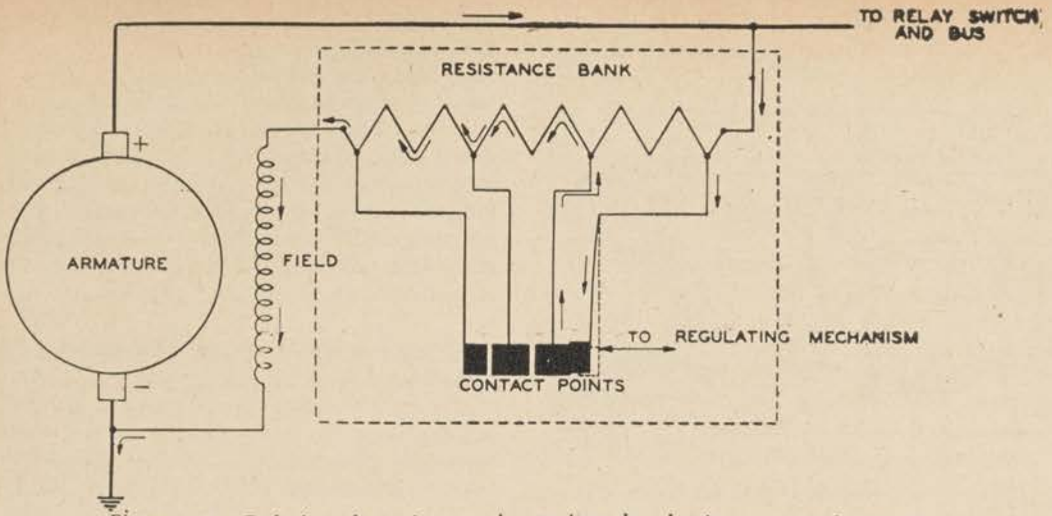


Figure 138. Reducing the resistance of a resistor by shorting-out tapped portions.

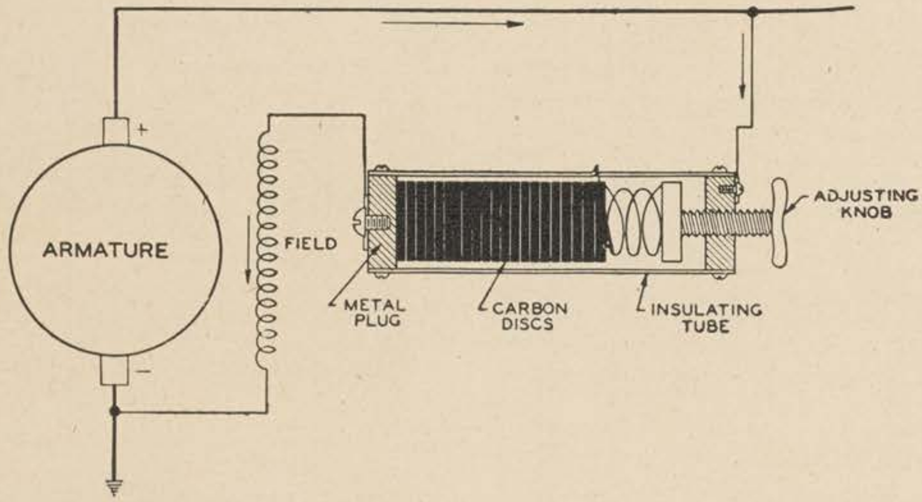


Figure 139. The resistance of a carbon pile reduces with increased mechanical pressure.

Figure 140. Westinghouse 24-volt voltage regulator.

Figure 141. General Electric 24-volt voltage regulator.

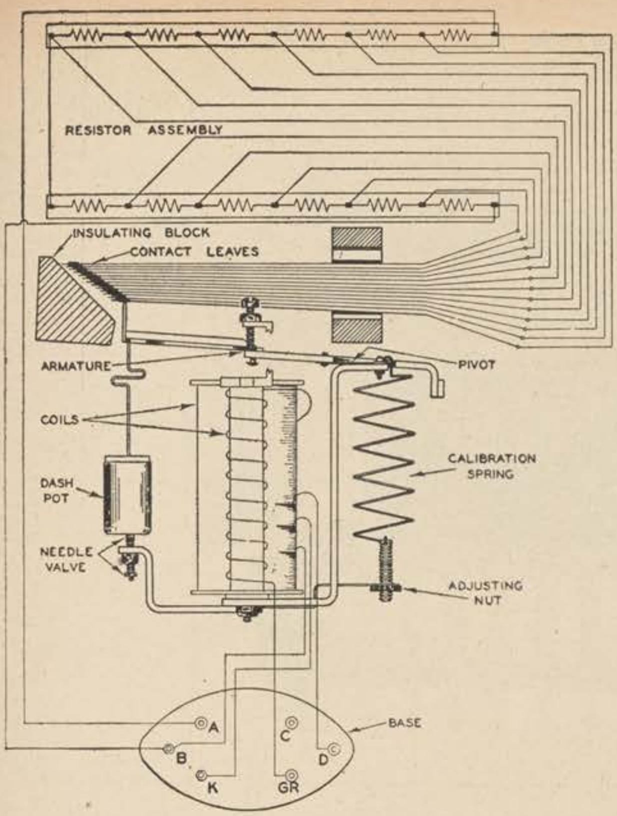


Figure 142. Detail drawing of Westinghouse 24-volt voltage regulator showing internal circuits.

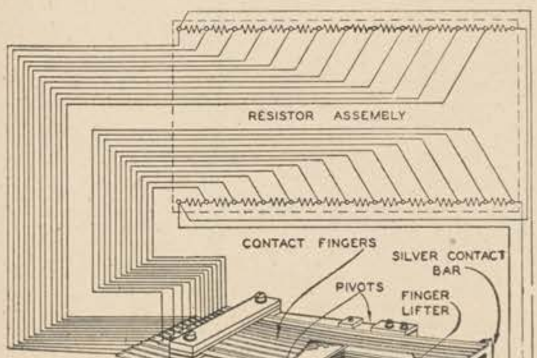


Figure 143. Detail drawing of General Electric 24-volt voltage regulator showing internal circuits.

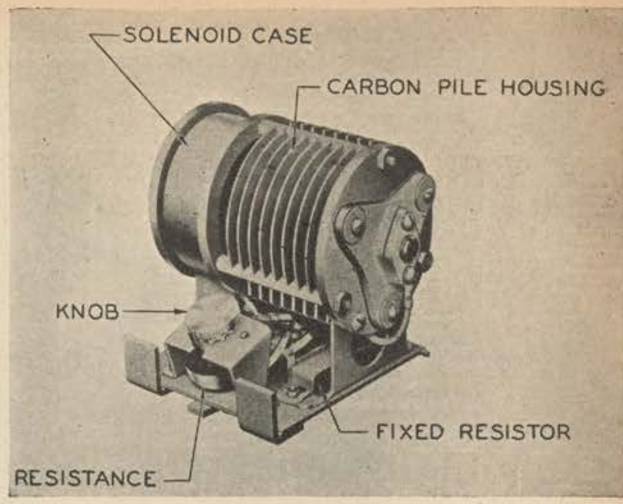


Figure 144. Delco-Remy 24-volt carbon-pile voltage regulator.

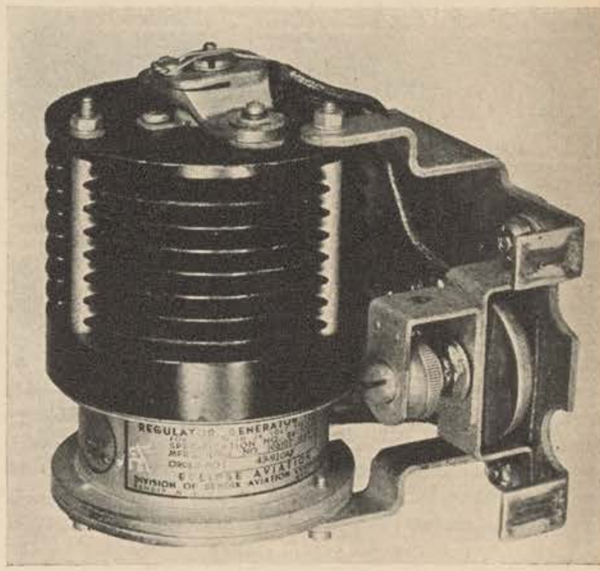


Figure 145. Eclipse 24-volt carbon-pile voltage regulator.

tance to the field circuit. To adjust the voltage of the generator system the tension of the spring is increased or decreased to correspond to the desired voltage. The detailed construction may be seen in figures 142 and 143.

(2) The carbon-pile voltage regulator. The carbon-pile voltage regulator also is used by the Army Air Forces (fig. 144). The Delco-Remy, Leece Neville, and Eclipse are of this type and are similar in construction (fig. 145). General Electric and Westinghouse also will soon produce carbon-pile-type voltage regulators. In the Delco-Remy carbon-pile regulator, a group of approximately 20 carbon disks and 21 graphite disks are alternately placed in an insulating ceramic tube inside of the carbon-pile housing which is fitted with fins to radiate the heat. A solenoid arrangement regulates the pressure of a spring on one end of the carbon disks (fig. 146). An insulated plate and adjusting screw which makes a contact with the carbon-pile is mounted on the

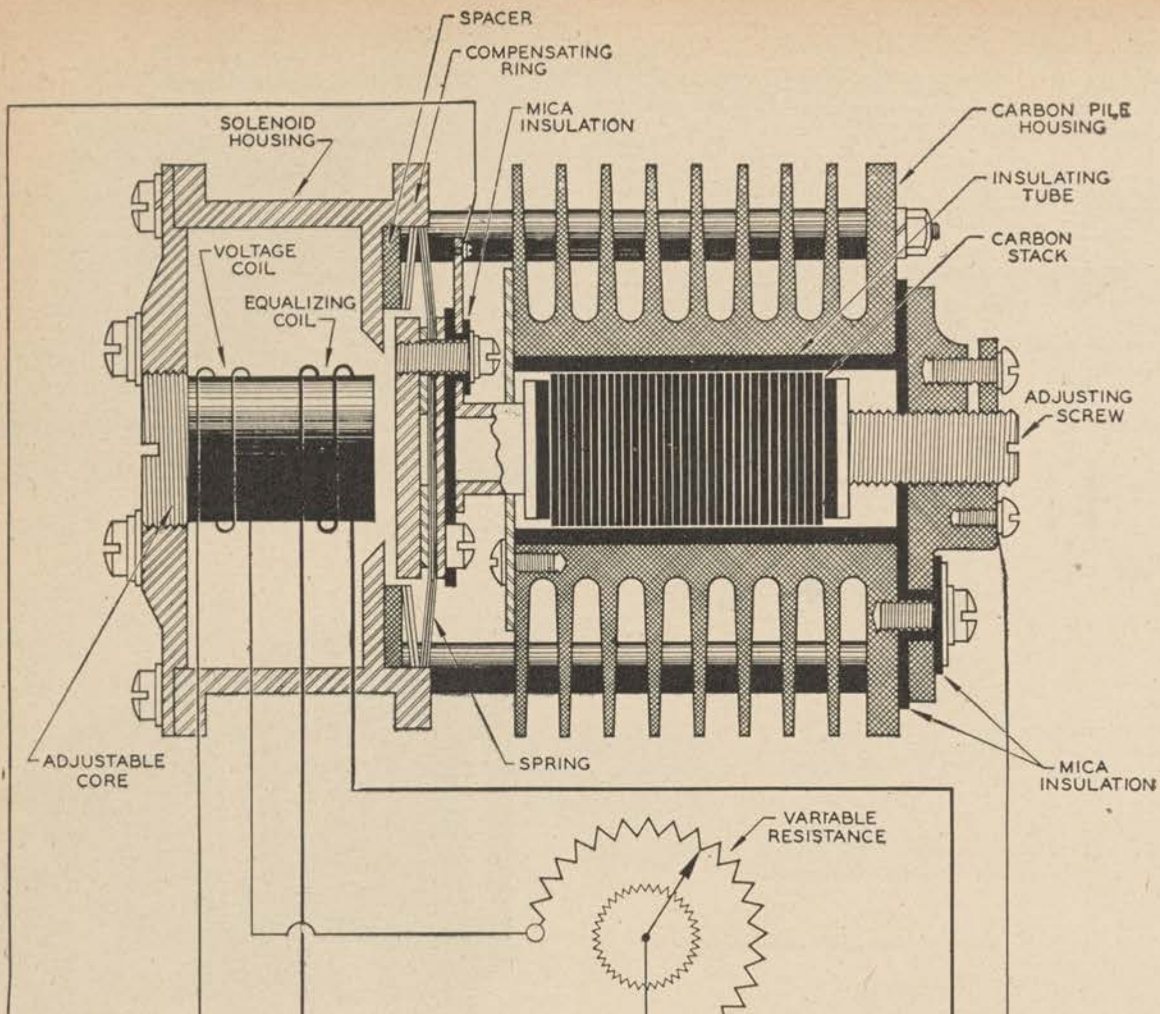


Figure 146. Detail drawing of Delco-Remy 24-volt voltage regulator showing internal circuits.

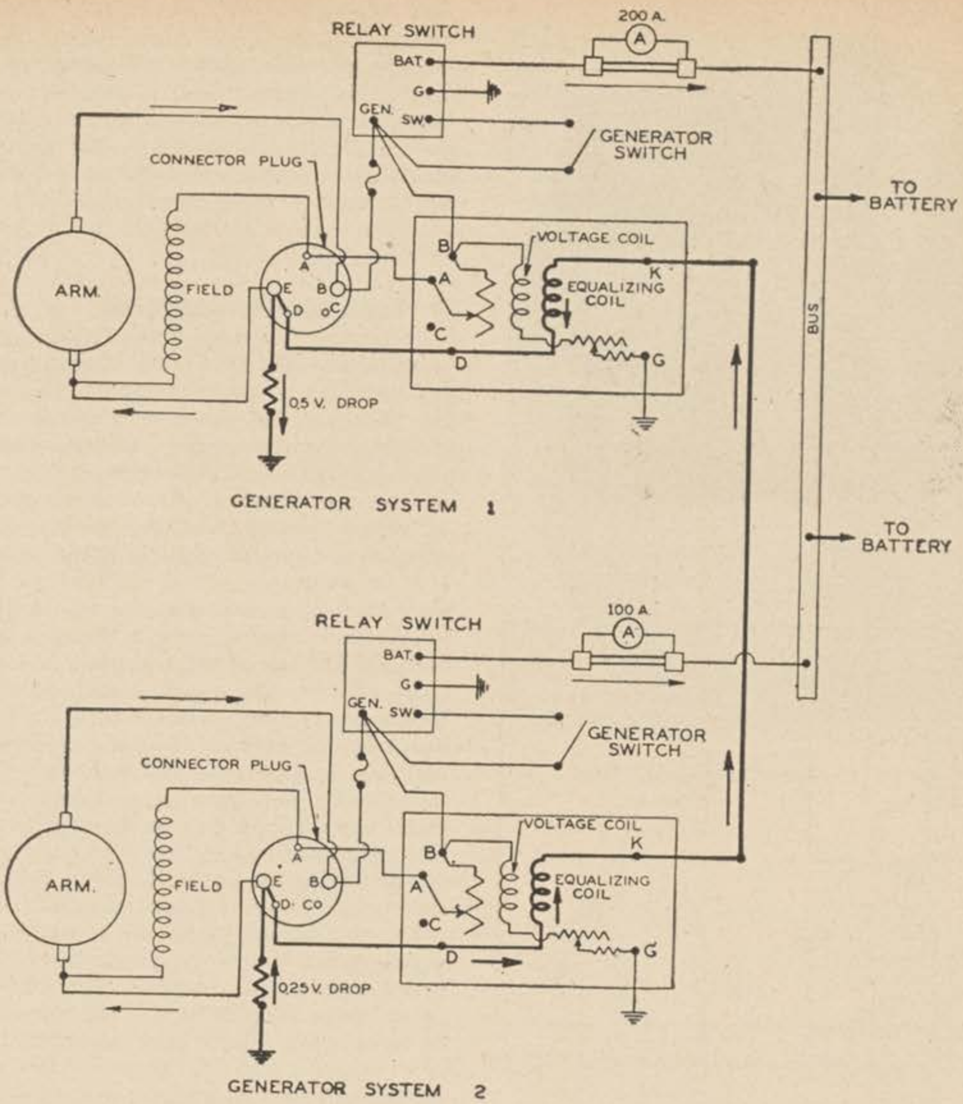


Figure 147. 24-volt generator-system equalizing circuit.

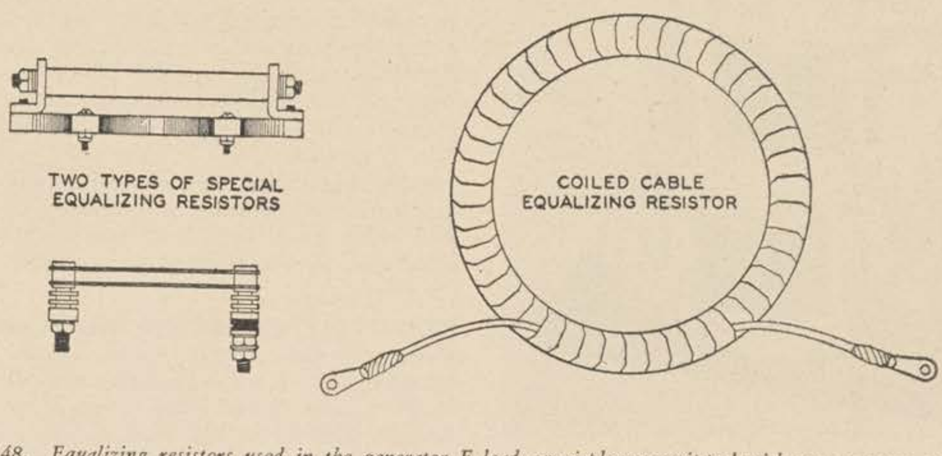


Figure 148. Equalizing resistors used in the generator E lead on airplanes equipped with two or more generators.

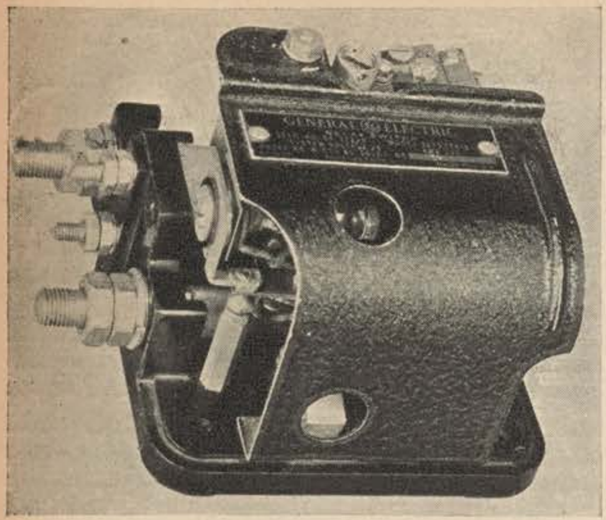


Figure 149. General Electric 24-volt relay switch.

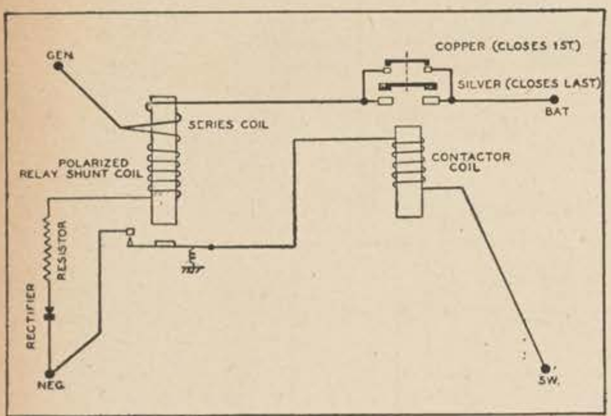


Figure 150. General Electric 24-volt relay-switch circuit.

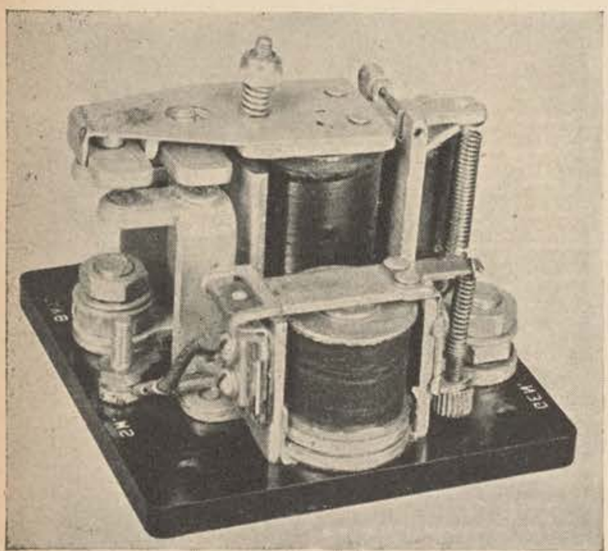


Figure 151. Leece-Neville 24-volt relay switch.

other end of the carbon-pile housing. The other contact with the carbon pile is made through the spring and armature assembly. When the voltage of the generator changes, the solenoid which is connected to the generator varies the tension of the spring, thus changing the mechanical pressure on the disks. The disks, in turn, vary the resistance in the field circuit of the generator. This type of regulator is adjusted by means of a small rheostat which increases or decreases the current flow in the regulator solenoid.

71. PARALLELING CONTROLS. a. General. For the successful operation of two or more generators connected in parallel, it is essential that the generators share the load equally. A very small increase of voltage in one generator will cause the generator to supply the greater part of the power. The load on a generator is often referred to as ampere-load. The load or power actually is measured in watts but because the voltage is considered to be constant, the power is directly proportional to the ampere output of the generator.

b. In order to distribute the load equally among the generators, an equalizing coil is wound with the voltage coil of the voltage regulator as shown in figures 143 and 146. The circuit of the equalizing system is shown in figure 147. A fixed resistance is placed in the lead from E to ground. The resistance of this lead will be such that, when the generator is operating at full current output, there will be a 0.5 volt (*IR*) drop between *E* and the ground. The operation of the equalizing system depends upon the *IR* drop in the separate ground leads. The resistance in the ground lead may be put in the circuit by making the ground lead long enough to have the required resistance, or special resistors may be used (fig. 148). In the installation of the auxiliary power plant a piece of No. 8 nichrome wire approximately $4\frac{1}{8}$ inches long is mounted between the negative brush and ground for the equalizing resistor. The generator furnishing the most power will have the greatest voltage (*IR*) drop in its negative lead; the generator furnishing the least power will have the smallest voltage drop in its negative lead. The point *E* of the generator supplying the most power will be at a lower potential than the corresponding point *E* of the other generator, thus current will flow through the equalizing system from *E* of generator No. 2 to *E* of generator No. 1. From the figure 147, it will be noticed that current will flow in the opposite direction in the equalizing coil of regulator No. 2, than it does in the equalizing coil of regulator No. 1; that is, the equalizing coil will aid the voltage coil of the regulator of generator No. 1 and oppose the voltage coil of the regulator of generator No. 2. The effect will be that the voltage of generator No. 1 will be lowered and the voltage of the other generator will be increased. The current flow in the equalizing circuit thus tends to produce an equal load division between generators.

72. 24-VOLT GENERATOR RELAY SWITCHES. a. General. The generator relay switch performs the same function in the high-output 25-volt system as the reverse-current cut-out in the 12-volt system. It connects the generator to the bus whenever the voltage becomes 26.5 ± 0.05 volts and disconnects the generator from the bus when the bus voltage exceeds that of the generator. The relay switch uses a modified reverse-current cut-out to operate a heavy relay which controls the bus circuit. Another function of the relay switch is to break the generator circuit whenever the pilot wishes to disconnect the generator from the bus. Rather than run a heavy lead to the cockpit and use a large switch, the circuit is controlled with a small switch in the relay or contactor-coil circuit.

b. (1) The General Electric relay switch is shown in figure 149. This switch incorporates a polarized relay which will cause the main contacts to close whenever the voltage of the generator becomes 26.5 + 0.05 volts. The copper-oxide rectifier unit prevents the relay from closing when the generator polarity is reversed. The polarized relay also serves the same purposes with the result that the rectifier's main function is temperature compensation. The polarization of the relay by means of a permanent magnet also insures that the relay will open even on high values of the reverse current which otherwise might reverse the magnetism of the voltage coil and hold the relay closed.

(2) Whenever the generator voltage has reached 26.5 $\pm$ 0.05 volts the polarized relay and switch connect the generator to the contactor coil; thus the control circuit is complete and the contact relay energized. The contactor or relay is so constructed that two copper points close first and open last; two silver points close last and open first. This arrangement eliminates any arcing at the silver points, thus insuring a good contact. In the reverse process when the generator voltage drops below the bus voltage, a series coil in the generator line will neutralize the effect of the shunt or voltage coil on the polarized relay. This will demagnetize the core of the relay and the relay points will open. The opening of the relay points will break the circuit of the contactor coil, the contactor points will break the circuit of the contactor coil, and the contactor points will then open and break the generator circuit (fig. 150).

c. The Leece-Neville relay switch is similar in construction to the General Electric except for a few details (fig. 151). The rectifier, instead of being a copper oxide type, is a selenium oxide type. The shunt or voltage coil of the polarized relay is connected somewhat differently in that the current must also pass through the control switch before the polarized relay points can close. The contactor is very much the same as that used in the General Electric relay switch. It incorporates two sets of points, one of which closes first and opens last to protect a set of low-resistance points (fig. 152).

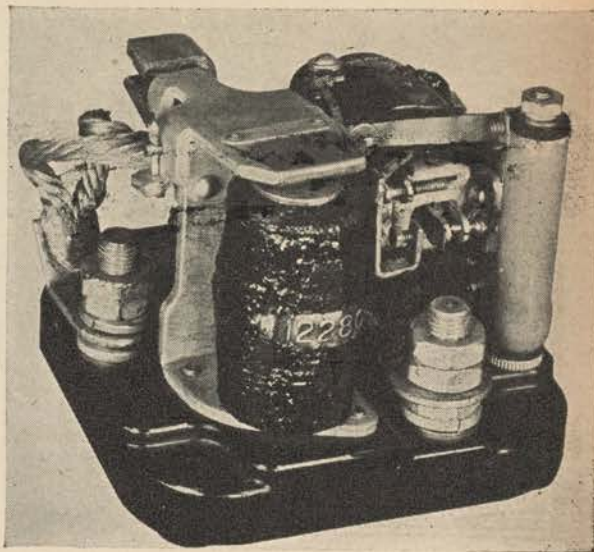


Figure 153. Westinghouse 24-volt relay switch.

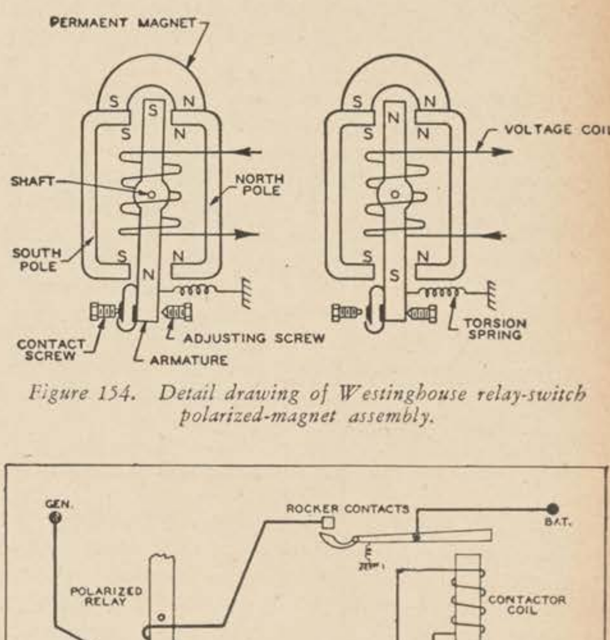


Figure 154. Detail drawing of Westinghouse relay-switch polarized-magnet assembly.

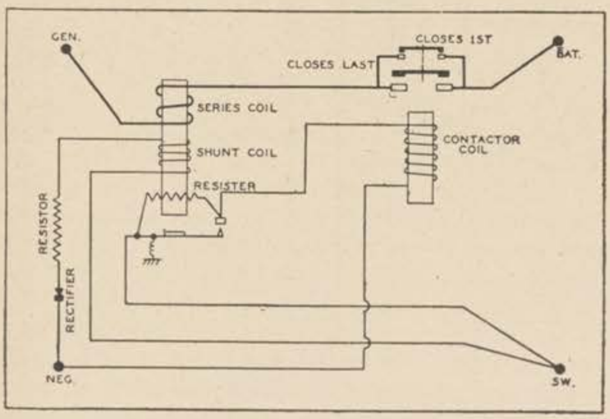


Figure 152. Leece-Neville 24-volt relay-switch circuit.

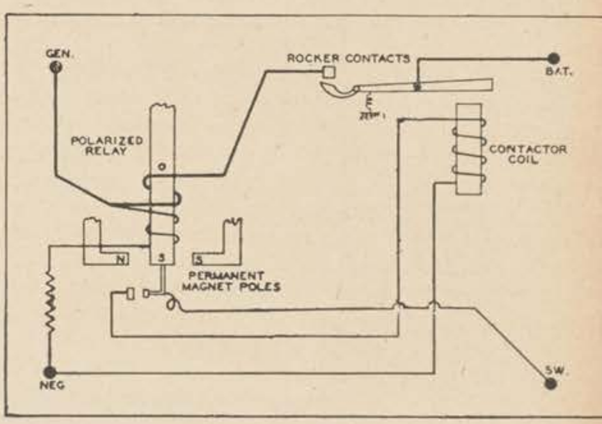


Figure 155. Westinghouse 24-volt relay-switch circuit.

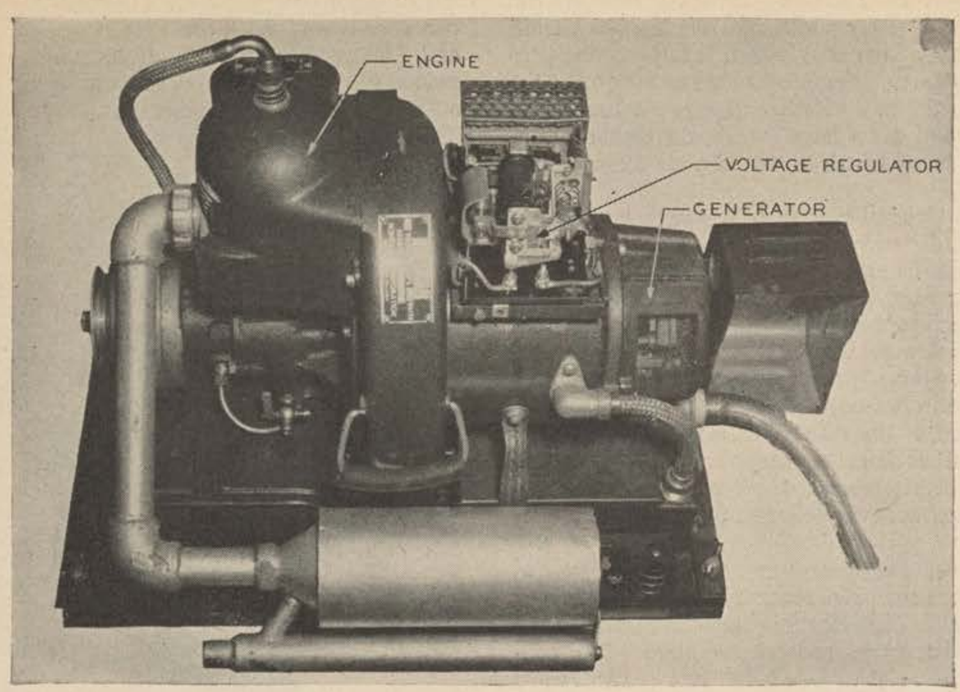


Figure 156. Homelite HRU-28, 24-volt auxiliary power plant.

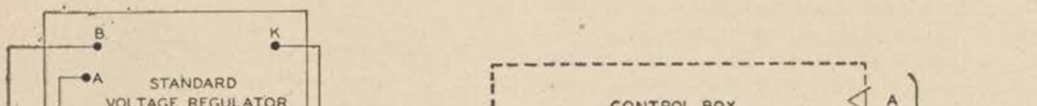


Figure 157. Homelite HRU–28, 24-volt auxiliary power-plant circuit.

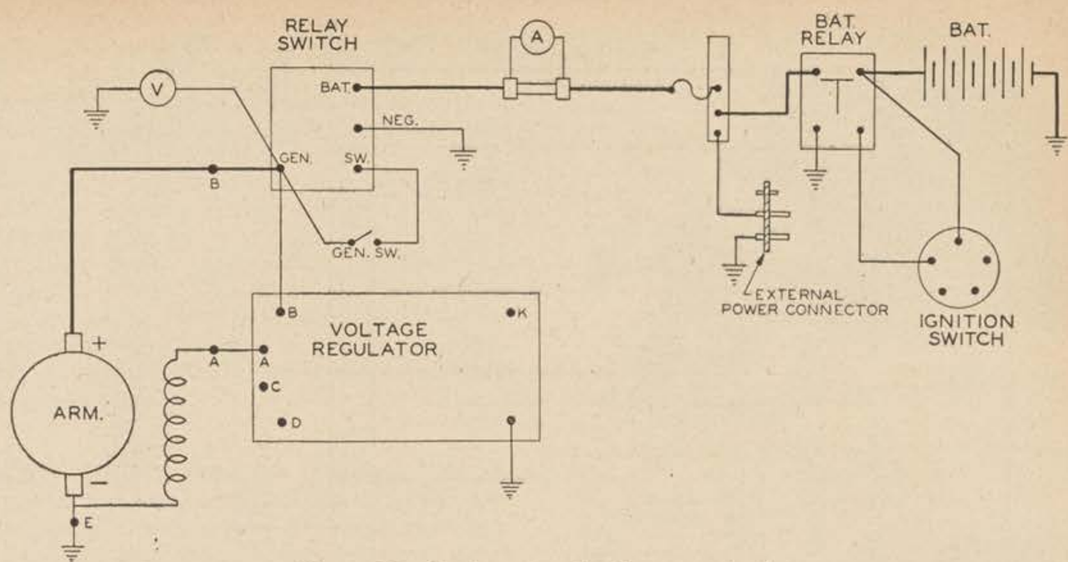


Figure 158. Single-engine 24-volt power circuit.

d. The Westinghouse relay switch (fig. 153) is essentially the same as the General Electric and Leece-Neville. It uses a set of permanent magnets to gain its polarized effects (fig. 154). From the figure, it can be seen that the current passing one way will magnetize the movable bar and cause it to be attracted to the south pole (where the contacts are located). A current passing through the current winding will neutralize the effects of the voltage winding which is acting to hold the bar against the contacts at the south pole and the spring will then pull the bar to the stop at the north pole position, opening the contacts. The circuit of the Westinghouse relay switch is shown in figure 155. The contactor is essentially the same except for a slightly different arrangement of the contact points. Instead of using two points to break the circuit, a rocker-type contact is used. Contacts are made and broken at the beginning and end of the movement of the armature. Hence, only the end of the point is subjected to the arc.

73. AUXILIARY POWER PLANT. a. General. The purpose of the auxiliary power plant (fig. 156) is to serve as a source of electric power for storage battery charging and for the testing of electrical aircraft equipment while the airplane is on the ground. It may also be used as an auxiliary source of electrical power at low altitudes in case of an emergency. (The Homelite auxiliary power plant is limited in output at altitude above 5,00 feet and should only be used for limited periods of time or in the event of emergencies.) The auxiliary power plant is sometimes mounted in the airplane and connected to the airplane's electrical system. The auxiliary power plant consists of a gasoline engine coupled directly to the generator. The voltage output of the generator is regulated by a standard voltage regulator. The generator furnished with Homelite auxiliary power units is usually a standard aircraft model and replacements can be drawn from stock.

b. Engines. The gasoline engine is a 2-cycle air-cooled engine. The speed of the engine is controlled by a governor which regulates the fuel and air mixture entering the engine's cylinder. The ignition system consists of a high-tension magneto and a spark plug in the cylinder head. Lubrication of the engine is provided by the mixing of crankcase oil with the fuel. The engine is cranked by motorizing the generator or with a "rope-type" starter.

c. Generator. The generator is of a special design and is connected directly to the crankshaft of the engine. In order to make the generator an electric motor of sufficient torque to crank the engine, a novel arrangement of a series field is incorporated in the generator. When the starter switch is closed the series field circuit is connected to the battery and the generator normally operates as a simple, shunt generator.

d. Voltage regulator. The voltage regulator of the power plant is the standard Army Air Forces design. The standard sub-base is mounted on the generator and any 24-volt voltage regulator available may be readily attached. The reverse-current relay is of a special design. A diagram of the generator system is shown in figure 157.

74. COMPLETE GENERATOR SYSTEM. a. In the present Army Air Forces airplane, the electrical system provides power for many of the airplane accessories and armament. Without the electrical system, the propellers, fuel pumps, radio, landing gear, lights, turrets, armaments, etc., would in many cases be inoperative. Consequently, *the electrical system must be in working order.*

b. The source of electrical power is the generator. The airplane electrical system is so designed that the electrical load necessary for flight can be carried by one-half of the generators on the airplane. The purpose of the battery is to provide power for starting the engines on the ground and for testing the electrical system. The only time it is needed in the air is to furnish power for short heavy intermittent loads. The auxiliary power plant

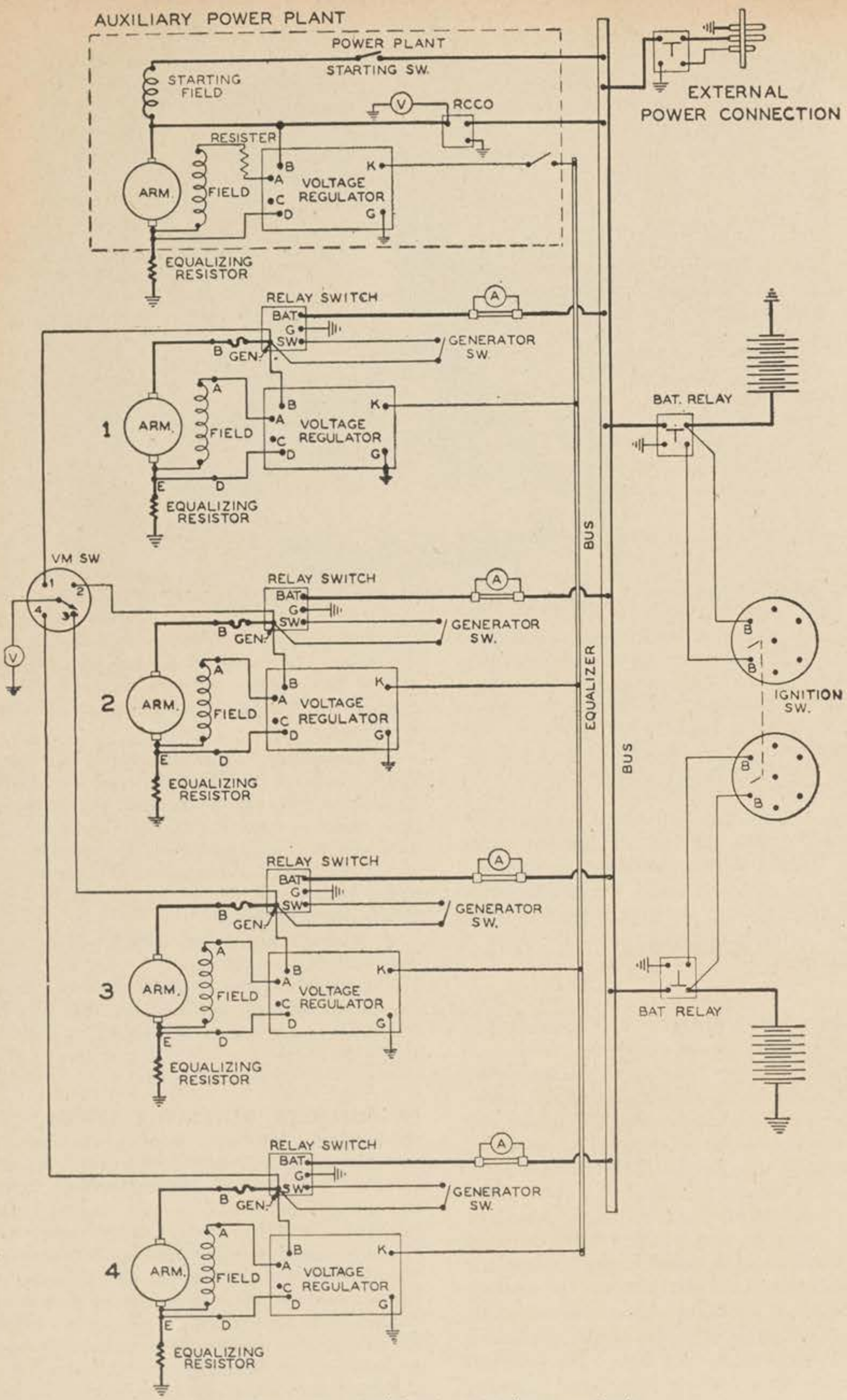


Figure 159. Multi-engine 24-volt power circuit.

(if installed) provides power for starting the engines on the ground, ground testing, and emergency power at low altitudes.

c. The electrical system of a single engine airplane uses a generator regulator and relay switch; a diagram of this system is shown in figure 158.

d. The complete system, as used on a large airplane or a multi-engine airplane, is shown in figure 159. This figure shows the main bus connected to the generator system, auxiliary power plant, battery circuit and external power connection. The generating units and the circuit are identical to the single-engine installation except the generators are connected in parallel and a suitable device is used to evenly divide the load among individual generators.

75. SYSTEM ADJUSTMENTS. a. General. The adjustments of the power system are chiefly to set the voltage regulators so that the generators will produce a constant voltage of 28 volts and to adjust the relay switch to close the circuit of the generators at approximately 26 to 26½ volts.

b. Voltage regulator. The voltage regulator is a precision device, will not withstand rough treatment, and must be handled with care. The adjustment procedure for the Army Air Forces voltage regulator, given in detail in TO 03-5-39, must be followed with care. This procedure is briefly as follows:

(1) Use a precision-type portable voltmeter, figure 160, 0-30 volt scale. This voltmeter must be handled carefully as it will not maintain its accuracy under conditions of mishandling, vibration, or shock.

(2) Place all generator switches located on the generator instrument panel in the "0" position.

(3) Start all engines which have generators and allow them to warm up for the period necessary to bring engines to operating temperature.

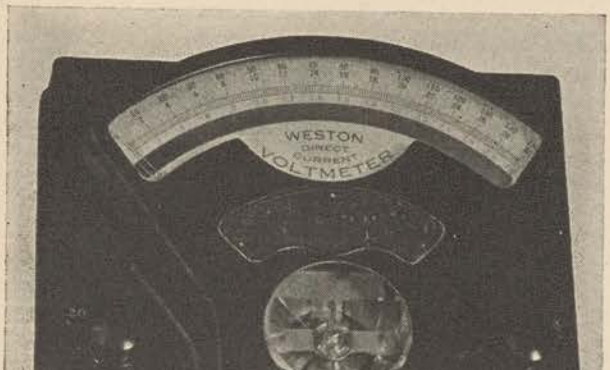


Figure 160. Precision voltmeter used in setting voltage regulators and relay switches.

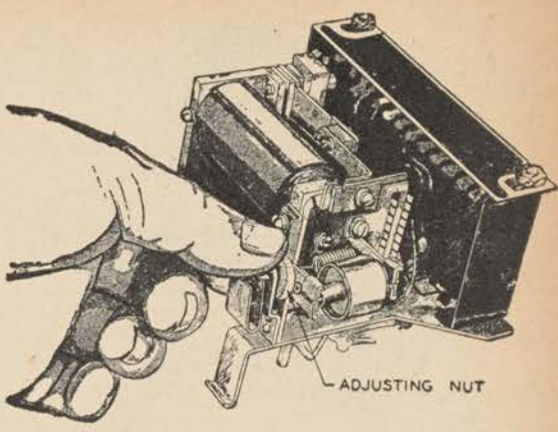


Figure 161. Adjusting General Electric 24-volt voltage regulator.

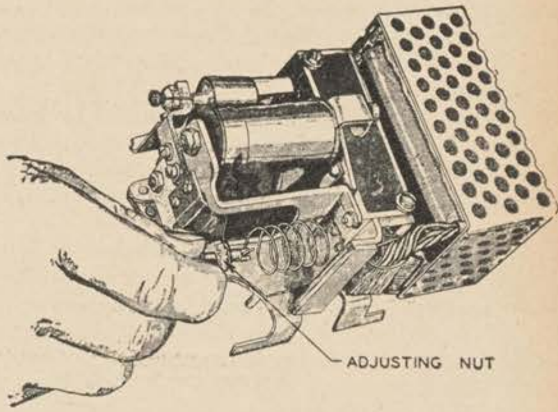


Figure 162. Adjusting Westinghouse 24-volt voltage regulator.

(4) Connect the negative terminal of voltmeter to the metal structure of airplane and the positive terminal to the *B* terminal of the voltage regulator (or to the general terminal of the relay switch).

(5) Increase to 1,800 r.p.m. the speed of the engine having the generator and voltage regulator being checked. Keep remaining engines, if a multi-engine airplane, at idling speed.

(6) If voltmeter does not indicate 28 volts, adjust the voltage regulator until voltmeter reads 28 volts by adjusting the spring tension on the armature in the case of General Electric, figure 161, and Westinghouse, figure 162, regulators by means of adjusting nut. In the case of the carbon-pile regulator adjustment is made by turning the small knob, figure 163, which changes the resistance of the voltage-coil circuit. After regulator is adjusted, reduce the speed of the engine to idling.

(7) On a multi-engine airplane, repeat the procedure outline for each voltage regulator including the voltage regulator of the auxiliary power plant.

(8) After the voltage regulator of all the generators on an airplane have been adjusted to produce a voltage of 28 volts, it is necessary to check to see if the generators share the load equally. This is done with the aid of a paralleling system (see TO 03-5-39). Close the generator main-line switches and equalizing switches (if pro-

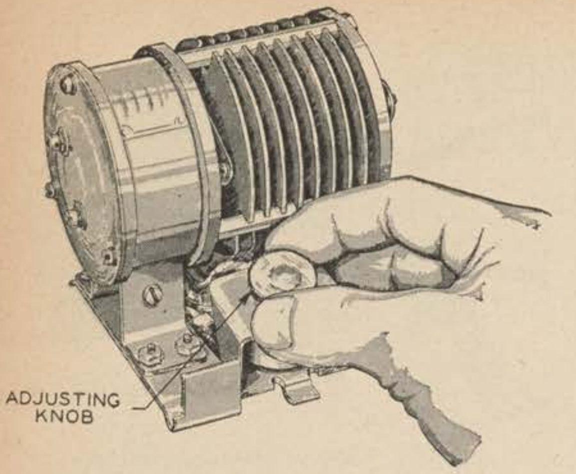


Figure 163. Adjusting Delco-Remy 24-volt voltage regulator.

vided) and run the engines up to approximately 1,800 r.p.m.; the autosyn instrument inverter should be turned on to provide a load, all other loads such as radio, lights, etc., being off.

(9) Check ammeter reading which should be steady and alike. Variation between ammeters should not exceed 3 amperes. If unbalance is severe, *lower the high reading* by adjusting the corresponding voltage regulator downward.

(10) Apply heavy load by closing switches for lighting equipment, inverters, and radio equipment. *Check ammeter readings again;* they should be steady and nearly alike. If the highest is no more than 20 amperes higher than the lowest, the setting is satisfactory.

(11) Should amperage difference be more than 20 amperes, check the following: paralleling, wiring, and regulators.

(12) If possible, all paralleling adjustments be made with the generator system warm and not while the component units are cold.

c. Relay. (1) The reverse-current relay should never be manually closed by pressing the contacts together as serious damage to the relay, the electrical system, and to the individual closing the contacts may result. Where possible, when a relay is removed, it should be replaced by a relay of the same type.

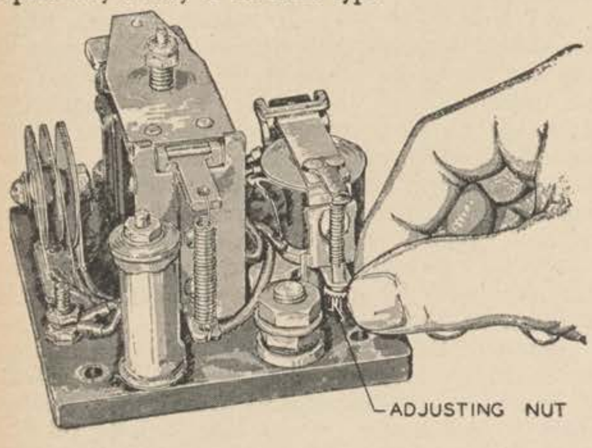


Figure 164. Adjusting Leece-Neville 24-volt relay switch.

(2) The adjustment procedure for a relay switch is to set the relay switch to close at between 26 and 26.5 volts. This is done as follows:

(*a*) Connect voltmeter in the same manner as for adjustment of the voltage regulator (see *b* above). Place the generator switch on the instrument panel in the "0" position. Slowly increase the speed of the engine on which the generator whose circuit is being checked is installed until a current reading is noted on the ammeter on the instrument panel. The voltmeter reading will show a slight drop as the relay closes. The voltage just before the relay closes is the relay closing voltage. It should be between 26 and 26.5 volts. If it is different from that value, the relay should be adjusted or, if adjusting equipment is not available, replaced.

(*b*) Adjustment of the closing voltage of a Leece-Neville relay (figure 164) is made by turning a small slotted nut near the generator terminal. This nut controls the tension on the small spring. Adjustment in the case of the General Electric relay (fig. 165) is accom-

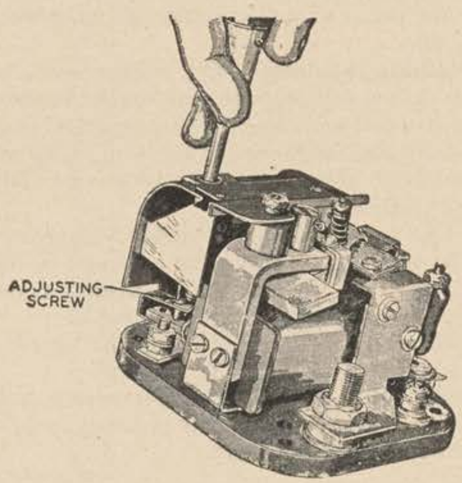


Figure 165. Adjusting General Electric 24-volt relay switch.

plished by turning a small screw in a spring clip immediately above the name plate. Adjustment of the Westinghouse relay is accomplished by turning a small screw with a screw driver to adjust the position of the armature inside the small coil. See TO 03–5–39 for details on adjusting relays. A differential type of relay switch will soon be placed in service which will require no adjustment; this fact will be noted on the nameplate.

(*c*) After the relay has been adjusted, the reverse-current value of each relay should be checked as follows. With the battery switches, operate engine so that the ammeter shows current output from generator. Slowly reduce engine r.p.m. Ammeter reading will decrease to zero and then begin to read in reverse direction. Note current reading just before the ammeter pointer returns to zero; this reading should be between 8 and 20 amperes. If the pointer does not immediately return to 0, advance the throttle until the ammeter shows a small current output from the generator, open main-line switch, and stop engine. In such cases, the relay is probably improperly adjusted and should be checked and replaced if necessary.

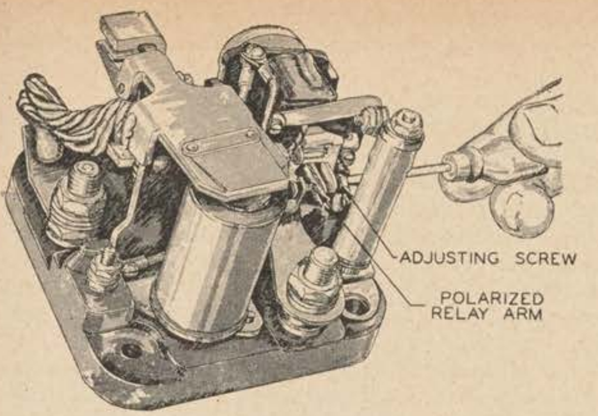


Figure 166. Adjusting Westinghouse 24-volt relay switch.

76. SYSTEM TROUBLE SHOOTING. a. Trouble shooting is the locating of the exact cause of the system's failure to function properly. The generator operates in connection with a voltage regulator and current-relay switch. Thus the failure of the system to deliver power to the bus can be caused by one of the three units or the wiring system connecting them. In trouble shooting a small sketch of the system's circuits will often help in finding the faults. Faults in the electrical power system and the probable causes are listed in the following outline:

(1) Generator produces no voltage.
(*a*) Voltmeter lead may be broken.
(*b*) Generator should be flashed.
(*c*) Commutator should be cleaned.
(*d*) Generator should be replaced.
(2) Generator produces approximately 2 volts or "residual" voltage.
(*a*) Voltage regulator does not allow sufficient field current to "build up" voltage.
(*b*) Field lead to regulator *A* terminal is open.
(*c*) Generator field circuit is open. Replace generator.
(3) Generator produces high voltage.
(*a*) Regulator is set too high.
(*b*) Regulator is inoperative, causing excessive field current. Replace voltage regulator. Causes may be:
1. Dash pot stuck.

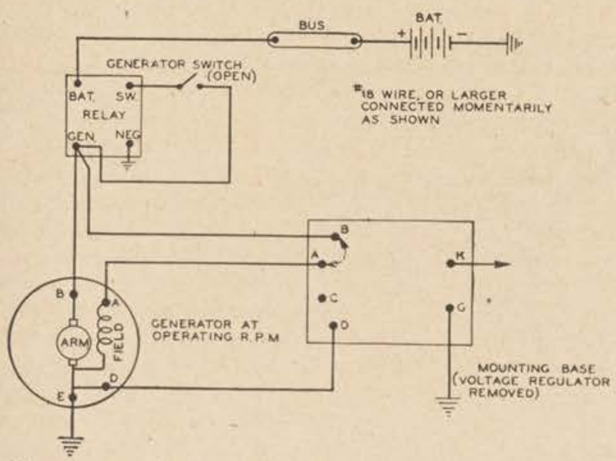


Figure 167. Checking voltage regulator by connecting A to B.

2. Voltage control coil open.
3. Contacts welded.
(*c*) Field lead *A* is shorted to generator positive within generator, at connector, or in wiring system.
(*d*) Generator delivers no current. Causes may be:
1. Main-line switch open.
2. Generator main-line circuit open.
3. Relay switch closing voltage set too high.
4. Reversed connections at generator. Relay switch is polarized so it will not close on a reversed voltage.
5. Ammeter leads broken.
6. Relay switch inoperative, requiring replacement.
7. Generator circuit open at either positive *B* or negative *E* side.
8. Circuit protector open.

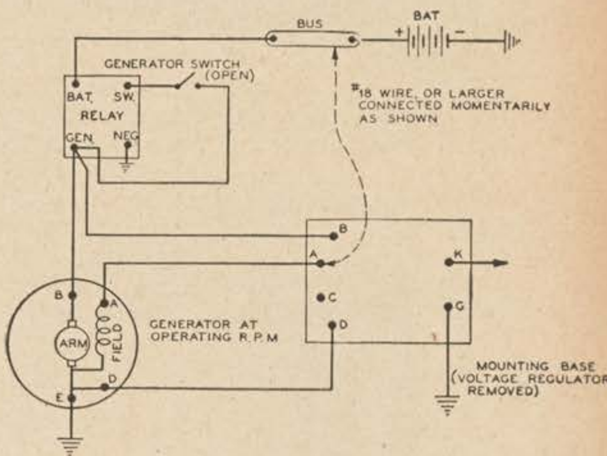


Figure 168. Method of flashing generator field.

77. MAINTENANCE OF GENERATOR SYSTEM. a. Generator. (1) In the case where no voltage is produced by the generator, remove the voltage regulator and with the engine running at approximately 1,800 r.p.m. short circuit the *A* and *B* terminals at the sub-base (fig. 167). If this test gives excessive voltage it indicates that the generator is not at fault but that the trouble lies in the voltage regulator.

(2) If this test fails to produce a voltage the generator field may have lost its residual magnetism. To restore residual magnetism the field may be flashed by connecting the *A* terminal of the regulator base (with regulator removed) to a source of battery voltage at a junction box or bus (fig. 168) (engine running at 1,800 r.p.m.). Again connect *A* to *B* as in (1) above and if still no voltage is produced, check the leads for continuity, shorts, and grounds. If the generator is so located that the brushes and commutator can be inspected, they should be checked for proper condition as specified in Technical Orders. If necessary replace brushes and clean the commutator. If the generator is so located that it cannot be serviced remove it from the airplane.

(3) After removal, disassemble the generator and check the field, armature, brushes, and commutator.

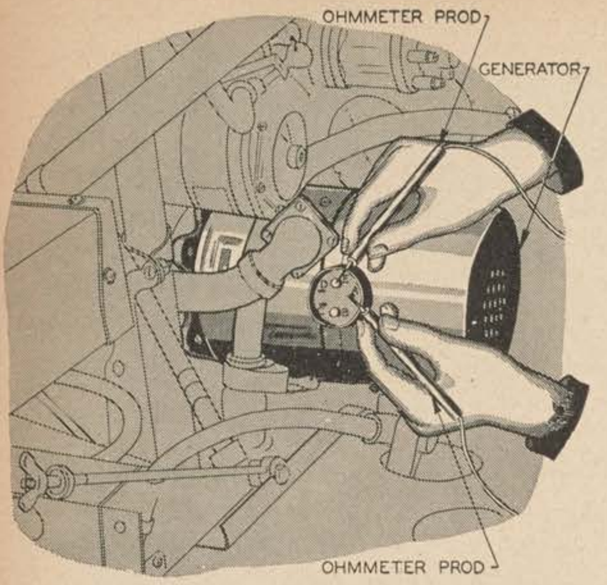


Figure 169. Checking generator field with an ohmmeter while generator is on engine.

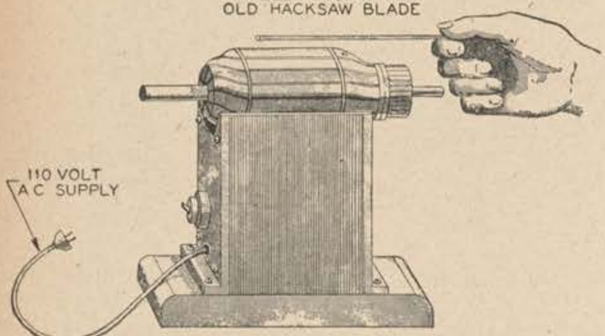


Figure 170. Using a growler to check for shorted armature coils.

(*a*) Check the field for opens, shorts, and grounds. The resistance of the field as measured with an ohmmeter should be from 1 to 7 ohms depending upon the type of generator (fig. 169).

(*b*) Check the armature visually for such troubles as burned insulation, unsoldered connections, dirty commutator, high mica, etc. Check the armature in a *growler* for shorts by placing the core of the armature in the V-slot as shown in figure 170. Explore the armature core with a hacksaw blade keeping the blade on top and rotating the armature. Since the armature is wound symmetrically, the blade will be attracted with the same force by a good armature regardless of its position. On the other hand, a shorted armature coil will cause a place of stronger attraction. Check with a continuity light between commutator and shaft for grounded armature coils.

(*c*) Check the brushes for length and general condition. Particular care should be given to generator brushes when working with airplanes used for high altitude flying. Consult Technical Orders on the specific generator for correct brushes. *Use only the recommended brushes.* New brushes should be seated with No. 000 or finer sandpaper (fig. 171). Consult Technical Order on proper brush spring tension.

(*d*) Clean commutator with No. 000 or finer sandpaper and blow out with compressed air blast. Replace armature if burnt.

(*e*) Check for high mica (fig. 172).

(*f*) Check for dirt and oil in the generator. Blow out any dirt with compressed air. If oil is found in the generator check oil seal.

(*g*) No lubrication of the generator is required between overhauls. *Do not attempt to lubricate;* consult Technical Orders.

b. Voltage regulator. (1) If the generator is generating the proper voltage, the generator and voltage regulator are not at fault.

(2) Maintenance of the voltage regulator will consist of keeping it clean.

(3) Particular care should be taken with the finger and leaf-type regulators not to bend the fingers or leaves.

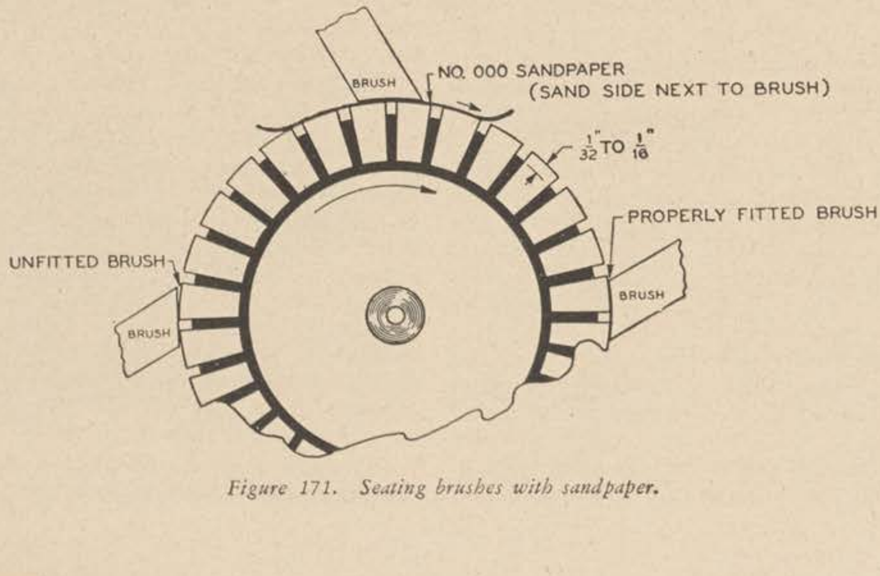


Figure 171. Seating brushes with sandpaper.

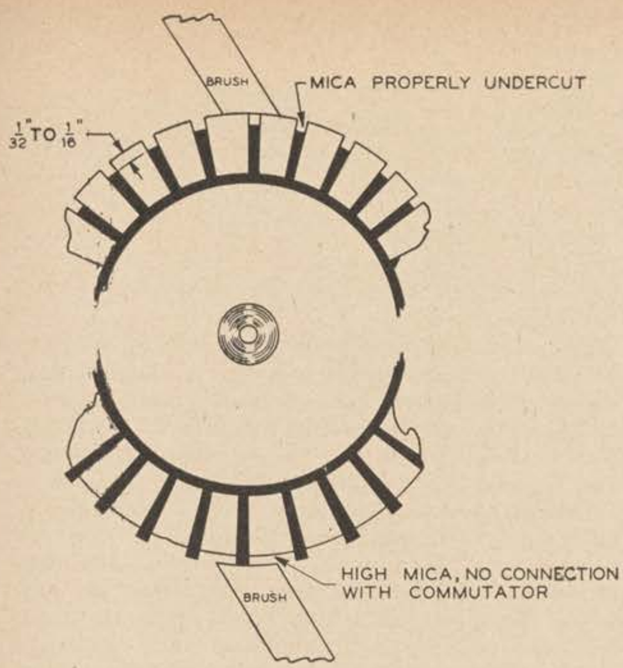


Figure 172. Commutation with proper under cut of mica and high mica.

The contacts should be kept clean and in case of burned contacts the finger or leaf assembly should be replaced. Consult Technical Orders on the servicing operations.

c. Generator relay switch. (1) Generator relay switch may be defective in that it will not disconnect the generator from the bus when the generator switch is opened. This can be detected by a reading on the ammeter with the engine running above 1,800 r.p.m. with the generator switch opened or a reverse reading on the ammeter when the engine is idling or stopped. This condition may be caused by:

(*a*) Welded contacts.

(*b*) Shorted leads.

(*c*) Broken contactor armature spring.

(2) A defective relay may be the cause of a generator not delivering power to the bus. This condition will be indicated by a normal voltage reading and a zero ammeter reading.

(*a*) *Make sure the generator switch is closed.*

(*b*) Check all cables leading to and from the switch relay.

(*c*) Check the ammeter leads.

(*d*) Check with Technical Orders for methods of cleaning contact points.

d. Auxiliary power plant. (1) The maintenance of the voltage regulator of the auxiliary power plant is the same as the regulator on the main engine-generator system.

(2) The maintenance of the auxiliary power-plant will be done in the same manner as outlined for the main engine generators. The bearing on the generator end is grease packed and requires no lubrication between overhauls.

(3) In regard to the auxiliary power-plant engine, care must be taken to mix the oil and gasoline properly by actual stirring of the mixture. The engine must be properly checked for carbon deposits, as carbon deposited on the spark plugs will cause a short. Carbon will also build up in the valve port, closing off the port to the exhaust gases. Check the Technical Order covering the individual power plant for detail inspections and repair operations.

SECTION X

IGNITION SYSTEMS

78. GENERAL. a. When a mixture of fuel-vapor and air is admitted into a cylinder and compressed, the next event in the cycle of engine operation is the ignition of the compressed charge at the proper moment. Even and complete combustion is obtained conveniently by means of electric sparks which are made to occur between the electrodes of spark plugs installed in the cylinder head or combustion chamber of the cylinder (fig. 173).

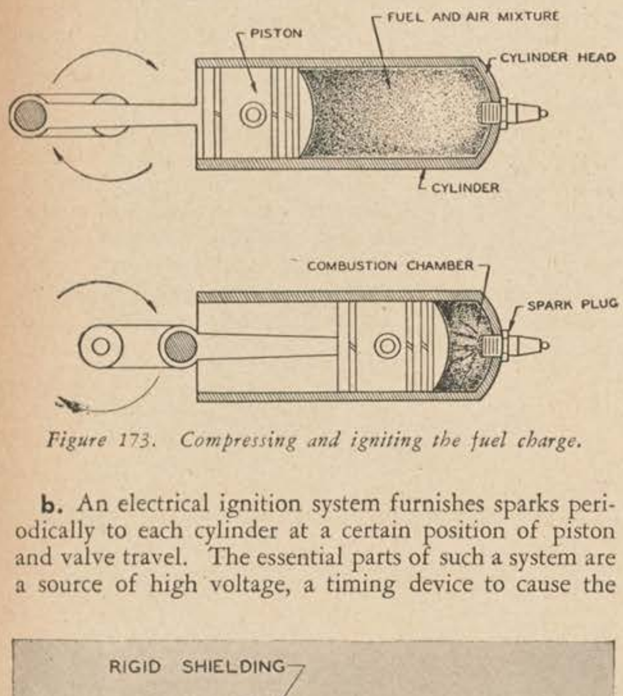


Figure 173. Compressing and igniting the fuel charge.

b. An electrical ignition system furnishes sparks periodically to each cylinder at a certain position of piston and valve travel. The essential parts of such a system are a source of high voltage, a timing device to cause the high-voltage source to function at the set position of piston travel, a distributing mechanism to route the high voltage to the various cylinders in the proper sequence, spark plugs to conduct the high voltage into the cylinders and produce ignition of the fuel mixture, control switches, and the necessary wiring. The source of high voltage may be either a magneto driven by the engine or an induction coil connected to a battery or generator.

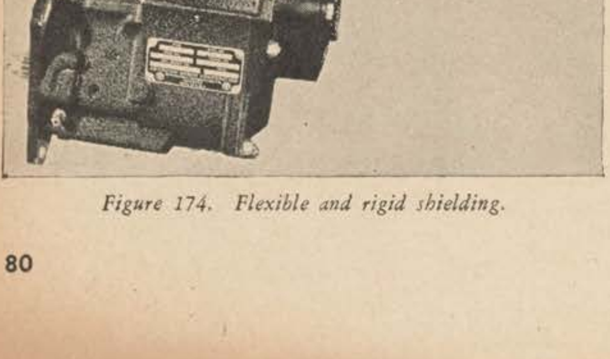


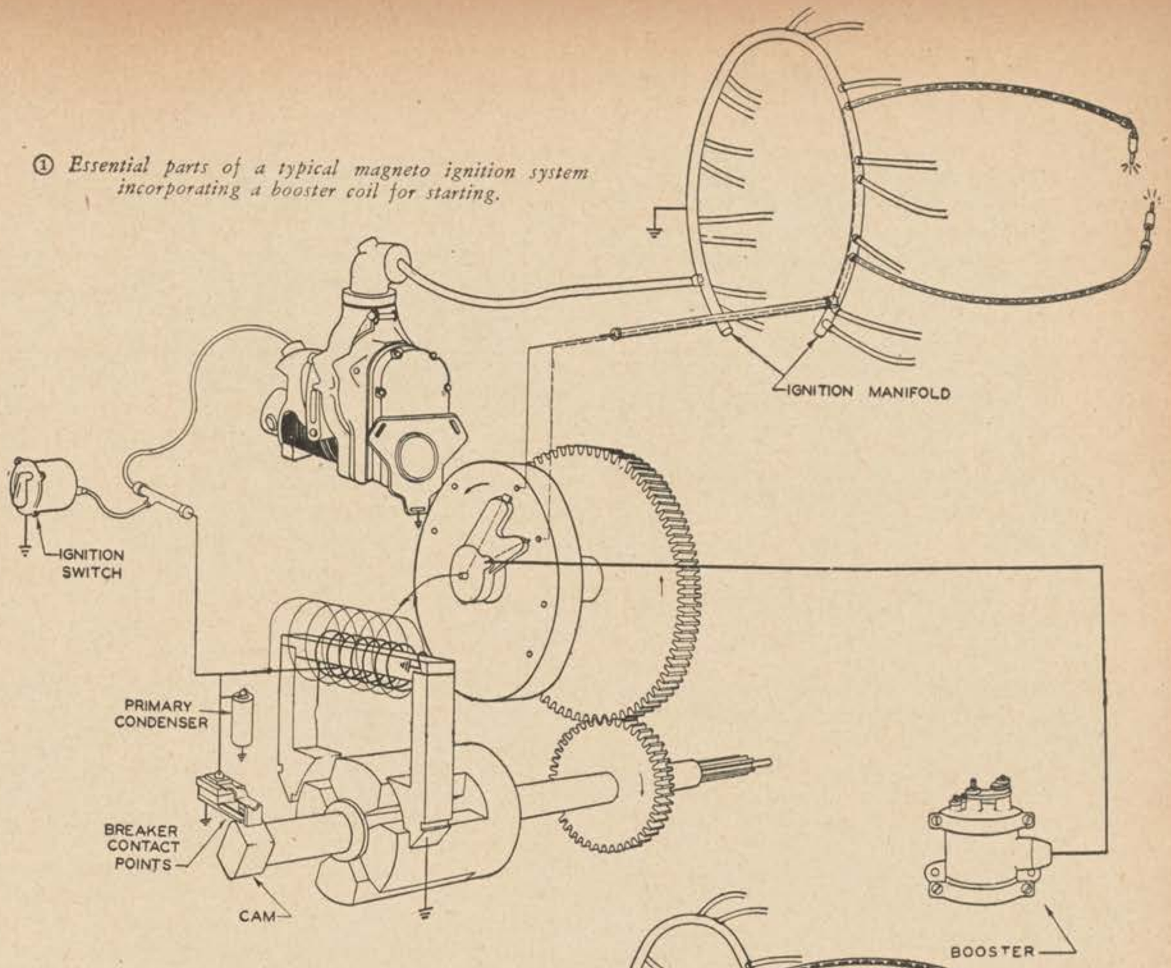
Figure 174. Flexible and rigid shielding.

c. All parts of the ignition system are enclosed in flexible or rigid metal covering called shielding (fig. 174). The shielding "receives" and "grounds-out" electrical radiations coming from the ignition system which would otherwise produce electrical interference (noise) in radio equipment installed in the aircraft.

79. MAGNETO IGNITION. a. General. The magneto is regularly used as the source of high voltage in modern aircraft ignition systems. In starting an engine, the starter turns the engine over too slowly to permit the magneto to operate. Hence, a booster coil or vibrating interrupter is required to generate the required voltage. On small aircraft engines a starter impulse coupling is used; this device is a spring-like mechanical linkage between the engine and magneto shafts which will "wind up" and "let go" at just the right moment to spin the magneto shaft and thus provide the necessary high voltage. The "winding up" process also serves to retard the spark a predetermined amount to prevent backfiring.

b. The essential parts of a typical magneto ignition system, for a single engine, are shown in figure 175. For better engine performance and safety two identical but independent ignition systems are used. The magnetos, which are identical, may be "turned on" separately (for testing) or both at the same time (normal operation) by means of an ignition switch. In figure 175, one magneto is shown assembled and the other with the essential parts exposed. When the magnet (rotor) of either magneto is revolved, the cam on the end of the shaft periodically opens the breaker contact points. It is when the points first open that the high voltage is set up in the secondary coil and the spark occurs. The voltage induced in the secondary is applied to the leading electrode of the distributor rotor which is properly geared to the magneto; then the high voltage is supplied to each distributor electrode at the proper moment. The distributor finger does not touch the electrodes but passes by them with a small clearance. The high voltage must break down two gaps in series, one in the distributor and the other in the spark plug. The magneto is capable of developing sufficient voltage to do this. The high voltage is conducted from the distributor electrodes to the spark

① *Essential parts of a typical magneto ignition system incorporating a booster coil for starting.*



② *Essential parts of magneto system incorporating an induction vibrator for starting.*

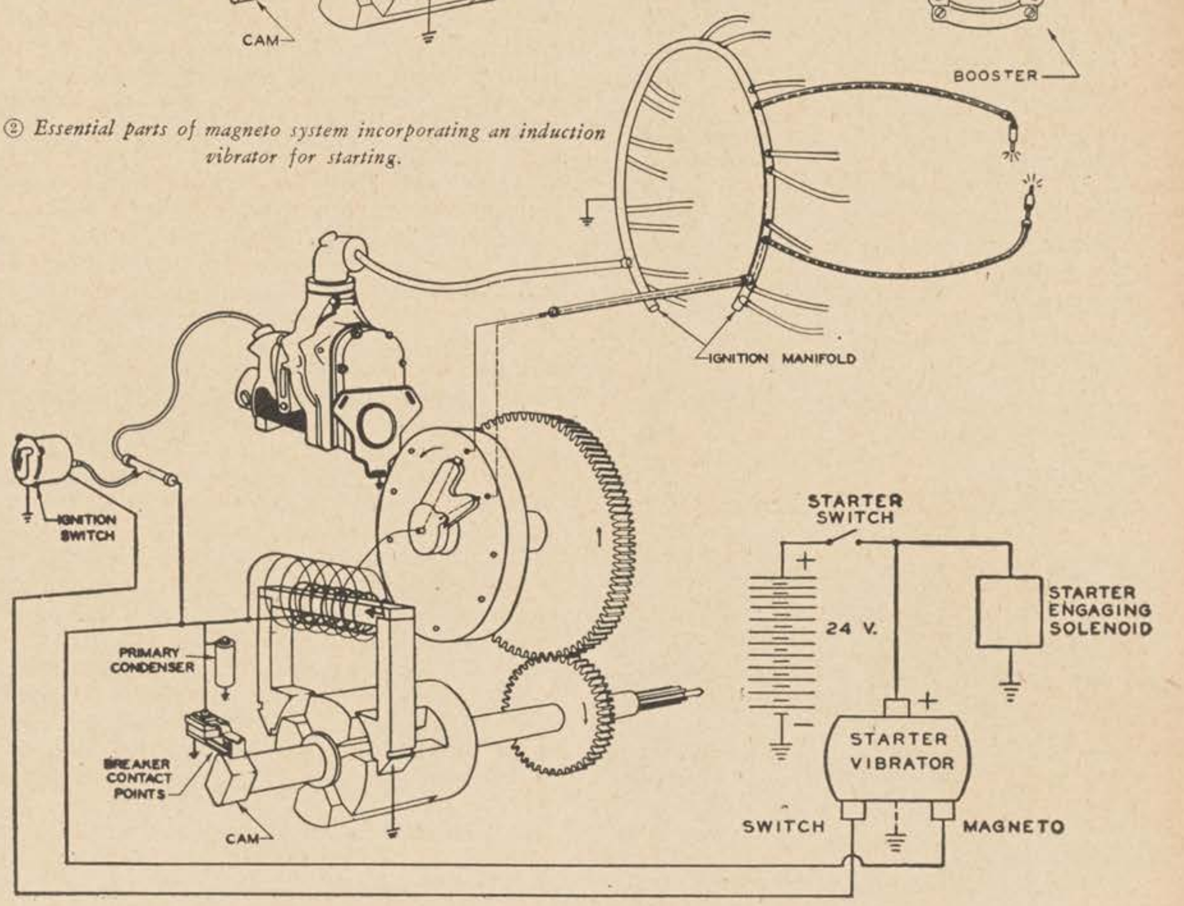


Figure 175.

plugs by well-insulated wire in flexible metal conduit and a non-flexible metallic ignition manifold, referred to as the "ignition harness' (fig. 176). High voltage may be supplied during cranking by an ignition booster which is attached to only one of the magnetos. This ignition booster may be in the form of a booster coil or an induction vibrator. The high-voltage output of a booster coil is carried through a separate terminal and a collector ring on the distributor finger to an electrode which trails the regular or running electrode, thereby retarding the spark for starting. The pulsating low-voltage output of an induction vibrator is carried through the primary grounding terminal to the primary winding of the magneto coil, thereby utilizing the magneto coil for transformation to high voltages. Distributor fingers in induction vibrator systems incorporate only one electrode because the magneto coil secondary is the source of high voltage for both starting and running.

c. In figure 177 is shown a wiring diagram of the magneto ignition system. The functions of the various units are discussed in the following paragraphs.

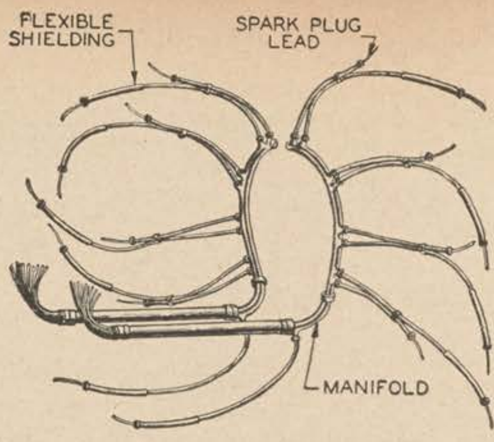


Figure 176. Ignition harness.

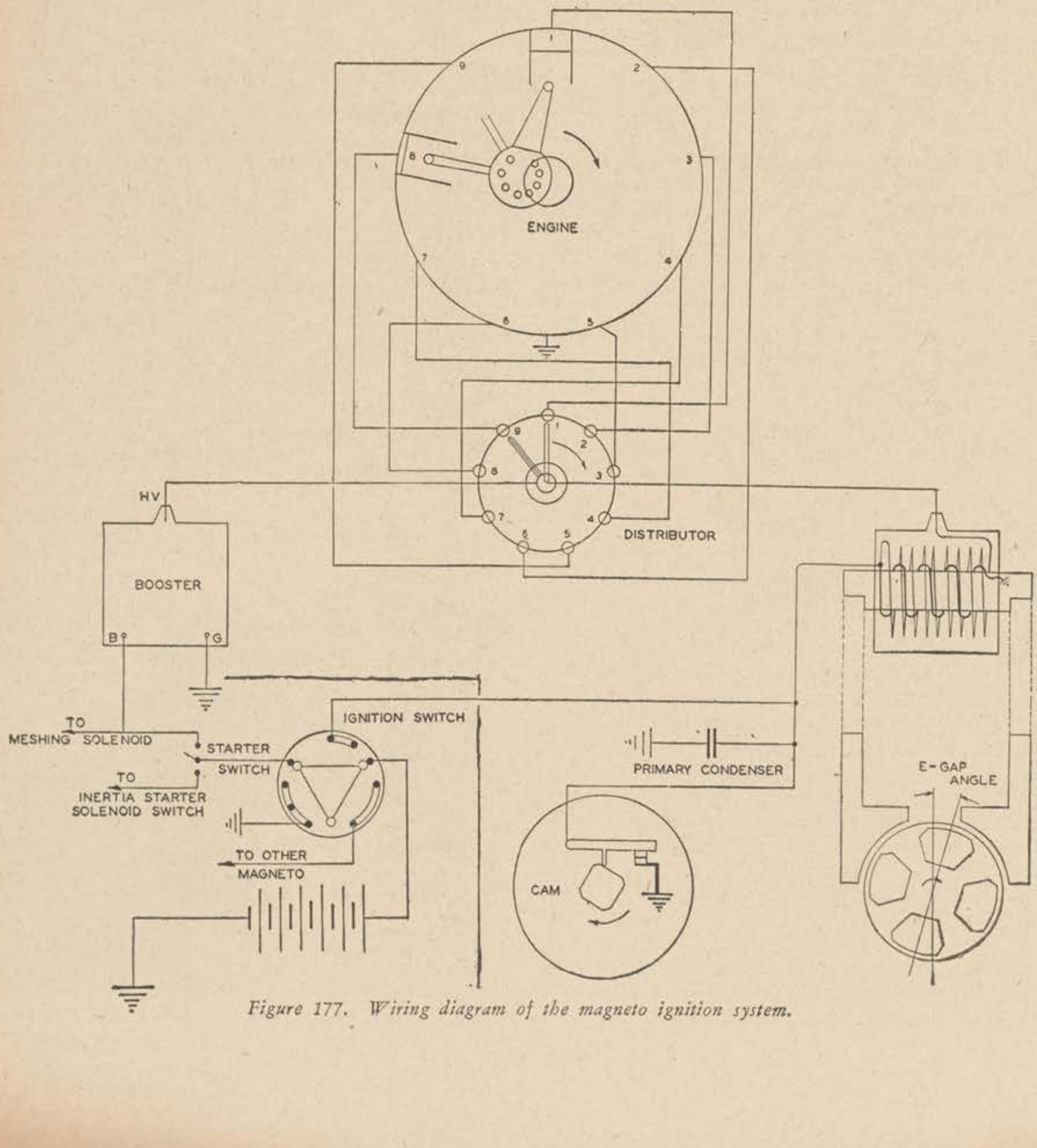


Figure 177. Wiring diagram of the magneto ignition system.

80. CONSTRUCTION FEATURES OF TYPICAL MAGNETOS. a. Magnetic circuit. The magnetic circuit of the magneto may be designed in several different ways. One system uses rotating permanent magnets; 2, 4 and even 8 magnetic poles may be incorporated (fig. 178). These magnets are made of Alnico material, which is an alloy of iron, aluminum, nickel, and cobalt and will retain their magnetism for a long period of time. The magnets rotate under pole pieces which complete a magnetic circuit through a coil core. Another type of magneto uses stationary permanent magnets and a system of rotating inductors which complete the magnetic circuit through the coil core by two different paths thus giving the flux of the magnet two directions through the coil core (figure 179). The latter type is called the inductor rotor and the former the rotating-magnet type.

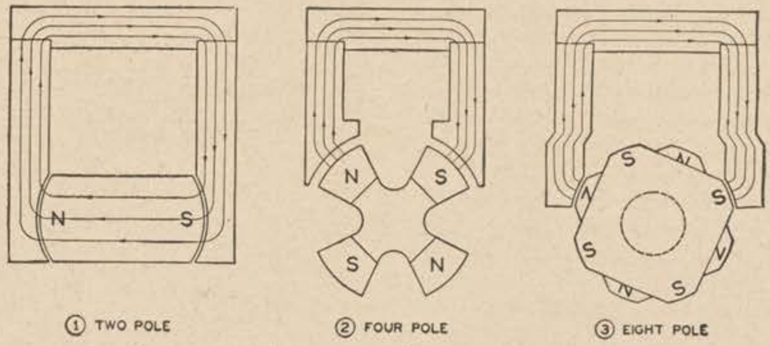


Figure 178. Arrangement of magneto magnet poles.

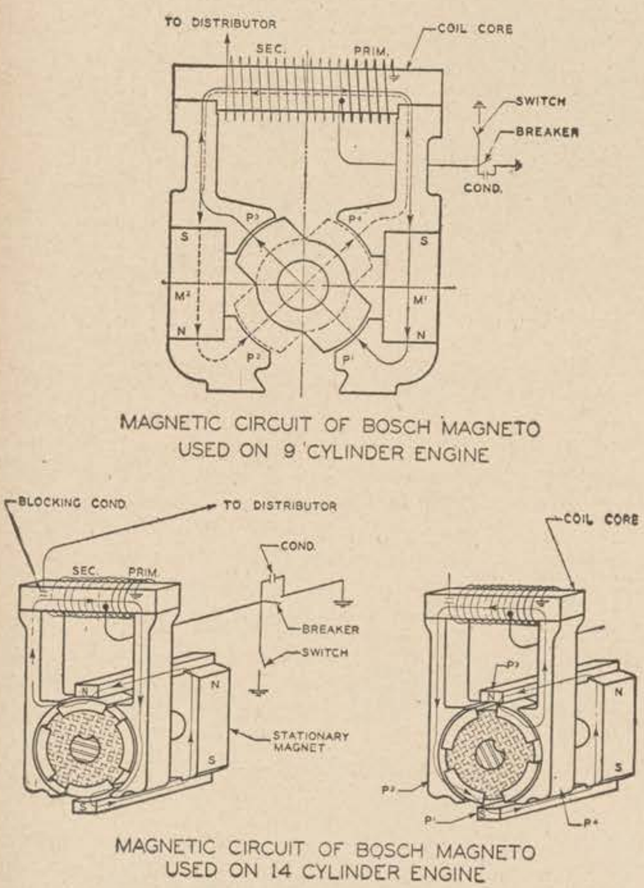


Figure 179. Inductor rotor type magneto.

b. Coil assembly. The coil assembly consists of a laminated soft iron core around which is wound a primary and secondary coil. The coil is covered with a case of hard rubber, bakelite, or varnished cambric. The primary condenser may be encased with the coil. The ends of the core extend beyond either end of the coil assembly and are fastened on top of the poleshoe extensions with screws and clamps. One end of the primary is usually internally connected to a coil-assembly primary terminal. On some models connection is made to this terminal by a spring contact; late models make the connection to this terminal by means of a copper strap. One end of the strap is connected to the primary terminal while the other end is connected to the movable contact point of the breaker assembly. The primary terminal, to which one side of the condenser must be connected, is located where a spring contact from the ignition-switch terminal of the magneto may press against it. The underground end of the secondary makes electrical contact with the distributor rotor.

c. Distributor. The distributor rotor is a device which distributes the high-voltage current to the various connections of the distributor block. This rotor may be in the form of a disk, drum, or finger arrangement (fig. 180). Also the distributor rotor may contain either one or two distributing electrodes. The leading electrode, which obtains high voltage from the magneto

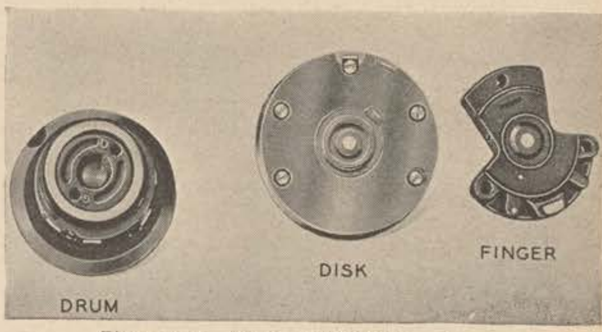


Figure 180. Types of distributor rotors.

secondary, makes its connection with the secondary through the shaft of the rotor. The trailing electrode obtains a high-tension voltage from the booster, by means of a collector ring mounted either on the stationary distributor block or on the rotor itself. The numbers on the distributor block mark the *magneto sparking order* and do not represent the firing order of the engine. The distributor-block position marked "1" is connected to No. 1 cylinder; distributor-block position marked "2" to the second cylinder to be fired; distributor-block position marked "3" to the third cylinder to be fired, etc. One end of an ignition wire is cut off squarely and washer and spacing sleeve are installed. The wire is then forced into the proper distributor-block hole (fig. 181) until it butts up against the bottom and is then fastened with a piercing screw driven through the insulation into the wire thus making good electrical contact. The other end is connected to the spark plug with a special fitting.

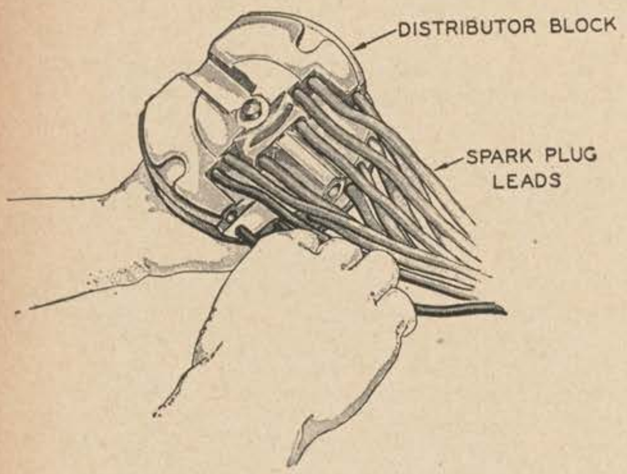


Figure 181. Ignition wires fitted into distributor block holes.

d. Breaker assembly. (1) The cam on the end of the magnet shaft (except a compensated cam) has as many lobes as there are poles on the magnet. The number of high-voltage impulses produced per revolution of the magnet, is equal, therefore, to the number of poles. The number of cylinder firings per complete revolution of the engine is equal to one-half the number of engine cylinders. Therefore the ratio of the magneto-shaft speed to that of the engine crankshaft is equal to the number of cylinders divided by twice the number of poles on the rotating magnet. Earlier models (lever-type breaker) have a movable contact point mounted on a pivot arm and are actuated by a cam follower. In the modern, pivotless-type breaker assembly, the movable point is mounted on a spring (fig. 182). The points are made of platinum-iridium alloy. A frosty appearance of the points indicates that they are in good working condition. The cam is lubricated by means of a felt oil pad which rides on the cam on older models, and by a plunger type oiler on later models. The plunger-type oiler does not ride the cam, but is depressed at designated inspection periods.

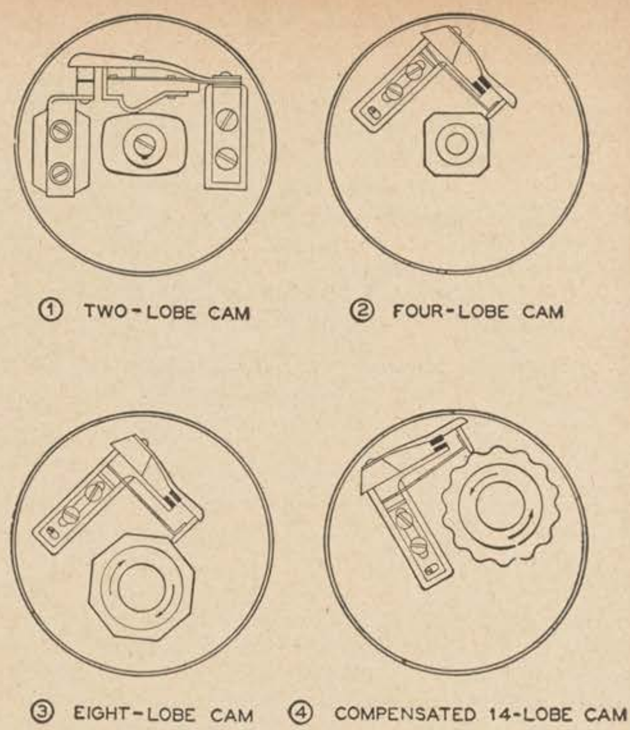


Figure 182. Pivotless-type breaker assemblies.

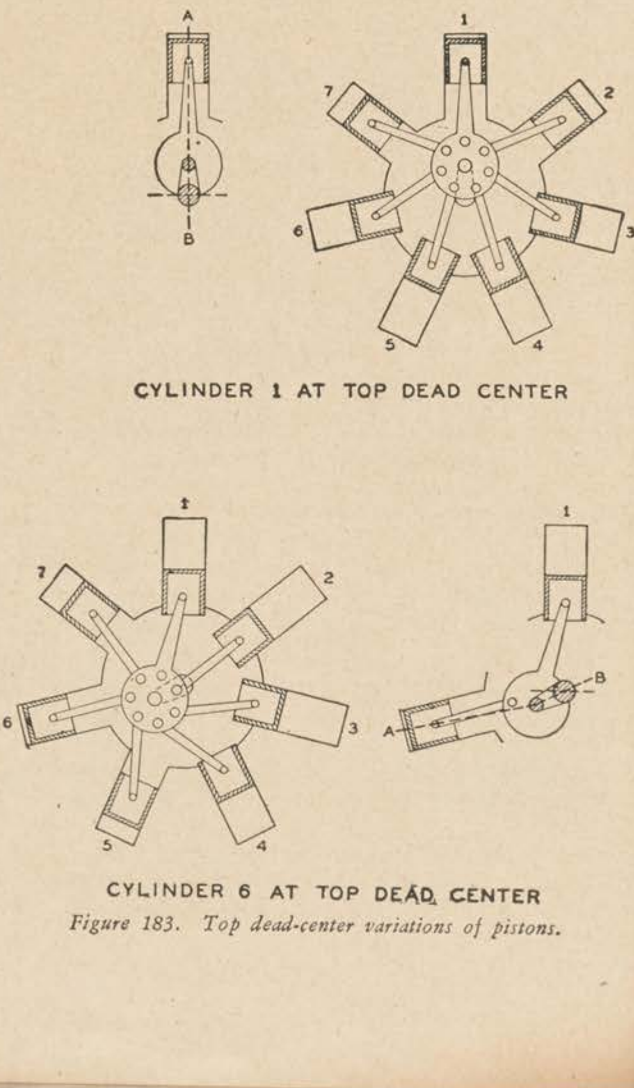


Figure 183. Top dead-center variations of pistons.

(2) Magnetos used with radial engines may be equipped with a compensated cam (one lobe for each cylinder). In this type of cam, the lobes are ground at unequal intervals to compensate for the top dead-center variations of each piston due to master and connecting rod design (fig. 183).

e. Condensers. The primary condenser is always connected across the points. It may be of several different shapes—round, flat, or square. It may be located in the breaker housing with the breaker points, on top of the coil, or in the coil housing. Whenever a secondary condenser is used, that is, a condenser in series with the secondary wiring, it is located internally in the coil form or in the distributor rotor.

by each coil assembly per revolution of the magneto drive shaft. The high voltage is distributed by two distributors mounted elsewhere on the engine. The double-type magneto is generally used on "in-line" engines. A double magneto is also designed for use on radial engines. This magneto is basically the same design as the double magneto used on "in-line" engines except that two compensated cams are added on some installations.

c. A base-mounted magneto is attached to a bracket on the engine by means of cap screws which pass through the bracket and into tapped holes in the base of the magneto (fig. 186). A flange-mounted magneto is attached to the engine by means of a flange on the magneto (fig. 187). The holes in the flange are slots which permit a

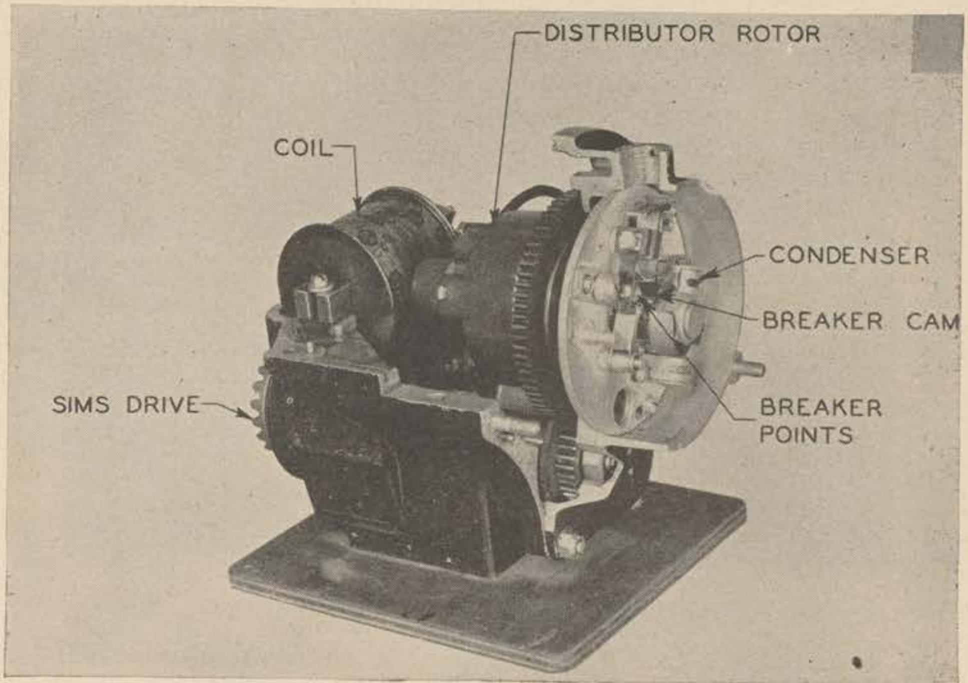


Figure 184. Cutaway view of Bosch magneto.

f. Shielding and coil cover. The magneto has a metallic cover which is made of a non-magnetic material; the cover joints are tightly fitted to prevent moisture and dirt from entering. The purpose of this metallic shielding is to prevent the ignition system from interfering with the radio circuits. Fittings are provided on the magneto to attach a shielded ignition harness so that the cables may be completely covered. Ventilation is provided to remove condensation and corrosive gases formed by the arcing in the housing.

81. TYPES OF MAGNETOS.

a. Magnetos are built in a number of different types. A cutaway of one of the common types is shown in figure 184. The design of each type depends upon the particular requirements of the aircraft engine on which it is to be used. In the Army Air Forces, one type of magneto can often be used on a number of different engines.

b. Magnetos are built in single and double types. The double types consist of two magnets (fig. 185). The double-type magneto contains two sets of breaker points; therefore, an equal number of sparks will be produced

slight adjustment, by rotation, in timing the magneto with the engine. The single-type magneto may be either base or flange mounted; the double-type magneto is always flange mounted.

d. The various types and models of standard aircraft magnetos are designated by letters and numbers which describe the magneto as follows:

Place in type designation	*Symbol*	*Description*
First	S	Single type
	D	Double type
Second	B	Base mounted
	F	Flange mounted
Third	9, 12, 14, etc.	Number of distributor electrodes
Fourth	R	Clockwise rotation (from drive-shaft end)
	L	Counterclockwise rotation (from drive-shaft end)

Place in type designation	Symbol	Description
Fifth	G	General Electric
	N	Scintilla
	A	Delco Appliance
	U	Bosch
	C	Delco Bemy (Bosch design)
	D	Edison-Splitdorf

Example: The type DF18RN (fig. 188) is a double-type magneto, flange mounted for use on an 18-cylinder engine. It is designed for clockwise rotation and is made by Scintilla. An additional number or letter in the type designation such as *1a* following a dash, denotes that some change or new feature has been incorporated in the magneto.

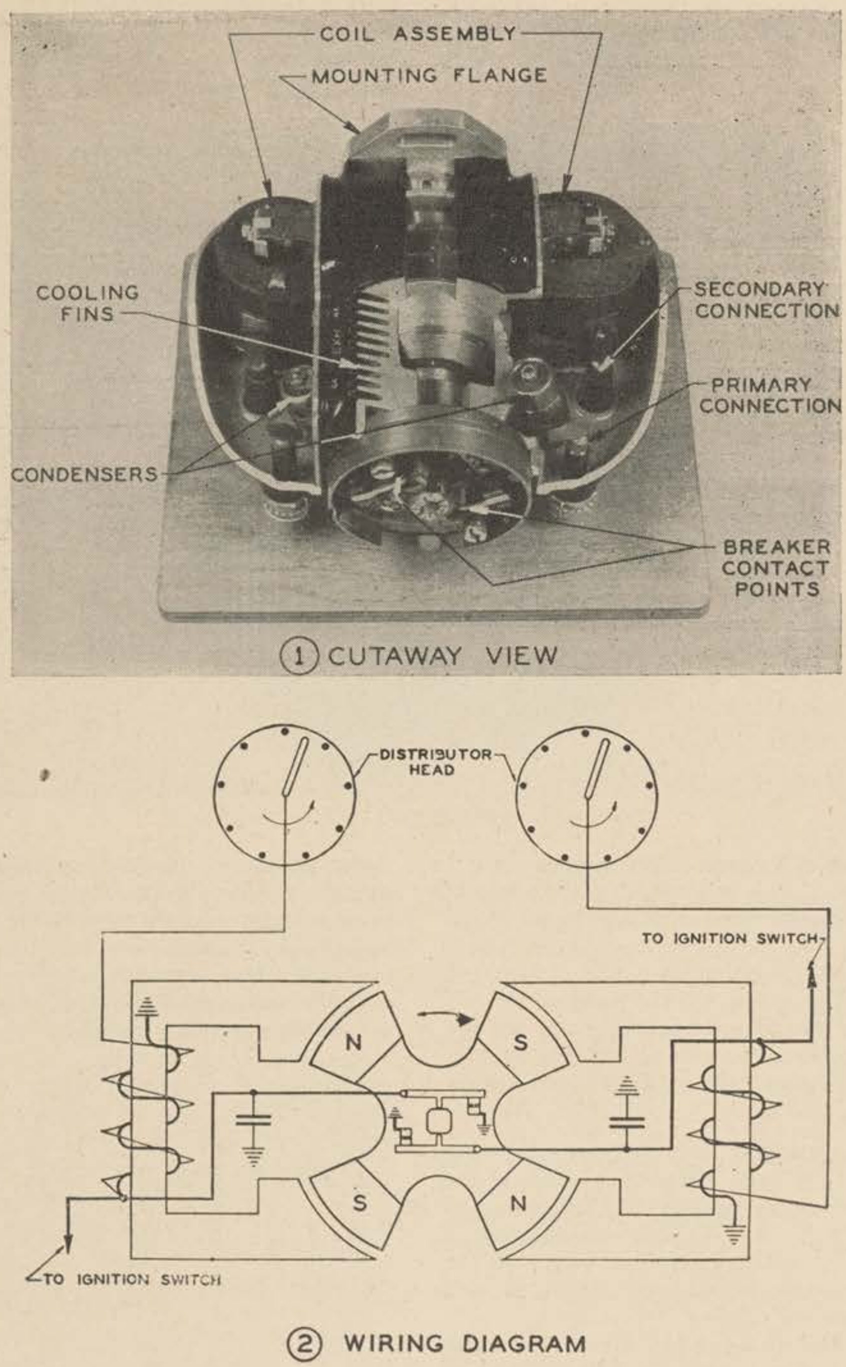


Figure 185. Double-type magneto cutaway and wiring diagram.

82. INTERNAL TIMING OF MAGNETOS. The manufacturer determines, for each model of magneto, how many degrees beyond the neutral position a pole of the rotor magnet should be in order to result in the strongest spark at the instant of breaker-point separation. This angular displacement from the neutral position, known as the *E*-gap angle, varies from 5 to 17 degrees depending upon the model. The rotating magnet will be in the *E*-gap position as many times per revolution as there are poles. A step is cut on the end of the breaker cam for internal timing of the magneto. When a straight-edge, laid across the step, coincides with the timing marks on the rim of the breaker housing, the magnet rotor is then in the *E*-gap position and the breaker contact points should be just opening (fig. 189). In a compensated

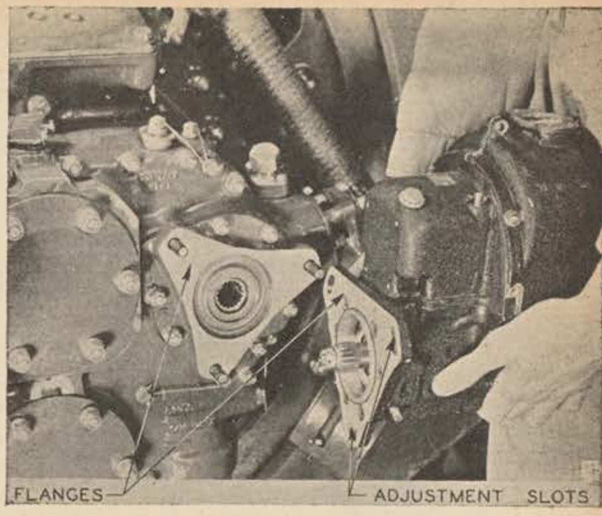


Figure 187. Mounting a flange-type magneto.

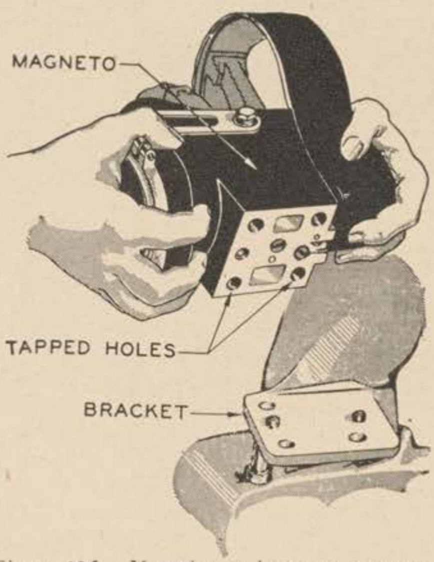


Figure 186. Mounting a base-type magneto.

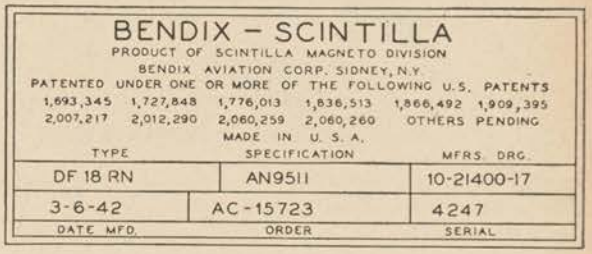


Figure 188. Plate numbering on a magneto.

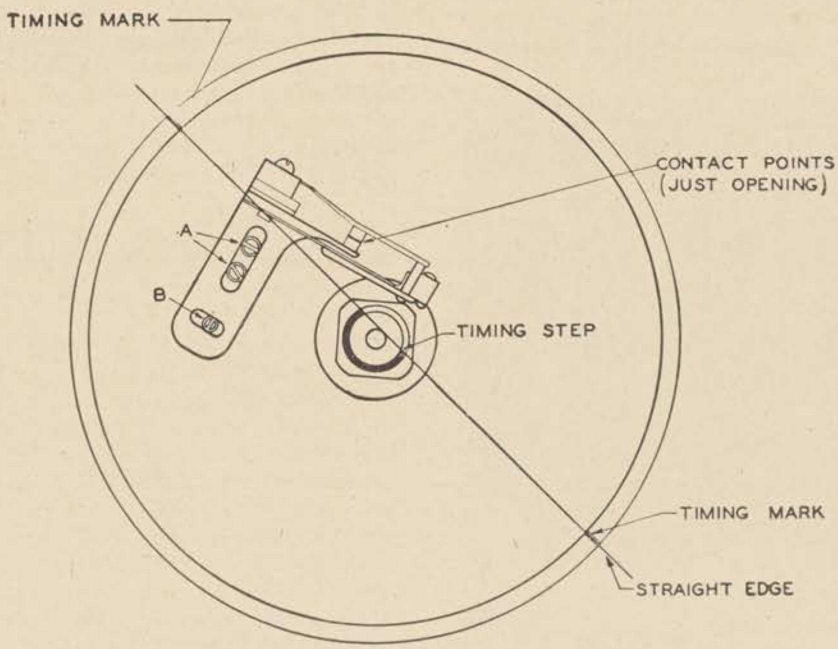
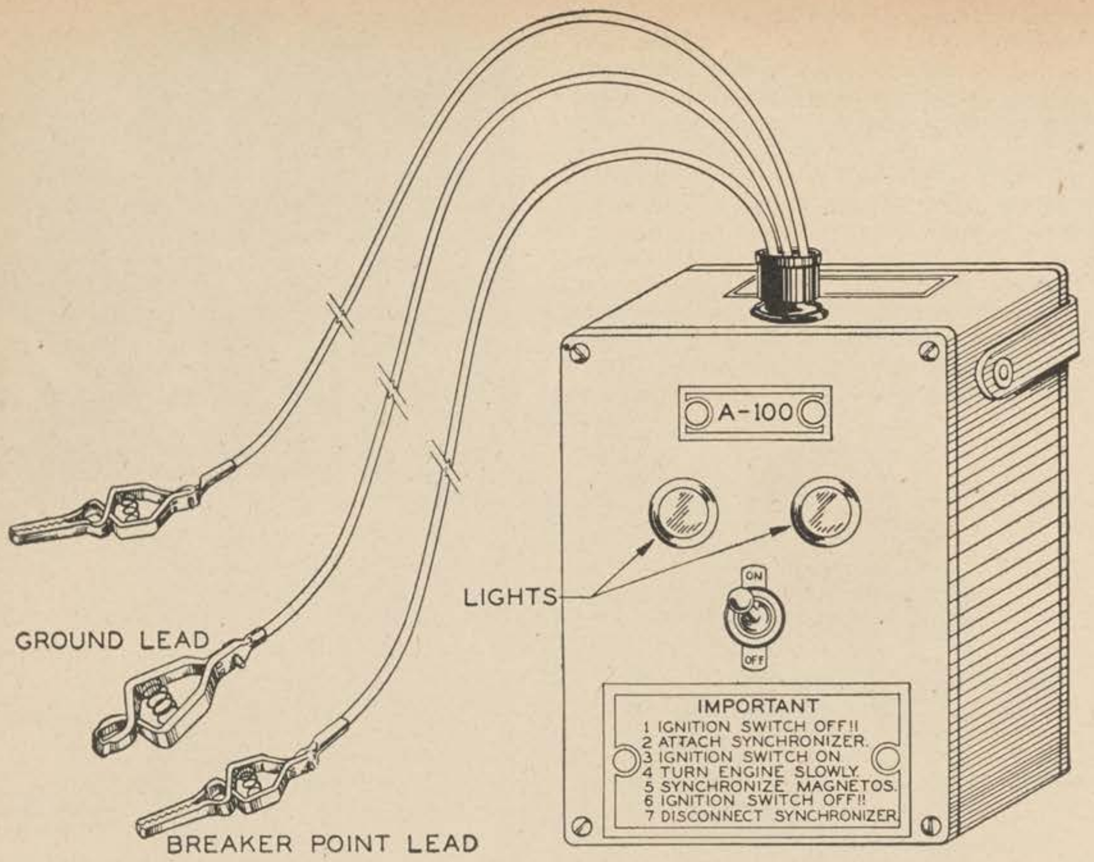


Figure 189. Internal timing of magnetos.



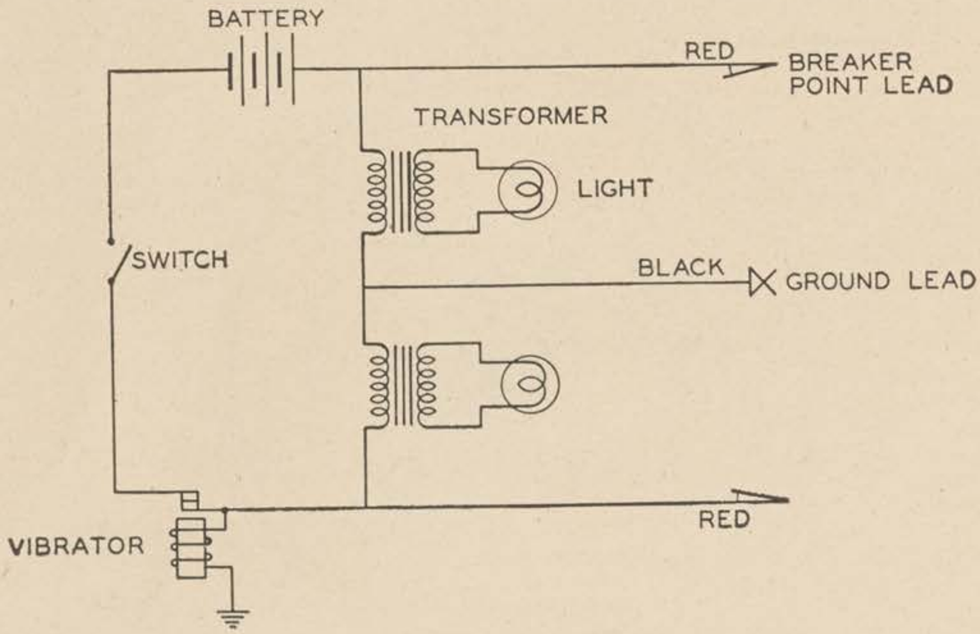


Figure 190. The Abbott synchronizer and its circuit.

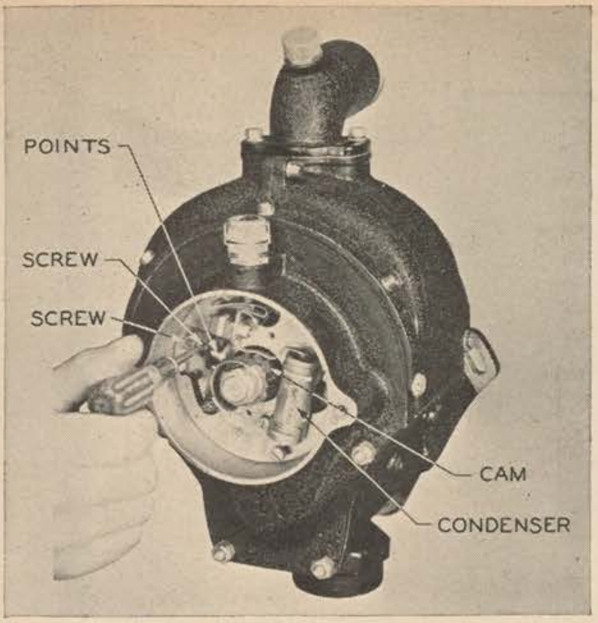


Figure 191. Loosening a lock screw.

cam, the cam may be put on in such a way that the step or timing marks will not mean *E*-gap position. An approved timing light or synchronizer is used to determine when the points have opened. An approved synchronizer and its circuit is shown in figure 190. When the points close, most of the current will flow through the points and not through the transformers; therefore, the light will not burn. When the points break the circuit, current flows through the transformer and the light will burn. The two magnetos are synchronized by this device. In adjusting the points, the technical order for each type of magneto should be consulted. In one common type of magneto, the points are adjusted by loosening two lock screws (fig. 191) and turning a third (eccentric screw) which raises and lowers the contact-point bracket. On all double magnetos, particular care should be taken to get the distributor finger in line with the correct segment. A finger not in line at the time of firing will increase the possibility of a "flash-over" in the distributor.

83. IGNITION BOOSTERS. a. A booster coil is a small induction coil (fig. 192). The booster coil has three terminals which, in figure 193 are marked *G, B* and *HV*. Terminal *G* is grounded while *B* is connected through the starter switch to the distribution bus for battery power. The *B* terminal connection may be routed through the magneto safety ignition switch, then the booster coil will remain inoperative, even if the starter switch is closed, until the magneto switch is placed in the "on" position. The terminal *HV* is connected to the trailing finger of one magneto distributor rotor. Later type coils for use on airplanes having one-wire electrical systems do not incorporate a "G" terminal. When battery voltage is applied to the coil, magnetism develops in the core until the magnetic force on the soft-iron armature, mounted on the vibrator, overcomes the spring tension and attracts the armature toward the core. This opens the contact points and the primary circuit which demagnetizes the core and allows the spring to reclose the contact points and complete the circuit. The armature vibrates rapidly, breaking and making the primary circuit as long as the battery voltage is applied to the booster coil. The booster coil generates high voltage by the same process as the ignition coil. This process is described in detail in paragraph 84.

b. The induction-vibrator starting coil is a source of interrupted *low* voltage for the magneto primary coil which induces a high voltage in the secondary for starting. This use of the vibrator eliminates the present booster coil and its high-tension leads and conduit. The advantage of the vibrator is that the magneto, without the booster finger, is less liable to "flash-over" at high altitudes (fig. 194).

(1) *Operation.* The vibrator supplies an interrupted battery current through the primary winding of the regular magneto coil. This coil then acts like a battery ignition coil, producing high-tension impulses which are distributed through the distributor rotor, distributor block, and cables to the spark plugs. This action occurs during the entire period that the magneto contact points are open. While these points are closed, no spark can be generated, although the vibrator continues to send interrupted current impulses through the magneto contact points with no harm to itself or any other part of the system.

(2) When the engine ignition switch is in the "on" position and the starter is engaged, the current from the battery is sent through the coil of the relay, causing the relay points to close (fig. 195). The closing of the relay points completes the circuit to the vibrator coil, and the vibrator produces a rapidly interrupted current. This current is sent through the primary winding of the magneto coil. High voltage is created in the secondary winding of the magneto coil by induction. This produces high-tension sparks. When the magneto contact points are opened, the sparks are delivered to the spark plugs through the magneto distributor-block electrodes. This

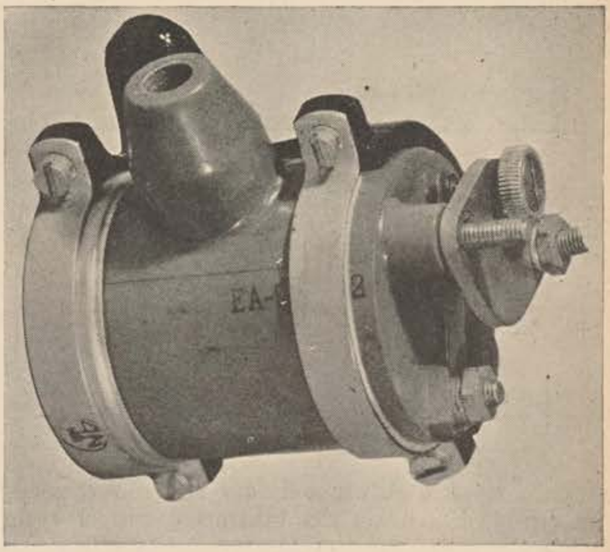


Figure 192. A booster coil.

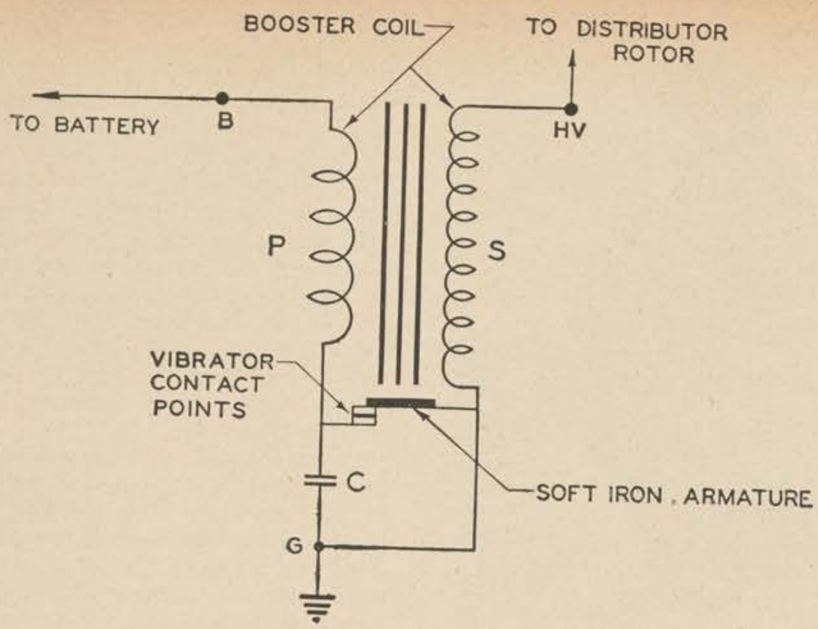
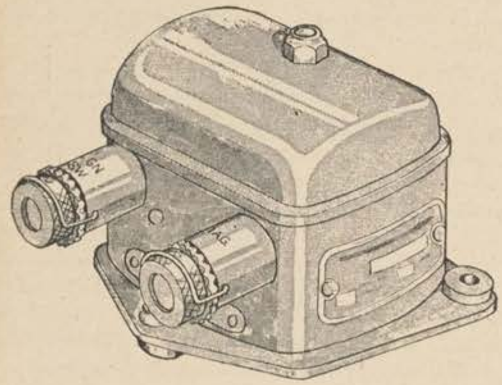


Figure 193. Diagram of ignition booster coil.



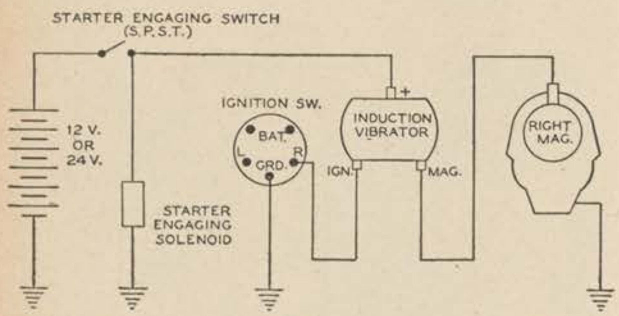


Figure 194. Induction-vibrator starting coil and its external circuit.

action is repeated each time the magneto contact points are separated, sending the interrupted current again through the primary of the magneto coil, where the action outlined occurs again. This action continues until the engine is firing under the regular magneto spark and the engaging starter is released.

c. The vibrator automatically starts to function when the switch is in the "on" position and the starter is engaged. It ceases to function when the starter is disengaged. Hence, no special operating instructions are necessary.

84. BATTERY IGNITION. In the type of electrical ignition referred to as battery ignition, an ignition coil, energized by a battery or generator, is employed as the source of high voltage. The other elements in the system are identical to those of the magneto ignition system except for the omission of a booster, which is not required since the system does not depend upon rotational speed of the magneto. A representative battery ignition system is shown in figure 196. The ignition coil does not possess a mechanical vibrator. A cam, with several flat surfaces, is geared to the engine shaft. A cam follower opens a pair of contact points and breaks the primary circuit each time a spark is required. Either manual or automatic control of the breaker mechanism may be provided for advancing or retarding the spark. Since the voltage which is applied to the primary by the battery always has the same direction, the polarity of the high-voltage impulses is always the same. This is in marked contrast to the output of a magneto; the high voltage impulses of a magneto alternate in direction. However, the heat of the spark created in the gap between the spark-plug electrodes to ignite the fuel, is independent of the polarity of the high voltage.

85. IGNITION SWITCHES. a. Control of ignition units, separately and in all necessary combinations, is provided at one point in the cockpit by the ignition switch. The ignition control switch for a magento functions oppositely from a switch which controls a battery-operated ignition unit. When a battery ignition unit is

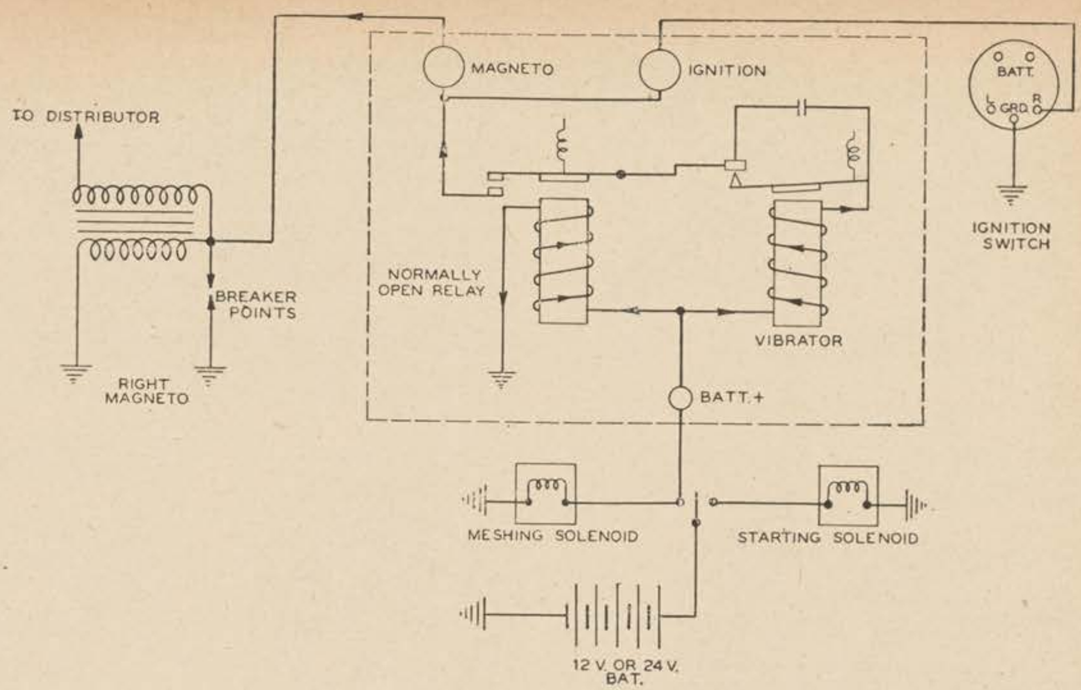


Figure 195. Schematic drawing of induction-vibrator starting coil.

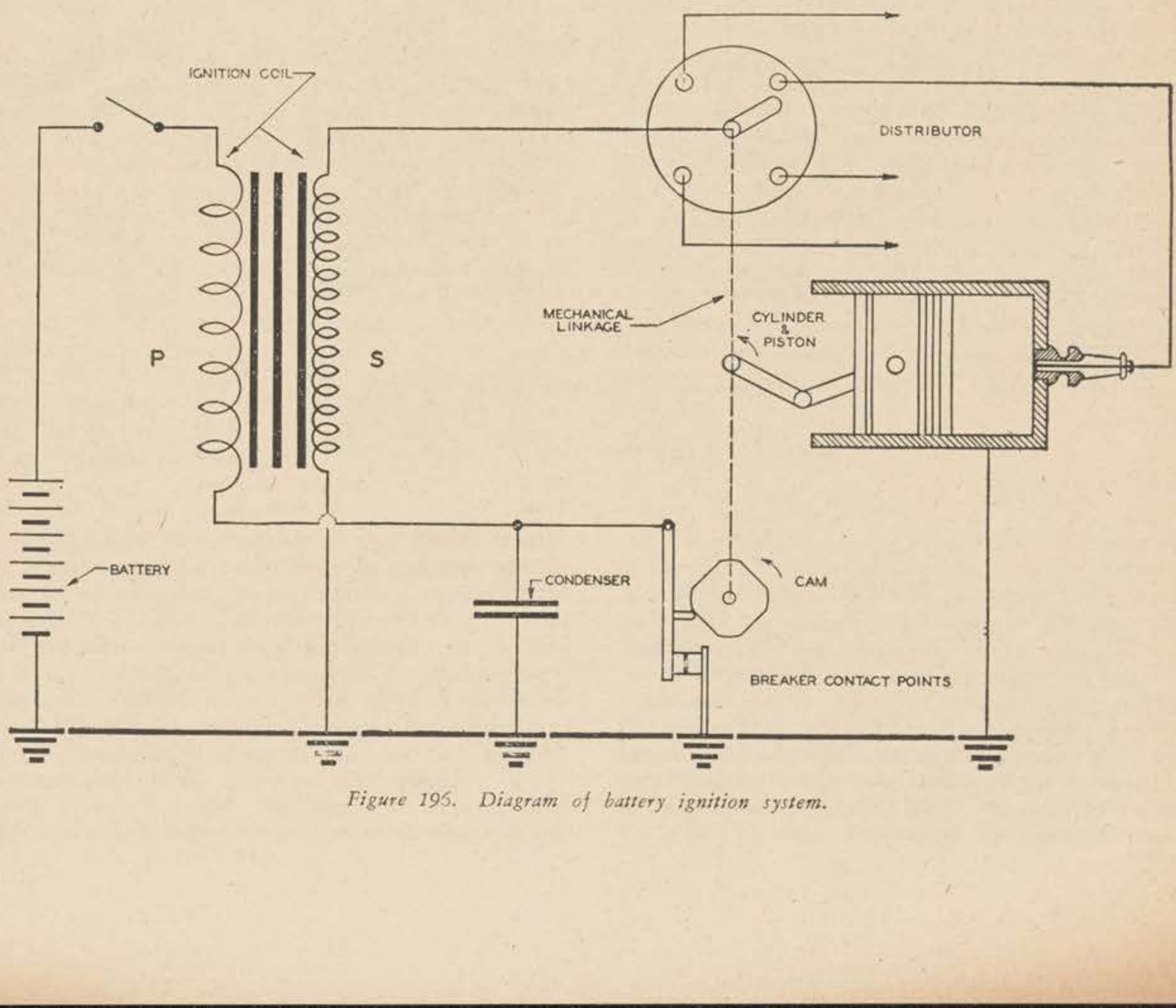


Figure 196. Diagram of battery ignition system.

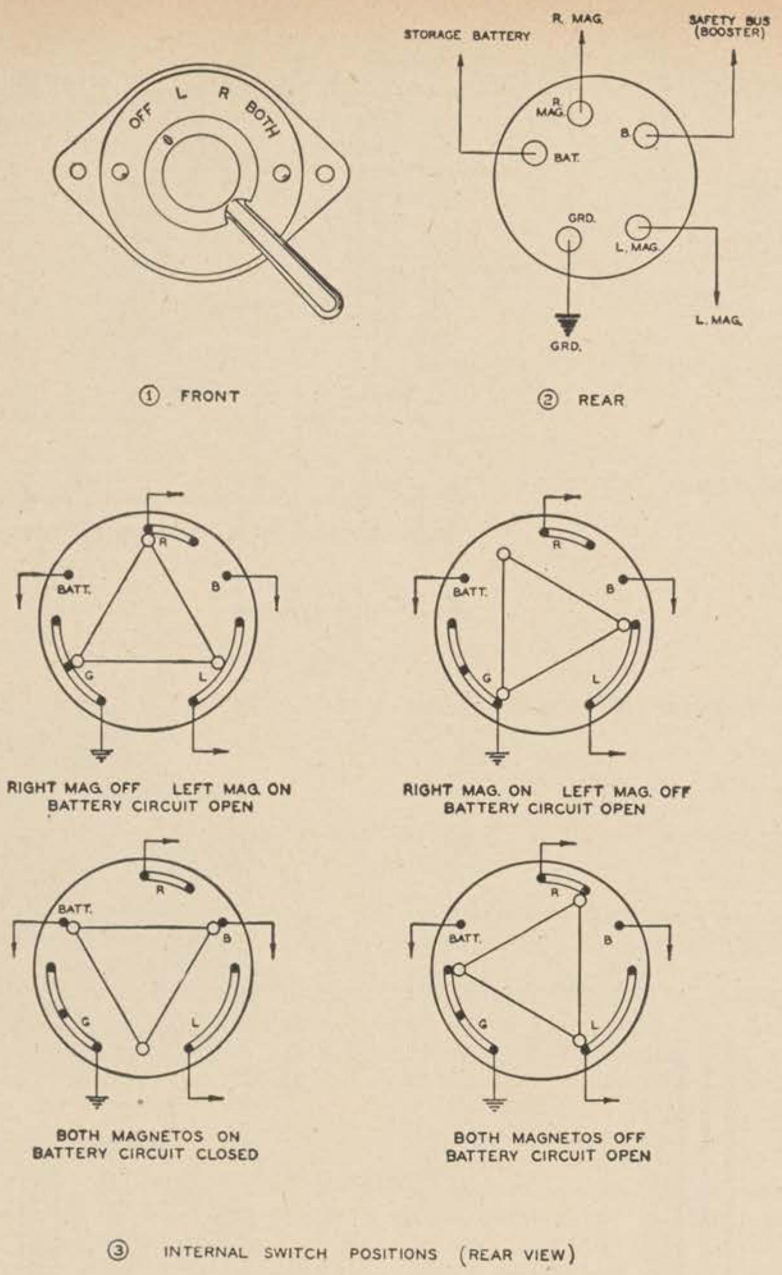


Figure 197. Single-engine magneto ignition switch.

inoperative, the control switch is open. When the control switch is closed, the circuit is completed and the ignition unit is operative. The control switch for a magneto is connected in parallel with the breaker points. In the "off" position, the switch is closed, thereby short-circuiting the breaker points. Thus, the magneto is inoperative because no interruptions of primary current occur even though the breaker points are successively opened and closed. When the control switch is in the "on" position the switch is open; the magneto is then operative because the primary current is interrupted by the action of the breaker point.

b. A switch used in connection with a single-engine ignition system will control the two magnetos and the battery circuit. One type of single-engine ignition switch (A-8) has four positions—"off," "left," "right," and "both" (fig. 197). With this switch in the "off" position, both the magnetos are grounded and the battery circuit open. In the "left" position, only the left magneto is operative and the battery circuit is open. In the 'right" position only the right magneto is operative. In the "both" position both magnetos are operative and the battery circuit is completed. Another type of single-engine ignition switch (A-9) has five positions— "off," "battery," "left," "right," and "both" (fig. 198). This switch is similar in appearance to the other single-engine ignition switch. Its battery circuit, however, can be completed individually and it remains "on" when the switch is in the "left," "right," and "both" positions.

c. The twin-engine magneto ignition switch (fig. 199) provides independent control of *each* magneto on *each* engine. In addition, it includes an emergency safety switch which, in the "off" position, grounds all magneto primaries and opens the battery circuit leading to the battery relay. The switch must be placed in the "on" position before the engines can be started. The terminal connections at the rear of the switch are shown in figure 200.

d. The basic functioning of the A–2A–10 twin-engine ignition switch is the same for the other types of twin-engine ignition switches. However, this switch, which is disappearing from use, operates in a slightly different manner. The A–2A–10 emergency safety switch is of the push-pull type instead of the toggle type utilized in other models. In addition, the individual magneto switch levers both move in a clockwise direction from "off" to "both" positions instead of moving in opposite directions as in the case of other twin-engine switches.

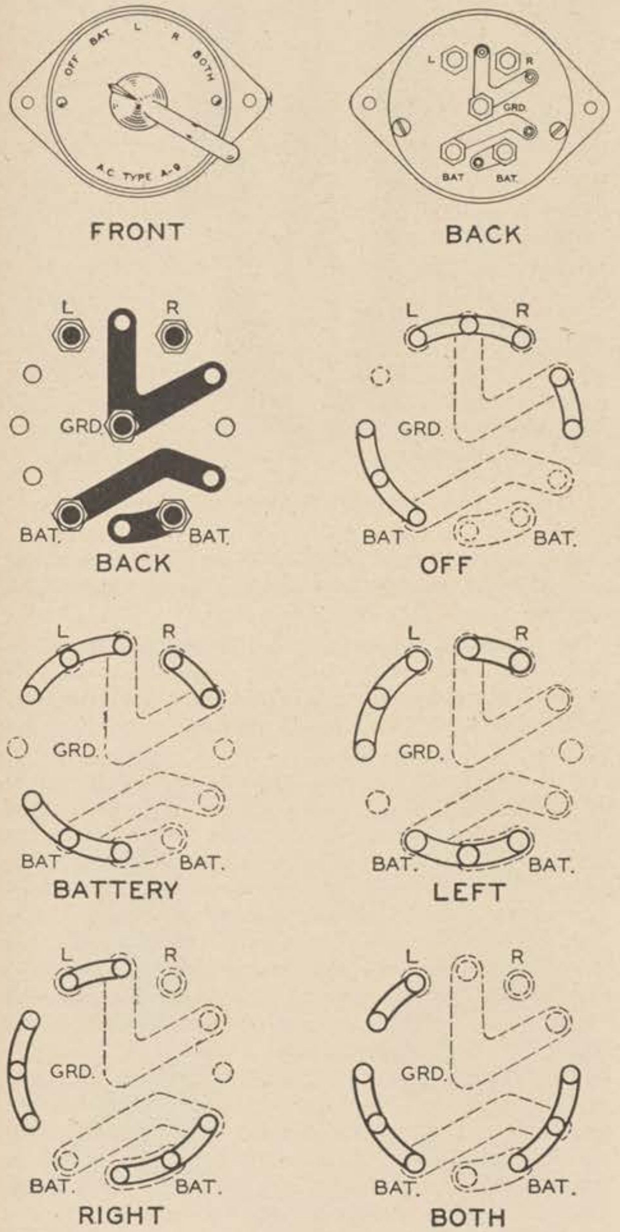


Figure 198. Single-engine magneto ignition switch A–9.

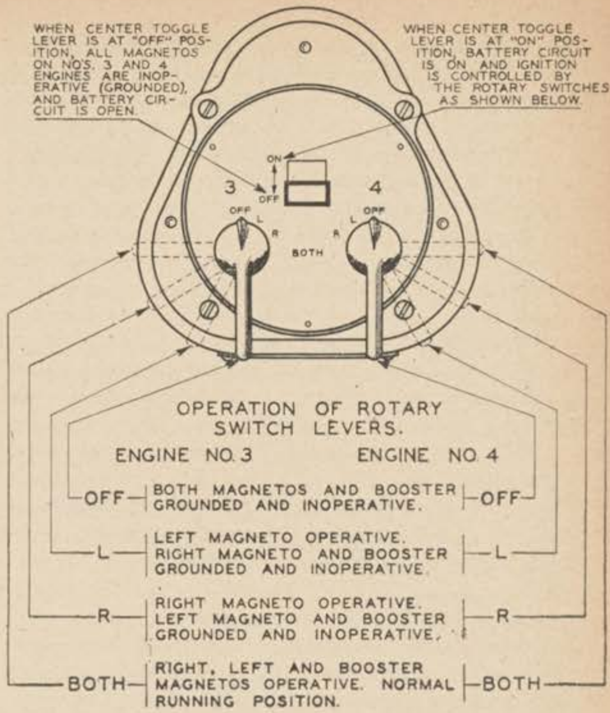


Figure 199. Front view of twin-engine magneto ignition switch.

86. IGNITION-SYSTEM WIRING.

a. Low-tension wiring. The low-tension wiring used on a magneto consists of a single conductor from the primary coil to the ignition switch. This wire is always shielded and is taken through the fire wall with a connector plug. The connector plug is often of a special design which automatically grounds the magnetos when the plug is disconnected.

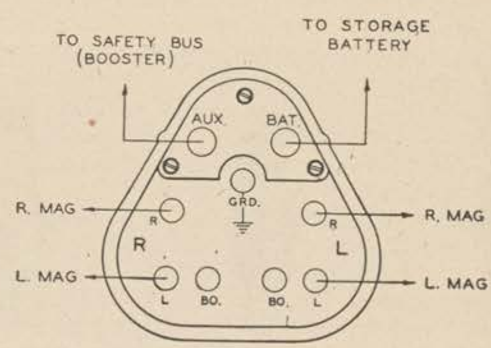


Figure 200. Terminal connection at the rear of the switch.

b. High-tension cable. The high-tension wire is always placed in a special conduit arrangement called the ignition harness. This harness, which consists of both flexible and rigid conduits, is so designed that its shielded portion fastens directly to the magneto shield and also to the shielded portion of the spark plug. The new type cable used in the high-tension system incorporates a conductor made up of several strands of small wire, a layer of rubber, a glass braid covering, and a neoprene sheath. It is used in three sizes: 5-mm, 7-mm, and 9-mm. The 5-mm size is used for spark-plug leads on engines of all series while the 7-mm and 9-mm sizes are used for magneto-to-distributor leads on some series. It will be noted that high-tension cable differs from low-tension cable in that the former incorporates a conductor of small cross section and insulation of comparatively large cross sectional area, while comparable low-tension cable has a large diameter conductor and a thin sheath of insulation. Current-carrying capacity is of primary importance in low-tension cable, whereas, dielectric strength is of primary importance in high-tension cable.

87. SPARK PLUGS. a. General. (1) The spark plug is that part of the ignition system which converts the high voltage electrical energy produced by a magneto or similar device into the heat energy required to ignite the combustible mixture in the cylinder. It is composed essentially of a high-tension conductor serving to introduce the electrical energy into the combustion space and a gap across which a spark will jump when the electrical pressure (voltage) is sufficient to break down the resistance of the gases in the gap space.

(2) Because of its simplicity of design and the comparative monotony of its maintenance procedure when large numbers of units are involved, some personnel feel that a spark plug is unimportant and tend to grow careless in the performance of spark-plug servicing and reconditioning. It is true that present types of aircraft plugs are simple in design, fairly rugged, and, in some organizations, are monotonous to work on because of the procedure followed. However, there is no item of equipment on an airplane which is more vital to its proper operation and continued flight than its spark plugs. When it is considered that improper maintenance of a small number of spark plugs can result in the loss of several men's lives and an airplane costing many thousands of dollars, it is seen that only experienced maintenance personnel should handle spark plugs and that spark plugs must be afforded the same painstaking care which is given to other more intricate parts of the airplane.

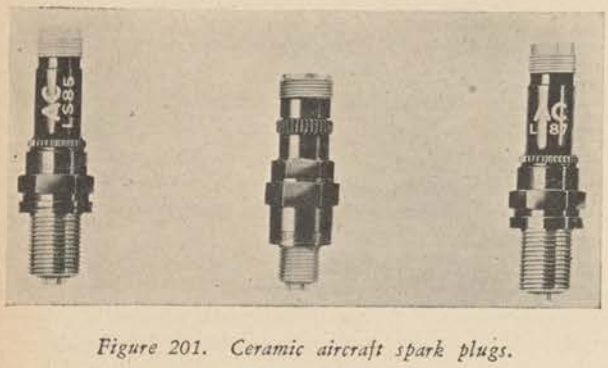


Figure 201. Ceramic aircraft spark plugs.

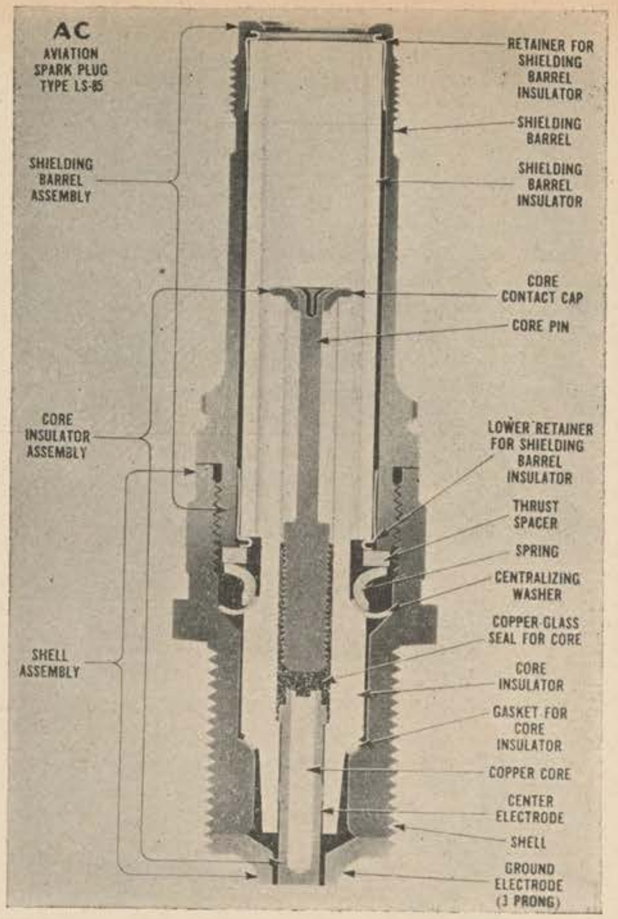


Figure 202. Cross-section of ceramic spark plug.

b. Structural features. The general type of spark plug most universally used for high-output aircraft engines (fig. 201) has ceramic insulation and consists of three main parts: the core assembly, the shell, and the shielding barrel (fig. 201).

(1) The center electrode is a continuous metallic lead, as shown in figure 202, conducting the high voltage from the contact cap at its upper end to the high-tension electrode of the spark gap which forms its lower end. The upper cap is contacted by a spring conductor which is part of the ignition-harness spark-plug terminal. The center electrode is insulated from the adjacent grounded metallic part, that is the shell, by a ceramic core insulator. Cement or other high-temperature pressure-sealing material is used to maintain a gas-tight seal between the center electrode and its insulator.

(2) The shell and radio shielding barrel form the external portion of the spark plug and complete the ground circuit for both the ignition system and the radio shield. These may be constructed in two pieces or machined as a single piece. In any case ceramic spark plugs are considered as one piece and must not be disassembled, as pressure tightness on the 2-piece type of spark plug depends upon the application of the correct

tension during assembly. The shell is externally threaded to screw into the cylinder head and has an hexagonal portion for application of the spark-plug wrench. The lower end of the shell carries the grounded electrodes of the spark gap. The shielding barrel is a steel sleeve threaded at its upper end to provide continuity with the ignition-harness shielding. Internally, the barrel is fitted with an insulating sleeve of mica or ceramic material to provide electrical separation between the center contact and the grounded barrel. A seal composed of gaskets or cement is provided between the shell and the core insulator.

(3) Unshielded spark plugs, figure 203, are used on engines installed in airplanes which are not equipped with radio. Such engines are low-output types used in training. The unshielded spark plug is similar to the shielded type except that it lacks a barrel and has a snap-on type of connection.

(4) The threaded portion of the shell has been standardized to two lengths, designated long and short reach, and two diameters, 18-mm and 14-mm. Generally, long-reach spark plugs are used in high-output engines.

c. Operating characteristics. The operating characteristics of a spark plug are determined by its design, the characteristics of the engine in which it is installed, and the type of engine operation imposed upon it.

(1) The temperature that the portion of the core insulator exposed to the hot combustion gases will assume in a given engine is an important characteristic of a spark plug. The operating temperature is inherent in spark-plug design. It is determined by the resistance of the internal heat-exchange path in the spark plug. This path is generally from the core insulator tip to the lower internal-gasket seat, through the gasket to the spark-plug shell, and into the cylinder-head material through the external gasket. The longer this heat path, that is, the greater its resistance to heat flow, the higher will be the operating temperature of the spark plug. A satisfactory spark plug for a given engine is one whose operating temperature is not so cold that it will oil-foul when the engine is idling nor so hot that it will cause pre-ignition at maximum engine output.

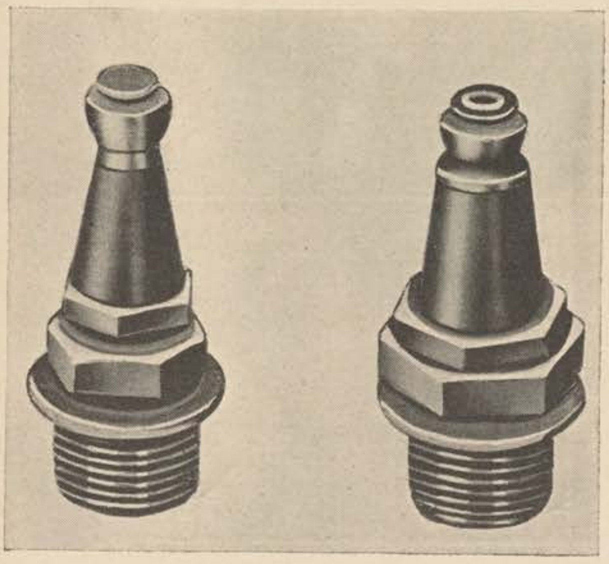


Figure 203. Unshielded ceramic spark plugs.

(2) Aircraft spark plugs formerly used incorporated mica insulation, both in the firing chamber and in the shielding barrel. This material was subject to moisture and lead absorption and, therefore, was not entirely satisfactory for spark-plug insulation. Aircraft spark plugs now in use incorporate ceramic insulation which is not subject to lead or moisture absorption and which has a much greater resistance to high temperatures than porcelain material used in automotive spark plugs. In addition, ceramic material is more adaptable to mass-production methods than is mica material.

(3) Operation of a spark plug (sparking) is accompanied by removal of metal from both the ground and center electrodes (gap erosion). The effect of such erosion is to increase progressively the spark-gap width and consequently the voltage required to force a spark across the gap. Too wide a gap will result in misfiring, rough engine operation, and perhaps even detonation. Periodic removal of spark plugs is necessary to reset the gaps to within the allowable limits. This is particularly true on airplanes which operate at high altitudes. The insulating efficiency of the less dense air at these altitudes is considerably reduced and the consequent electrical leakage may so reduce the voltage available at the gap that sparking will not occur when the gap width is above the designated limits. Latest design ceramic spark plugs incorporate a resistor in the center electrode. This has the effect of reducing gap erosion because the added resistance in the high-tension circuit reduces current flow at the instant of gap breakdown (sparking).

88. MAINTENANCE. a. Magnetos. (1) Check the breaker assembly by removing the breaker cover and inspecting for general cleanliness, damaged or worn cam follower, and proper felt lubrication. If major defects are found replace the breaker assembly. In the pivotless-type breaker, cam-follower wear is indicated by a small depression where the cam follower lifts against the end of the main spring. The clearance between the cam follower and the main spring is checked with the breaker assembly removed. Felt lubrication is satisfactory if oil appears on the surface when the felt is squeezed with the fingers. If the felt is dry and requires lubrication, do not apply too much oil for the excess oil may be thrown onto the contact points during operation; this will cause the points to burn and pit. Oil must not show on the surface of the felt except when the felt is squeezed.

(2) Check the main breaker spring for proper tension with an appropriate spring-tension gauge.

(3) With the breaker assembly installed, check for worn or loose cams and cam bearings by turning the engine crankshaft and measuring the opening of the contact points for each lobe of the breaker cam.

(4) When checking the condition of the contact points of the pivotless-type breaker, do not raise the main breaker spring beyond one-sixteenth of an inch (clearance between the contacts). A further separation may weaken the spring and result in faulty operation. If contact points are excessively burned or pitted, they should be replaced (see applicable Technical Order).

(5) Check the internal timing of the breaker contact points. With the pivotless-type breaker points, use a timing light or a thin strip of shim stock. Do not use cellophane or cigarette paper because of the danger of leaving a tiny piece between the points. As the crankshaft is turned, the light will indicate point opening or the shim stock will become free when the straight edge

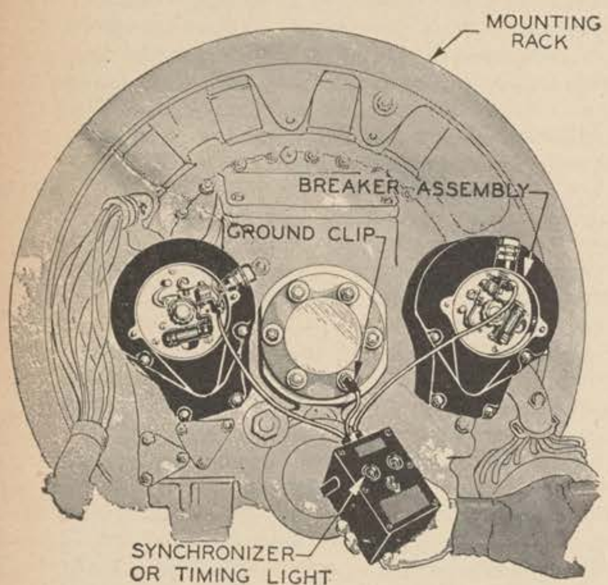


Figure 204. Checking the timing of the breaker contact points.

is lined up with the timing marks (fig. 204). Permissible service tolerances (maximum distances which may be permitted between the straight edge and the timing mark on the rim of the breaker housing) are given in the Technical Order for the particular type of magneto. If the adjustment is not satisfactory, the lock screws *A* (fig. 189) are loosened, the eccentric pin *B* (fig. 189) rotated until the proper adjustment is obtained and then screws *A* (fig. 189) are retightened. The adjustment is rechecked. When checking the contact-point clearance on the *lever-type* breaker, rotate the engine crankshaft until the lever rests upon the peak of any lobe of the cam and adjust the contact-point clearance in accordance with the applicable Technical Order.

(6) Check the distributor head and distributor finger for cracks and results of electrode arcing. Check the distributor finger for security of mounting. Check distributor block and rotor for cleanliness. If carbon dust or oily finger prints are found on the distributor block they should be removed. If the distributor is dirty, clean with acetone and a stiffly-bristled brush. Check for sticking or broken brushes. Determine that proper ventilation is being obtained by checking lines and/or vent screens for cleanliness.

(7) Magneto ball bearings and gears do not require lubrication between overhaul periods.

(8) Check security of magneto mounting.

(9) The magnetos are individually checked while the engine is operating at cruising manifold pressure. Operate the engine on *one* of the magnetos for 15 seconds and observe the tachometer to see that the decrease in r.p.m. does not exceed the amount specified in the Technical Order. The switch should be turned back to the *"both"* position to allow the engine to operate normally before the *other* magneto is checked. Magnetos which permit an excessive loss of r.p.m. should be replaced after definitely determining that the magneto is the cause of the r.p.m. loss.

(10) When it becomes necessary, during magneto maintenance, to disconnect the primary ground lead, be sure this lead is grounded. When the primary ground lead is open the magneto is in the "on" position.

b. Spark plugs. (1) Check the terminal connection of unshielded spark plugs for condition and security.

(2) Check the barrel core nut (of mica-insulated plugs only) for tightness and if it is loose, remove the plug for tightening; special tools are used for the tightening process. After tightening, the gap clearance is checked. Before reinstalling, check the threads of the spark plug for evidence of damage and apply specified lubricant to the threads of the base.

(3) Check the shielded spark-plug elbow terminal and shielding nuts for condition and security. *A snug but not-too-tight fit is desirable.*

(4) Check shielded-type spark-plug terminal for mechanical or insulation failure and for accumulation of moisture.

(5) When spark plugs are removed from an engine, they should be set out in a row for comparison. Be sure to identify each plug with the cylinder from which it was taken. Before installation, visually inspect the ceramic core and shielding-barrel insulator for cracks and check gap clearance for proper tolerance in accordance with the applicable Technical Order.

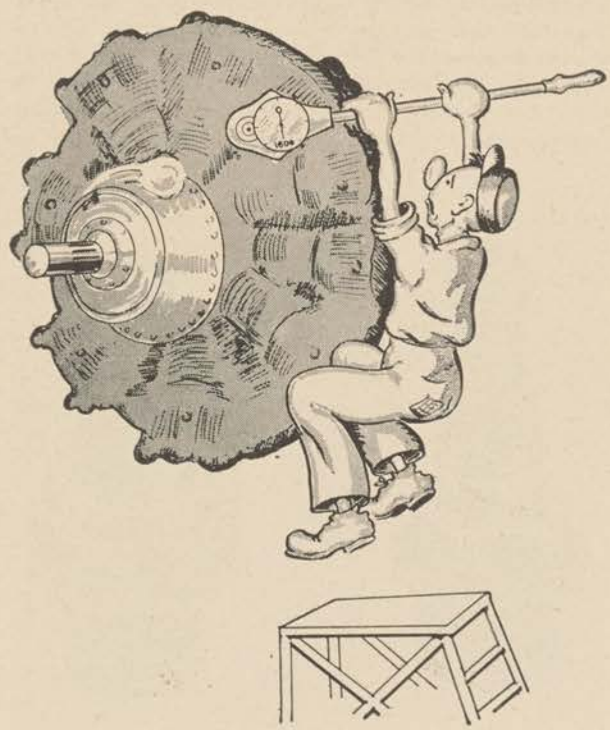


Figure 205. Do not tighten plugs excessively.

(*a*) If the plug is clean and the metal parts show sign of overheating, the cylinder has been running "hot." This indicates pre-ignition, detonation, or inadequate cooling.

(*b*) If the plug is generally clean but is wet with gasoline or covered with a film of fresh oil, no conclusion should be drawn on this basis alone; the appearance of the plug may have been caused by conditions which were present at the moment the engine was stopped.

(*c*) Caked carbon on a spark plug is evidence of excessive oil consumption or that the plug has not been firing because of magneto failure, terminal wire defects, or a failure of plug to clean-up after starting.

(*d*) A thin layer of black soot on the nose of an insulator which otherwise appears free from deposits may be an indication that the plug has not been operating hot enough. If this condition exists, check in Technical Orders for approved plug for that engine. The plug may have to be changed.

(6) Use proper tools when removing or installing spark plugs. Install new gaskets where necessary and do not tighten the plugs excessively into the cylinder bosses (fig. 205). This is very important. The use of an excessive installation torque will result in stretching of the spark-plug shell with resultant loss of the gas-tight seal. This, in turn, will allow gas leakage and high-tension failure and, in more severe cases, complete loss of internal parts.

c. Ignition switch. (1) Check the switch mounting, terminal connections, plugs, and leads for security and condition.

(2) With the engine running at approximately one-third throttle, turn the ignition switch, momentarily, to the "off" position; if the engine does not entirely cease firing, a defective switch and/or connection are indicated. During the test, the engine must not be excessively hot. The period when the switch is in the "off" position must be brief to insure that an excessive charge of fuel does not accumulate in the cylinder or that the spark plugs do not become fouled with oil. If the engine does not cease firing when the switch is placed in the "off" position, the engine can be stopped by cutting off the fuel. After the engine has stopped, do not rotate the propeller until the cause of the trouble has been found and corrected.

d. Ignition boosters. If a battery-operated ignition booster is installed, check the contact points for condition. Dirty or pitted points may be resurfaced with an oilstone and then washed with carbon tetrachloride. If no vibrating sound can be heard when the switch is closed, check the battery circuit at the switch and coil terminal. This trouble, provided the battery circuit is complete to the coil, probably results from defective contact points or open primary winding; if the latter is true, the booster will be replaced. If the vibrating sound can be heard when the switch is closed and the booster does not furnish secondary voltage, the probable trouble is a defective secondary winding and replacement of the booster is required.

e. Ignition cable. (1) Check ignition manifold, for cracks, dents, moisture, anchorage, and lead connections. Check spark-plugs leads for broken or worn conduit, and securing of lead attachments to spark plugs. Check spark-plug lead terminals for contact, broken springs and ceramic insulation, also for security of attachment to lead cable.

(2) Trouble in the ignition cables is usually the result of rough handling of spark-plug leads, vibration, or loose cable clamps. Sometimes excessive engine heat and adverse weather conditions cause trouble within the ignition manifold.

MOTOR SYSTEMS

89. GENERAL. Electric motors on an airplane produce mechanical motion from electrical power for the operation of a great number of units. Some of the units operated by electrical motors are the starter, landing-gear mechanism, trim tabs, retractable landing lights, electrical variable-pitch propeller, fuel pump, engine-cowling flaps, de-icing equipment, dynamotor, inverter, turret, wing-flap mechanism, heaters, propeller governors, bomb-bay doors, hydraulic pumps, automatic pilot, etc.

90. DIRECT-CURRENT MOTOR CONSTRUCTION. **a.** The direct-current motor is constructed in much the same way as the d-c generator. However, the windings are usually heavier, particularly the field windings of a series motor. Usually the motor is not built as heavy as the generator since it is used for shorter periods. Figure 206 compares a motor to a generator. An example of a motor being used for a short period of time is the starter motor. It is used for less than a minute to energize the starter.

b. The following parts of a d-c motor are similar to those of a d-c generator (fig. 207).

(1) The *armature* is the rotating part of the motor. The parts of the armature are the shaft, commutator, core, and armature windings.

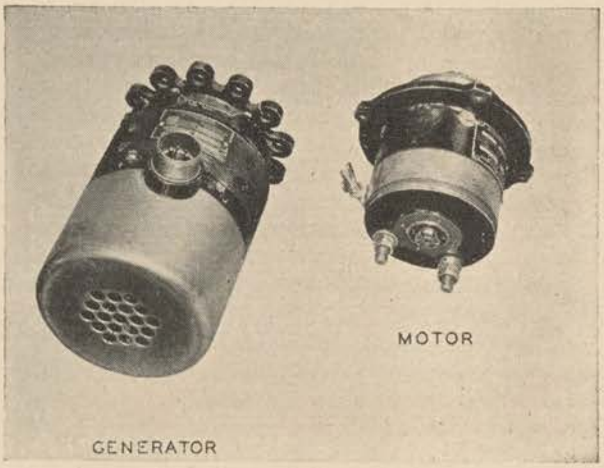


Figure 206. Direct-current generator and motor.

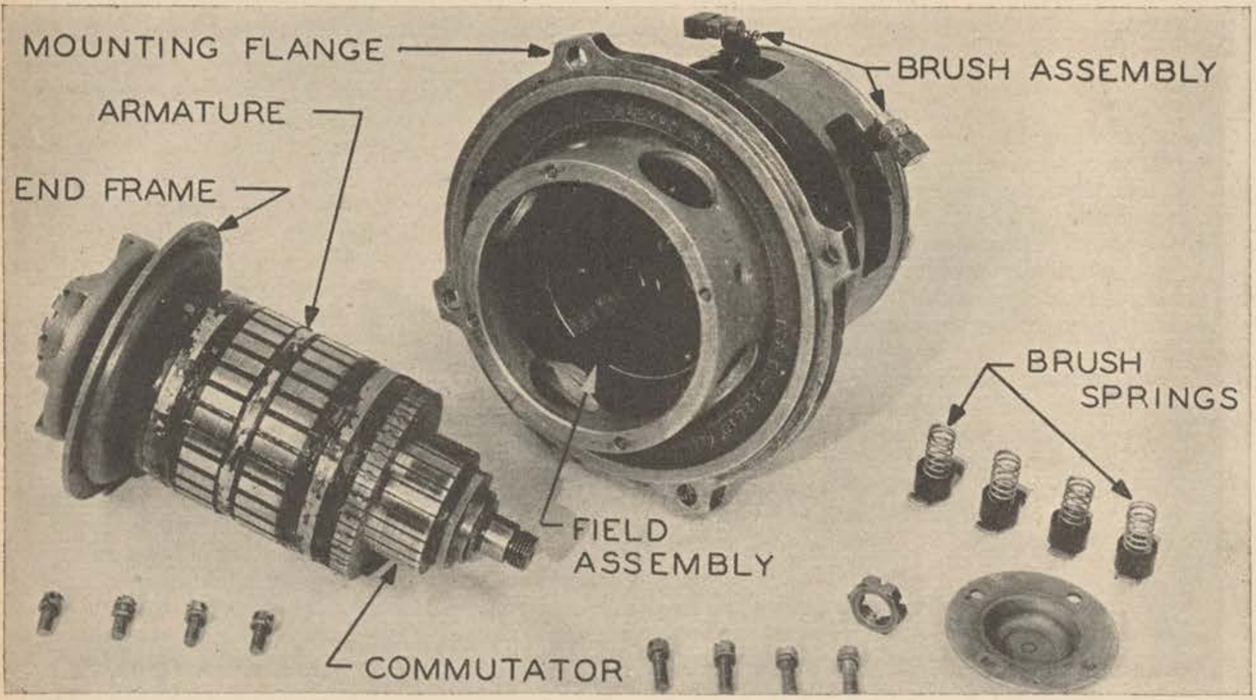


Figure 207. Parts of a d-c motor (Eclipse starter motor).

(2) The *field assembly* is mounted in the frame along the inner wall of the housing. The field assembly is made up of the pole pieces and field windings.

(3) The *brush assembly* consists of the brushes and brush holders and is usually built into one of the end plates which forms the support for one of the bearings. The brushes ride on the commutator and serve to conduct electricity to the commutator and through it to the armature windings.

(4) The *end frame* opposite the commutator is usually designed to fit the gear box of the unit it is driving. The drive-end bearing is also located in this end frame (fig. 208). In some special cases the end frame is machined as a part of the unit the motor drives. When this is done the bearing on the drive end may be located in any one of a number of places.

91. TYPES OF MOTORS. a. General. There are fundamentally two types of d-c motors: the shunt-field motor and the series-field motor. In some special installations a compound motor is used.

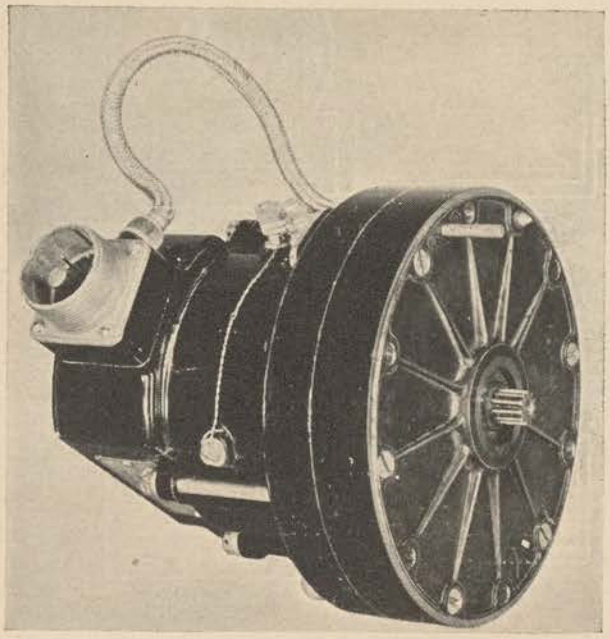


Figure 208. Jack and Heintz starter motor.

b. Shunt-field motor. The shunt-field motor has a high-resistance field connected across the armature. The speed of a shunt motor can be varied with a rheostat placed in series with the field (fig. 209). The speed of the motor will vary inversely with the applied field current, that is, an increase of field current will slow down the motor. The shunt motor has the characteristic of maintaining a constant speed under load. The shunt motor has a very low starting torque, which eliminates it from some applications on the airplane; however, it is used on pumps, inverters, in the amplydyne circuit for turrets, etc.

c. Series-field motors. The series motor has a few turns of low resistance wire for the field which is connected in series with the armature (figure 210). The

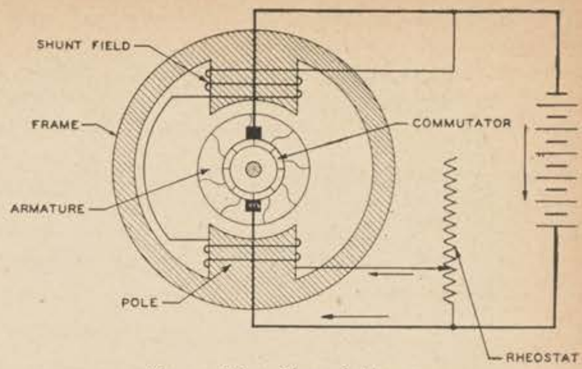


Figure 209. Shunt-field motor.

series motor has the characteristics of high speed and high starting torque. The speed of the motor varies with the load. The motor is always directly coupled with the load. The series motor will fly apart due to speed when run without a load on rated voltage. This motor has wide use on modern airplanes. Several variations of the series motor are used but they all have the same general characteristics.

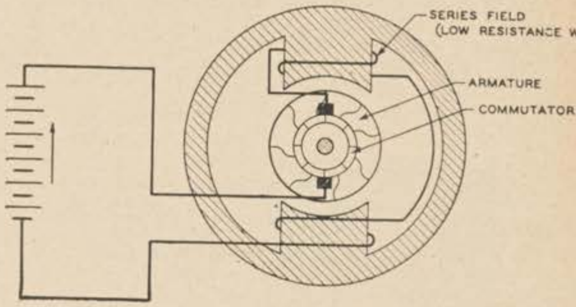


Figure 210. Series-field motor.

d. Compound-wound motors. The compound motor is used where the combined characteristics of the shunt- and series-field motors are desired—that is, where a motor which will run at a somewhat constant speed and have a greater starting torque than a shunt motor is desired.

e. Reversing the direction of rotation. In any direct-current motor the direction of rotation may be reversed by changing the direction of current flow in either the armature or the field, but not both. The two common methods of reversing the direction of the rotation of a motor are split field and D.P.D.T. (double-pole double-throw) switch.

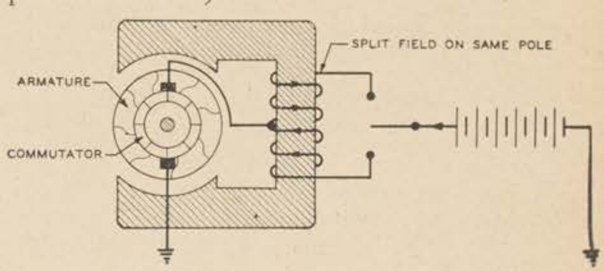


Figure 211. Series motor with two field windings in opposite directions on the same pole pieces.

(1) Split-field motors are used where the two directions of rotation of the motor are required. The split field is actually two field windings wound in opposite directions on the same pole pieces or two separate fields wound on alternate pole pieces as shown in figures 211 and 212.

(2) The D.P.D.T. switch is a means of changing the direction of current flow in either the armature or field. Figure 213 illustrates the reversing of the current through the field with the armature current remaining unchanged in direction.

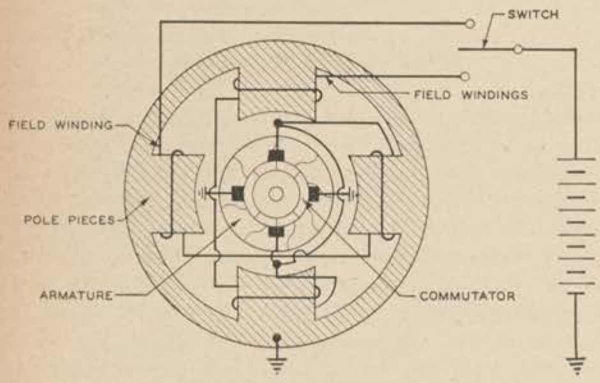


Figure 212. Series motor with two separate fields wound on alternate pole pieces.

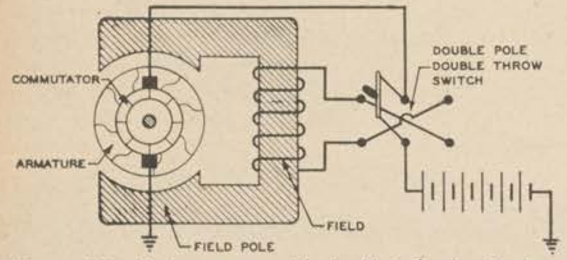
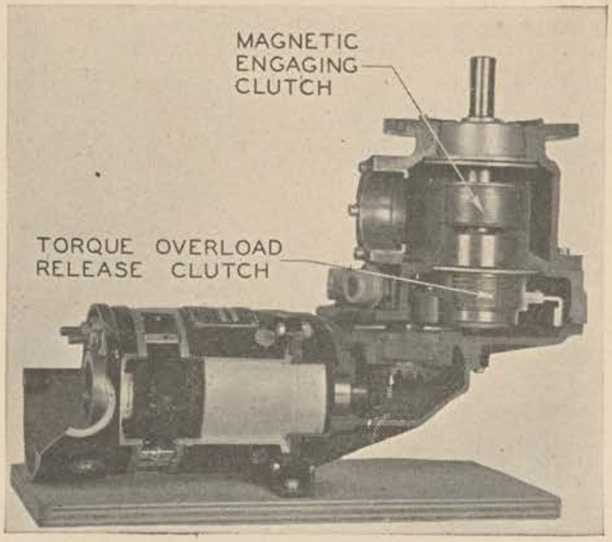


Figure 213. Series motor with double-pole double-throw switch.

92. MOTOR CIRCUITS. a. Electrical retraction of landing gear. One type of landing-gear retracting motor with its circuit is shown on figure 214. A train of gears is employed to reduce the speed and increase the torque. A torque-overload release clutch is built into the device as a safety factor. Limiting switches, mechanically operated by the landing gear, open the circuit to the solenoid switches and thus prevent over-travel of the landing gear or damage to the motor. A magnetic engaging clutch may also be incorporated in the system to engage the motor with the retracting mechanism only when the motor is energized. In the event of failure of the electrical system, the pilot may operate the retracting mechanism manually without the dead load of the gear train and motor.

b. Electrical propeller. An electrical controllable-pitch propeller is used extensively with pursuit airplanes. The pitch of the propeller is changed with a split-field series motor. The motor torque is transmitted through



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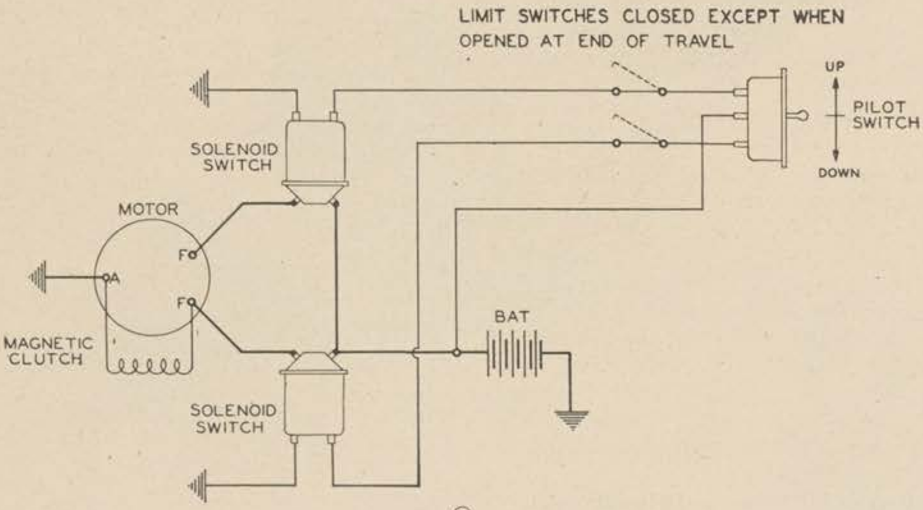

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Figure 214. Electrical landing-gear retracting motor and circuit.

a train of gears to a gear which is connected to the propeller blades (fig. 215). The pitch is increased and decreased by driving the motor in the required direction. The direction of motor rotation depends upon the field used. The complete electrical system is shown in figure 216.

c. Cowling-flap motors. The flap-motor assembly is a remote means of opening and closing the cowl flaps which govern the flow of cooling air over the engine in radial-engine installations. The electrical circuit is shown in figure 217.

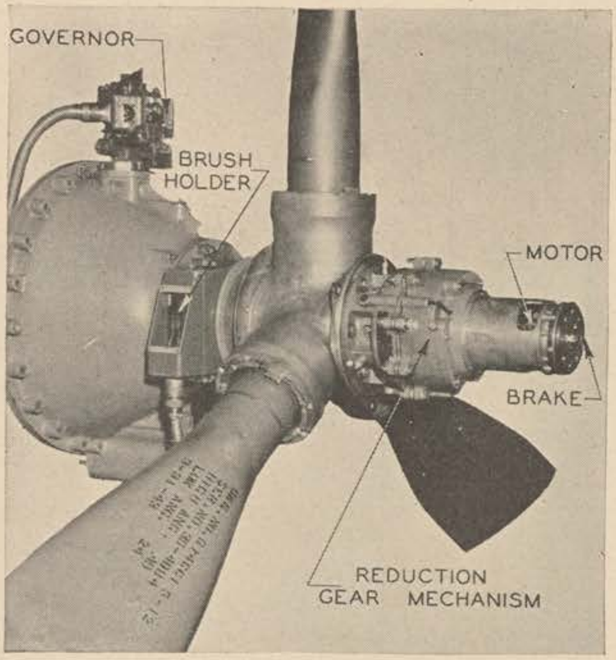

Figure 215. Power unit of a Curtiss electric propeller.

d. Anti-icer pump motor. A small series motor is used to drive anti-icer pumps which furnish the propellers with anti-icer fluid. The amount of fluid furnished is controlled by a small rheostat which varies the speed of the motor. The electrical circuit is shown in figure 218.

e. Hydraulic-booster motor. The hydraulic booster-pump motor and its circuit are shown in figure 219.

f. Fuel booster-pump motor. The fuel booster-pump motor circuit is a simple circuit requiring only a switch and fuse as controlling devices (fig. 220).

93. TROUBLE SHOOTING. a. General. In trouble shooting on the different motor systems several general troubles are common to motors and their systems.

(1) *Chattering relay switch.* The chattering of a relay switch controlling the motor is usually caused by a low battery. The open-circuit voltage of the battery is sufficient to close the relay, but with the heavy current draw of the motor, the voltage drops below the "hold-voltage on the relay. This permits the relay to open. When the relay opens the voltage of the battery will again increase enough to close the relay. Chattering is very harmful to the relay switch as the heavy current will cause an arc which will burn up the contacts.

(2) *Non-operation.* Non-operation of the unit, where the fuse is not blown, is usually caused by an open circuit. The open in the circuit can be traced with a voltmeter (switch on) as shown in figure 221. Start from the power source; whenever a zero reading is observed on the meter, the open is between that point and the last point where a voltage was indicated.

(3) *Ground or short (blown replacement fuse).* With fuse out, disconnect lead at motor and check back for grounds using an ohmmeter. Disconnnect each lead so as to isolate the trouble in one lead or unit (fig. 222). Where the ground is in the connector plug, the plug shell must be checked by holding one terminal on the shell.

b. Motor trouble shooting. Whenever the motor has been definitely proved to be at fault by a voltage check at the terminals, remove the unit and disassemble. (Consult Technical Orders covering the individual unit.)

(1) Check armature for binding; armature may be locked by gear train, etc.

(2) Check field and brush assembly for opens or grounds.

(3) Check armature visually for condition.

(4) Check armature for ground with ohmmeter or continuity light between commutator and shaft.

(5) Check armature for short and open on growler.

(6) Note condition of commutator and brushes.

94. MOTOR-SYSTEMS MAINTENANCE. a. Check all wiring, connections, terminals, fuses, and switches for general condition and security.

b. Check relay switches and clean points in accordance with the Technical Order covering the unit.

c. Keep motors clean and mounting bolts tight.

d. Check brush lengths and spring tension. Brushes and springs should be replaced when necessary in accordance with Technical Order covering the individual motor.

e. See that new brushes are seated properly and commutator cleaned with 000 or finer sandpaper.

f. Lubricate, if called for by Technical Orders covering the unit. Motors which are used on aircraft usually require no lubrication.

g. Adjust and lubricate the gear box or unit which the motor drives in accordance with the Technical Order covering the individual unit.

h. Check all other parts that may be listed for checking in applicable Technical Order.

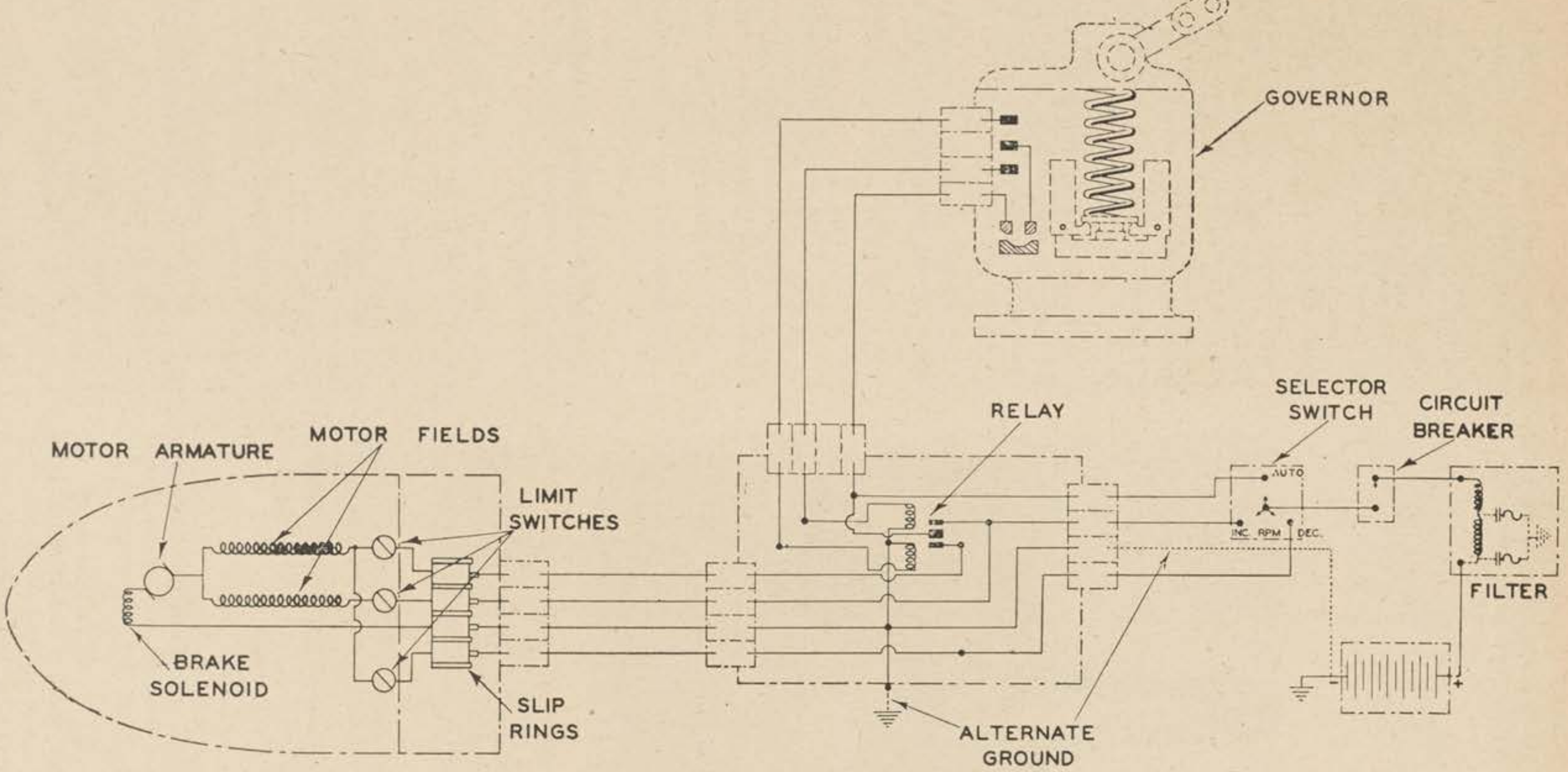

Figure 216. Electrical circuit of a Curtiss electric propeller.

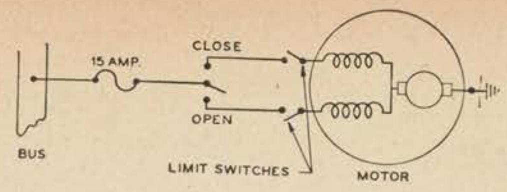

Figure 217. Electrical circuit of cowling-flap motor.

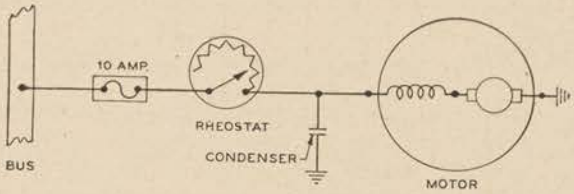

Figure 218. Electrical circuit of anti-icer pump motor.

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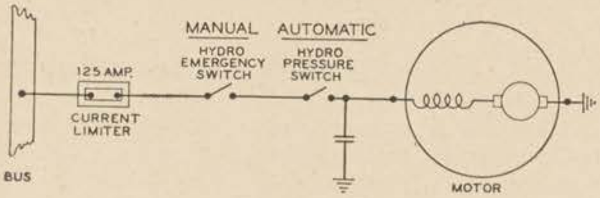

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Figure 219. Hydraulic booster-pump motor and circuit.

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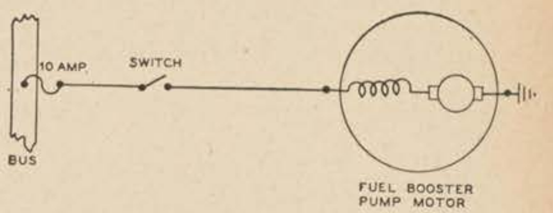

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Figure 220. Fuel booster-pump motor and circuit.

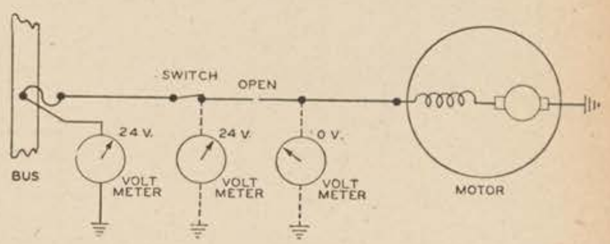


Figure 221. Checking for open lead in motor circuit with a voltmeter.

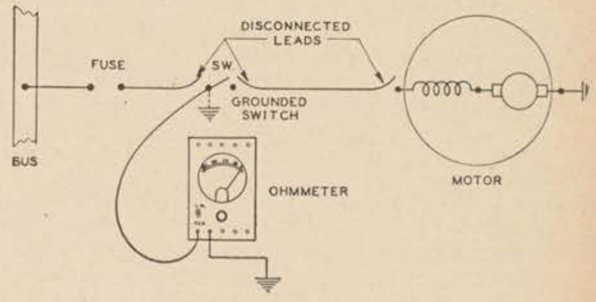


Figure 222. Checking for grounds in a motor circuit with an ohmmeter.

Table III. Starters

Type	Volts	Cubic inches displacement	Starter rotation	Style	Break-away torque	Clutch Setting Max. (Slipping torque)	Clutch Setting Minimum	Revolutions per minute
C–20	12	1,830	L	Hand and electric inertia	950	630 to 670	350	12,000
C–21	12	1,830	R	Hand and electric inertia	950	630 to 670	350	12,000
E–160	12	1,830	R	Direct electric	950	530 to 570	350	8,300
E–160	24	2,600	L	Direct electric		530 to 570	350	6,500
635	12		L	Direct electric	650	75 to 100	75	
E–80	12	750	L	Direct electric	650	280 to 320	200	9,000
J–1	24	750	L	Direct electric	650	280 to 320	200	9,000
F–1	24	1,830	L	Hand and electric inertia	950	630 to 670	350	12,000
F–2	24	1,830	R	Hand and electric inertia	950	630 to 670	350	12,000
G–1	24	2,800	L	Combination inertia and direct cranking	1,300	900 to 950	650	10,000
G–2	24	2,800	R	Combination inertia and direct cranking	1,300	900 to 950	650	10,000
G–5	24	1,830	L	Combination inertia and direct cranking	1,300	700 to 750	450	16,000
H–5	12	1,830	L	Combination inertia and direct cranking		700 to 750	450	16,000
G–6	24	1,830	R	Combination inertia and direct cranking		700 to 750	450	16,000
H–6	12	1,830	R	Combination inertia and direct cranking		700 to 750	450	16,000
H–1	12	2,600	L	Combination inertia and direct cranking	1,300	900 to 950	650	10,000
H–2	12	2,600	R	Combination inertia and direct cranking	1,300	900 to 950	650	10,000
JH–5	24	2,600	L–R	Hand and electric inertia	1,360	1,350	400	23,000
JH–5A	24	2,600	L–R	Combination inertia and direct cranking	1,360	1,350	400	20,000
JH–5B	24	2,800	L–R	Combination inertia and direct cranking	1,350	1,350	400	20,000
JH–5D	24	2,600	L–R	Hand and electric inertia	1,360	1,350	400	23,000
JH–5AD	24	2,600	L–R	Combination inertia and direct cranking	1,360	1,350	400	20,000
JH–5BD	24	2,800	L–R	Combination inertia and direct cranking	1,360	1,350	400	20,000
JH–5AF	24	2,600	L–R	Combination inertia and direct cranking	1,350	1,350	400	20,000
JH–5E	24	3,350	R or L	Combination inertia and direct cranking	1,350	900	400	23,000
JH–5EA	24	3,350	R or L	Combination inertia and direct cranking	1,350	900	400	23,000
JH–5F	24	3,350	R or L	Combination inertia and direct cranking	1,350	900	400	23,000
JH–5FA	24	3,350	R or L	Combination inertia and direct cranking	1,350	900	400	23,000
JH–3	24	2,000	R or L	Combination inertia and direct cranking	1.200	800	300	22,000
JH–3AR	24	2,000	R	Combination inertia and direct cranking	1.200	800	300	22,000
JH–3AL	24	2,000	L	Combination inertia and direct cranking	1.200	800	300	22,000
JH–10D	24	3,350	R or L	Hand and electric inertia	2,050	1,250	400	23,000
JH–10	24	3,350	R or L		2,050	1,250	400	23,000
JH–10E	24	3,350	R or L		2,050	1,250	400	23,000
JH–10EA	24	3.350	R or L		2.050	1.250	400	23.000

STARTING SYSTEMS

95. GENERAL. In early type aircraft, engines were small and could be started by manually turning the propeller. With the development of more powerful engines, special starting systems were devised. No single type of starter will serve for all types of engines. Brief descriptions of cranking systems, including those which are not electrical, are listed in this section. Table III, gives the characteristics of some aircraft starters used at present. In some cases the clutch setting of starters listed in Table III may be changed for adaption to engines with different cubic-inch displacement than that indicated. Applicable Technical Orders should be consulted for information relative to the interchangeability and clutch setting of starters.

96. PRINCIPLES OF THE INERTIA STARTER. An engine of considerable power or one having extensive accessory equipment imposes a heavy load upon the cranking mechanism. To obtain the necessary starting torque, the inertia starter is frequently used. The cranking ability of the inertia starter depends upon the amount of energy stored in a rapidly rotating flywheel, that is, energy is stored slowly during the energizing process and then the energy is used, in a very short period of time, to crank the engine. Consequently, a great deal of power can be obtained from the rotating flywheel for a short period of time. This energy is sufficient to rotate the engine crankshaft (under ordinary conditions) three or four times at a speed of approximately 80 to 100 r.p.m. If the engine uses magnetos for ignition, this speed may be less than its "coming-in speed" (the minimum crankshaft speed at which the magneto will function adequately) and therefore an ignition booster is usually installed on the engine and operates while the inertia starter is cranking the engine. There are two types of inertia starters; the hand-cranking-type, in which the flywheel is accelerated by hand only; and the combination hand-cranked and electric type, in which the flywheel is accelerated either by hand-crank or electric motor. During the energizing of an inertia starter, all movable parts within it, including the flywheel, are set in motion.

97. HAND INERTIA STARTER. Figure 223 shows a hand inertia starter. A sectional view of this starter is shown in figure 224. When a hand crank is inserted in the crank socket and the crank rotated, the speed of all movable parts is gradually increased with each revolution of the crank. One revolution of the crank increases the speed of the flywheel 100 or more revolutions, depending upon the model. Most of the energy used in cranking the starter is stored in a rapidly revolving flywheel. A pull rod, figure 225, or a cable is used to mesh the starter jaw with the engine jaw after the required r.p.m. of the flywheel is reached by cranking. The energy stored in the flywheel is transmitted to the starter jaw through speed-reduction gears and a torque overload release, which consists of a multiple-disk clutch under spring pressure. The clutch prevents damage to the starter in case of an overload or engine kick-back. If, for any reason, the engine crankshaft cannot rotate, the clutch will slip until the flywheel comes to rest. The Eclipse clutch consist of one set of disks fastened to the shaft and another set (of a different kind of metal) fastened to the barrel. Springs are used to press the disks to-

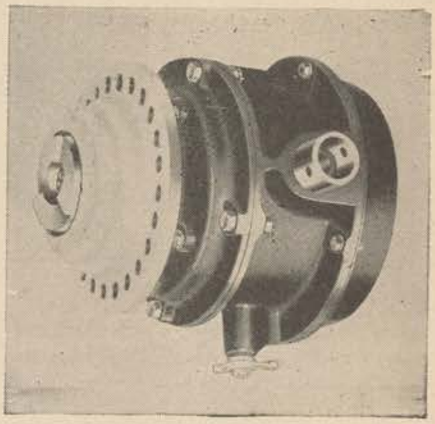


Figure 223. Typical hand inertia starter.

gether and the retaining ring, which compresses these springs may be adjusted to set the value of the slipping torque. The normal operation of the clutch is to slip for an instant after the starter and engine jaws become meshed, but, while slipping, a torque is exerted on the crankshaft until the initial resistance of the engine is overcome and the clutch is able to hold again. The specified values of the break-away (maximum holding) and slipping torque of the clutch are in accordance with the size of the engine to be cranked.

98. COMBINATION INERTIA STARTERS. a. The combination hand and electric inertia-type starter uses a gear and clutch arrangement similar to that of the hand inertia starter. The starter shown in figure 226 is the hand-cranked type to which an electric motor has been attached. The flywheel may be accelerated by either a hand crank or electric motor. When the starter is energized by hand cranking, the motor is inoperative because of a mechanical disconnection. When the motor is used, it is engaged directly to the inertia-starter flywheel by means of a movable jaw on the helically-splined shaft (fig. 227) of the motor. On some type starters when the motor armature starts to rotate, the starter jaw will tend to remain at rest. As the shaft turns the jaw will move forward along the splined shaft until it engages the flywheel jaw. One of the most common troubles with this starter is that the motor jaw binds on the armature shaft and does not engage the flywheel jaw. Be careful when energizing this starter not to throw the switch "on" until the flywheel is completely at rest. If this caution is not observed, either the motor jaw will not engage with the flywheel jaw with the result that the motor will race and damage itself, or the motor jaw will strip the flywheel jaw.

b. In another type of inertia starter, the starter motor is engaged to and disengaged from the flywheel by means of a roller clutch which fits snugly inside the flywheel (fig. 228). A slight rotation of the motor shaft forces the rollers out against the inner surface of the

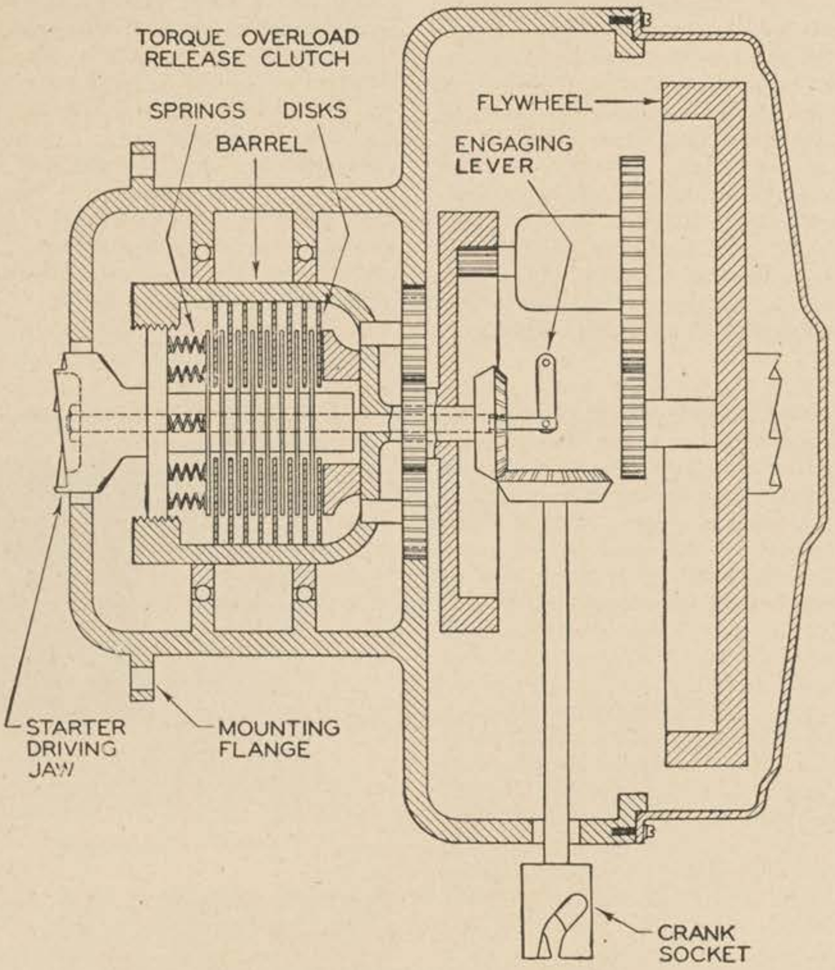


Figure 224. Sectional diagram of hand inertia starter.

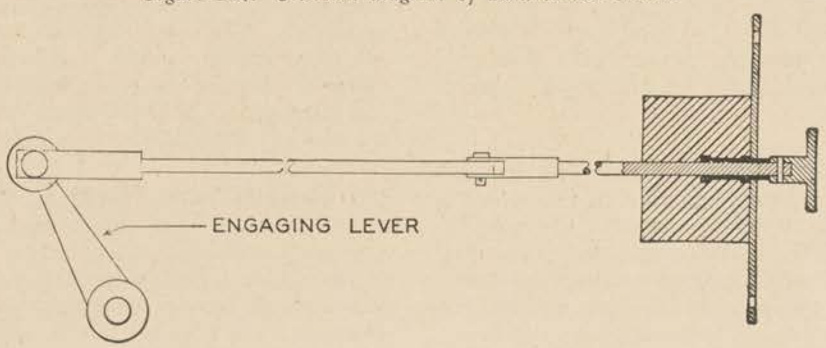


Figure 225. Typical hand inertia starter engaging control.

flywheel. Whenever the motor rotates more slowly than the flywheel, the rollers become free and the motor is automatically disengaged. There is no need to wait for the flywheel to come to a stop before re-energizing this electric motor. This type starter is very effective when used as a combination electric inertia and direct cranking starter. When used in this way, the flywheel is energized, as in the inertia starter, and then the starter jaw is meshed with the engine jaw; at this moment, the motor is energized again, as in a direct cranking starter. This adds the energy of the motor to the energy of the rotating flywheel.

c. In other types of inertia starters, such as the type G-6, JH-5 and JH-10 series, the flywheel is mounted on the motor shaft (fig. 229). Thus, the inertia of the armature is added to that of the flywheel. In the early JH-5 and JH-10 series, the brushes of the electric motor are lifted from the commutator by spring action (fig. 230) and caused to go down by solenoid action. On some models, the motor is turned off (by raising the brushes) when the starter jaw is engaged with the engine; while on others, the motor is permitted to remain running. Thus, by direct cranking action, the engine is rotated through several additional revolutions before the energy of the starter is exhausted. Later designs of this brush-lifting starter (JH-5E and JH-5F) use four brushes. These brushes are lifted manually for hand cranking, as a flywheel is connected directly to the motor armature. In order to lift the brushes, the hand energizing lever must first be pulled as in the hand meshing of the starter. On completion of the hand energizing, the starter may be engaged to the engine by again pulling the hand-meshing lever. To operate the starter electrically, after it has been used as a hand inertia starter, the meshing solenoid must first be energized to lower the brushes onto the commutator. On a similar type starter of another make (G-6) the brushes are lifted by moving a small knob on the motor end of the starter to the "off" position when the starter is to be hand energized. The knob must be returned manually to the "on" position before the starter can be energized electrically. Figure 229 ① shows the "on" and "off" positions controlled by the knob.

99. INERTIA-STARTER ELECTRIC MOTOR. Series-wound 12- or 24-volt d-c motors are employed with electric inertia starters. The constructional features of the motors are similar to those of the d-c generator. The electrical resistance of the windings of the motor used in an inertia starter is very small so that the instant the starter switch is closed, the current draw is extremely high; this results in a powerful starting torque. As the motor gains in speed, induced counter-electromotive force causes less current to flow. An inertia starter motor which draws approximately 350 amperes at starting will draw approximately 75 amperes at high speed; the value will depend upon the load. If the load is entirely removed and if the internal friction of the motor is small, it will "race" and the armature may "burst" from centrifugal stresses. For this reason, it is not safe to test an inertia starter motor at full voltage unless there is a load upon it.

100. INERTIA STARTER SWITCHES (STARTER RELAY AND ENGAGING SOLENOIDS). **a.** When the starter is located some distance from the cockpit, the inertia-starter motor is usually operated by means of a solenoid-actuated switch controlled from the cockpit. The starter relay (fig. 231) is usually mounted in a junction box near the starter. When the cockpit control switch is closed, a current of low amperage energizes the solenoid causing the solenoid plunger to advance and compress a spring. This action closes the relay contacts and completes the battery circuit through the starter motor.

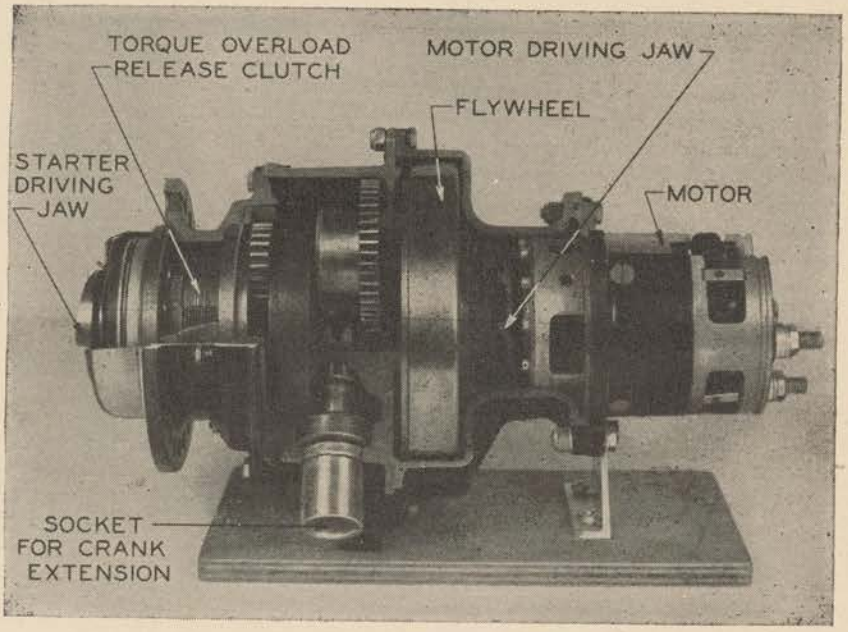


Figure 226. Cutaway view of hand and electric inertia starter type C-21.

When the required flywheel speed of the starter is reached, the cockpit control switch is opened; the solenoid coil loses its magnetism; the spring returns the solenoid plunger to its original position, and the starter circuit is thus opened.

b. When electrical control of the engagement of the inertia starter is desired, a meshing solenoid is used. The mechanism of the meshing solenoid is similar to that of the starter relay except that the plunger of the meshing solenoid is connected to the starter jaw-engaging lever. A meshing solenoid is shown in figure 232.

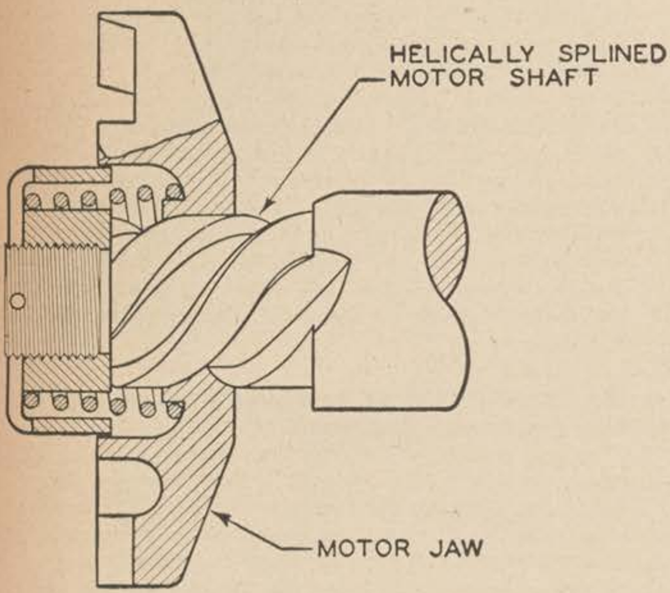


Figure 227. Jaw-type starter motor-engaging mechanism.

c. A diagram of a typical inertia starter electrical system is shown in figure 233. When the ignition switch is placed in the "both" position, battery voltage reaches the cockpit control switch. If the latter is placed in the "energize" position, the starter relay is thereby closed and the inertia starter begins to speed. When sufficient speed has been reached, the cockpit control switch is placed in the "engage" position. This actuates the meshing solenoid and at the same time energizes a booster coil which supplies high voltage to the trailing distributor finger of the right-hand magneto until the cockpit control switch is released.

d. The circuit shown in figure 234 will not permit the starter to be used as a direct cranking starter. In order to operate a starter, either for direct or inertia cranking, a switch arrangement must be provided to energize both the meshing solenoid and starter relay at the same time. A conventional system for single- and multi-engine airplanes is shown in figure 234.

101. DIRECT CRANKING STARTERS. a. General. Another type of starter is the electrical-cranking type. This starter, when energized electrically, provides instant and continual cranking. The starter consists basically of an electric motor, reduction gears, and an automatic engaging and disengaging mechanism which is operated through an adjustable torque overload release clutch. The engine is cranked directly by the starter. There is no preliminary storing of energy as in the inertia type starter.

b. Portable starters. With the increasing size of airplanes and the increasing number of engines used, much weight can be saved by having the starter gear box and a separate portable starter motor. When this method is used only one motor is needed for any number of

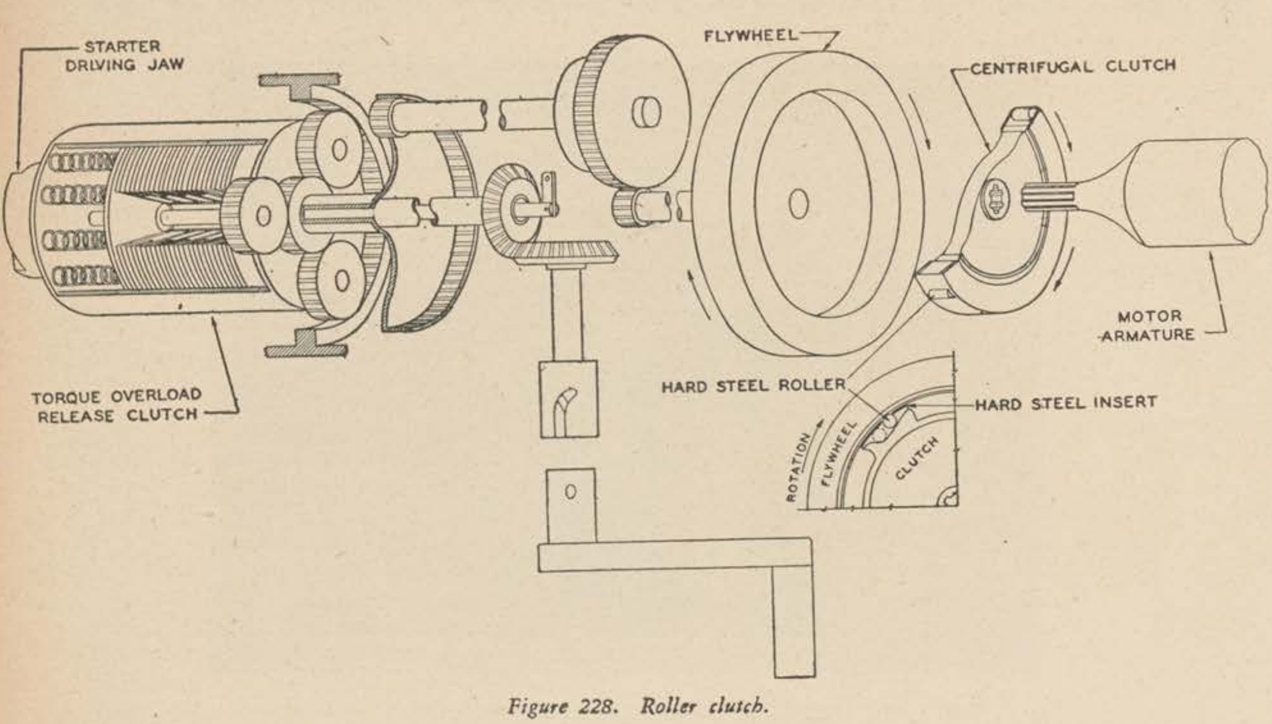


Figure 228. Roller clutch.

engines. The gear box is mounted directly on the engine and a small flexible shaft connects the gear box to a small coupling at the cowling surface. The shaft of a portable electric motor is inserted into the coupling. The motor is connected directly and has a speed of approximately 3 to 4 thousand r.p.m. The electric motor can receive its power from the airplane battery or from a portable power supply through a suitable plug arrangement. To date, this design has been limited to direct cranking starters only. Also, no provision has been made to crank the engine manually.

102. HAND-TURNING GEAR-TYPE STARTER. This type of starter may be used on low horsepower engines where a source of electrical power is not available.

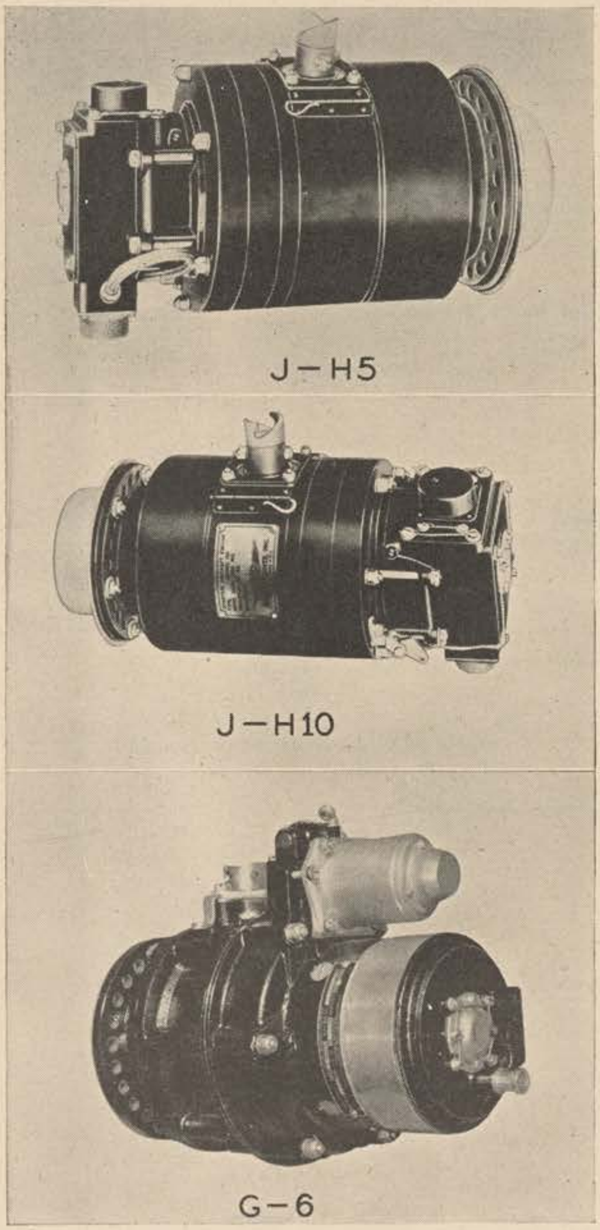


Figure 229. Types of inertia starters.

Using a gear ratio of 6:1, an engine rated up to 250 horsepower may thus be started by hand. The starter consists of a gear assembly which operates an automatic engaging and disengaging mechanism through an adjustable torque overload release clutch. A ratchet is provided on the hand crankshaft to prevent the possible transmission of any reverse motion to the crank handle.

103. PORTABLE FIELD STARTING SYSTEMS. The purpose of the various types of portable field starting units is to eliminate the manual labor required to operate hand starters and (with the electric starter) to minimize discharge of the aircraft battery, especially when starting the engine in cold weather. Two types of portable starting systems in common use are the portable battery cart and portable energizer.

a. An effective method to supply power to the airplane's electrical system externally is through the "external power source" receptacle (fig. 235). The external power supply may be either a battery cart or a generator driven by a gasoline engine. Often the power source is a combination of a gasoline engine-driven generator and a battery. The external source of power is always equipped with a flexible cable and a plug which fits the receptacle on the airplane.

b. The portable energizer consists of an electric motor which will operate either from an alternating- or direct-current 110-volt circuit. The electric motor is attached to a gear reduction unit which has some type of torque-limiting clutch for overload protection. The drive shaft of the portable energizer sticks out from the driving unit and engages with the crank socket of the engine starter. A trigger switch is used to control the electric motor of the energizer. Some energizers have a friction clutch similar to that used in the starter; however, the clutch is set with a slipping torque of approximately 70 foot-pounds. In another type of energizer, a fluid clutch is located on the motor shaft; this clutch is of a design similar to that used in modern automobiles. In order to make the energizer usable for both right-hand and left-hand starters, a means of reversing the direction of the energizer is always provided; one method is to reverse the direction of the motor rotation; another method is to change the final drive shaft from one side of a gear assembly to the other. To use the energizer with an inertia starter, the drive shaft is inserted into the protruding starter crank socket. The drive shaft pin fits into the spiral slot of the starter socket and accelerates the starter flywheel. As soon as the desired cranking speed is attained, the trigger switch is released and the energizer removed from the starter socket thus allowing the flywheel to run free. The operator may then engage the inertia starter with the engine. The energizer should never be used to drive the starter when it is engaged to the engine, as this may cause serious damage to the energizer or injury to the operator.

c. The portable electric power plant (fig. 236) consists of a generator driven by a gasoline engine. Although it may be used to energize various units of ground equipment which require 110-volt direct-current power, its principal use is to furnish power for the operation of the portable energizer. The speed of the unit is controlled

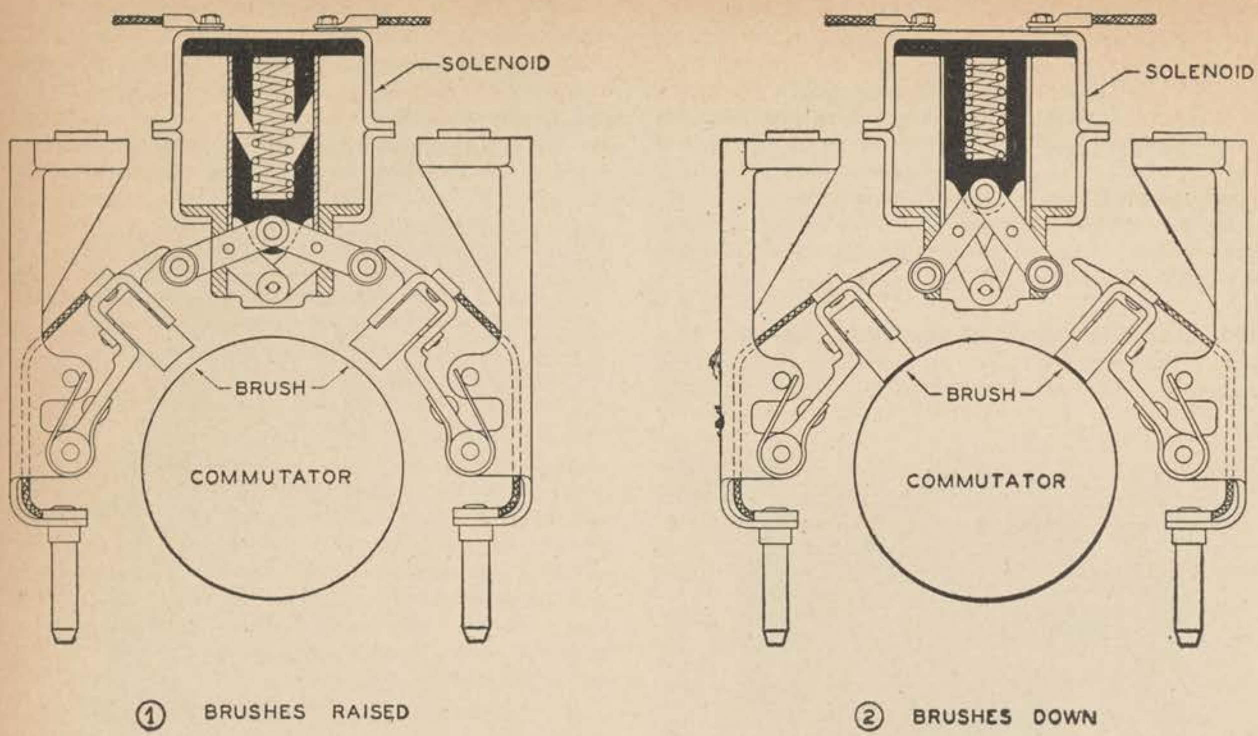


Figure 230. Solenoid-controlled motor brushes.

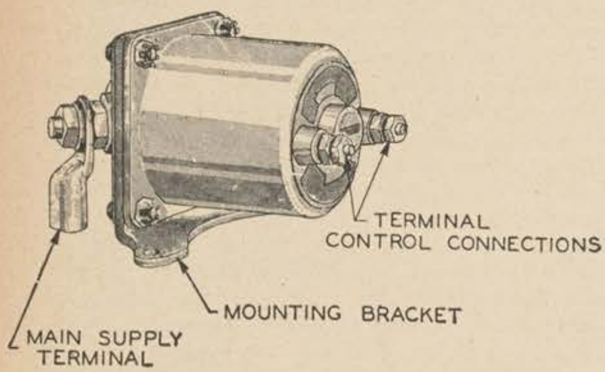


Figure 231. Solenoid switch.

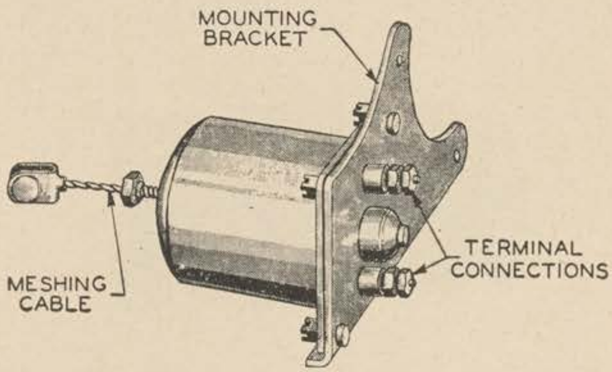


Figure 232. Starter-meshing solenoid.

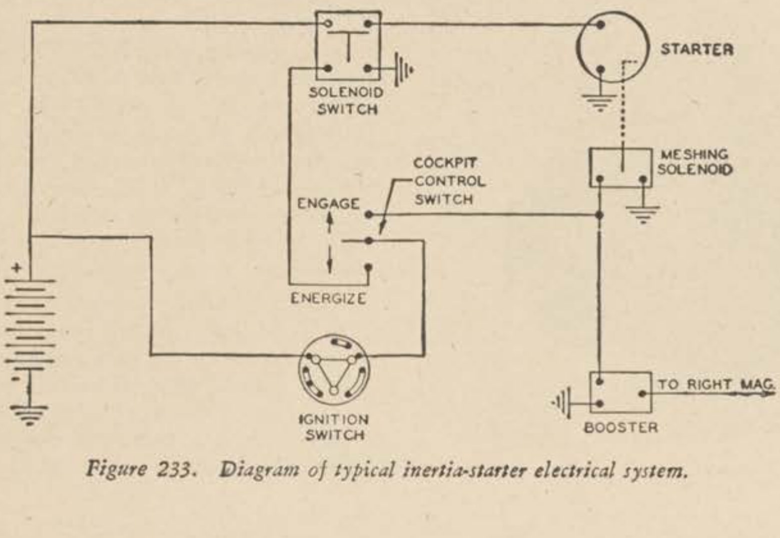


Figure 233. Diagram of typical inertia-starter electrical system.

by a governor. If it becomes necessary to increase or decrease the speed, this may be accomplished by varying the tension of the governor spring. The voltage of the generator is controlled by a field resistor located in a terminal box into which the extension cord of the portable energizer is plugged.

104. MAINTENANCE. a. General. Starting equipment should be checked for security of mounting, tightness of bolts, and proper safetying. Check for breaks or cracks in housings and flanges. Equipment should be lubricated whenever necessary.

b. Starter. (1) When installing a starter on the engine, first remove the cover which is placed over the starter jaw for shipment and storage, and match it with the engine jaw. Check the jaws for the same direction of rotation, the same number of teeth, and the same size. With the starter jaw engaging rod properly adjusted for correct travel, determine the clearance between the starter jaw and the engine jaw, with the starter jaw in a retracted position. This clearance should be approximately 1/16 inch. (Check Technical Orders for exact measurements.) This clearance can be adjusted by adding shims or gaskets between the starter flange and the mounting pad.

(2) To check the operation of an inertia starter, hold the control switch in the "start" position for the time required to bring the flywheel up to speed and then move the switch to the "mesh" position. When the engine starts, release the switch which should return to its neutral position. If the engine fails to start and the starter jaw remains meshed with the engine jaw, it will be necessary to turn the propeller by hand (with magnetos off) part of a revolution in the direction of rotation to release the starter jaw before operating the starter again.

(3) To check the free turning of gears, the flywheel is energized and, without meshing to the engine, is allowed to "run down." (Check with the Technical Order for the correct "free-coasting" time.)

(4) Electric circuits should be examined for loose terminals.

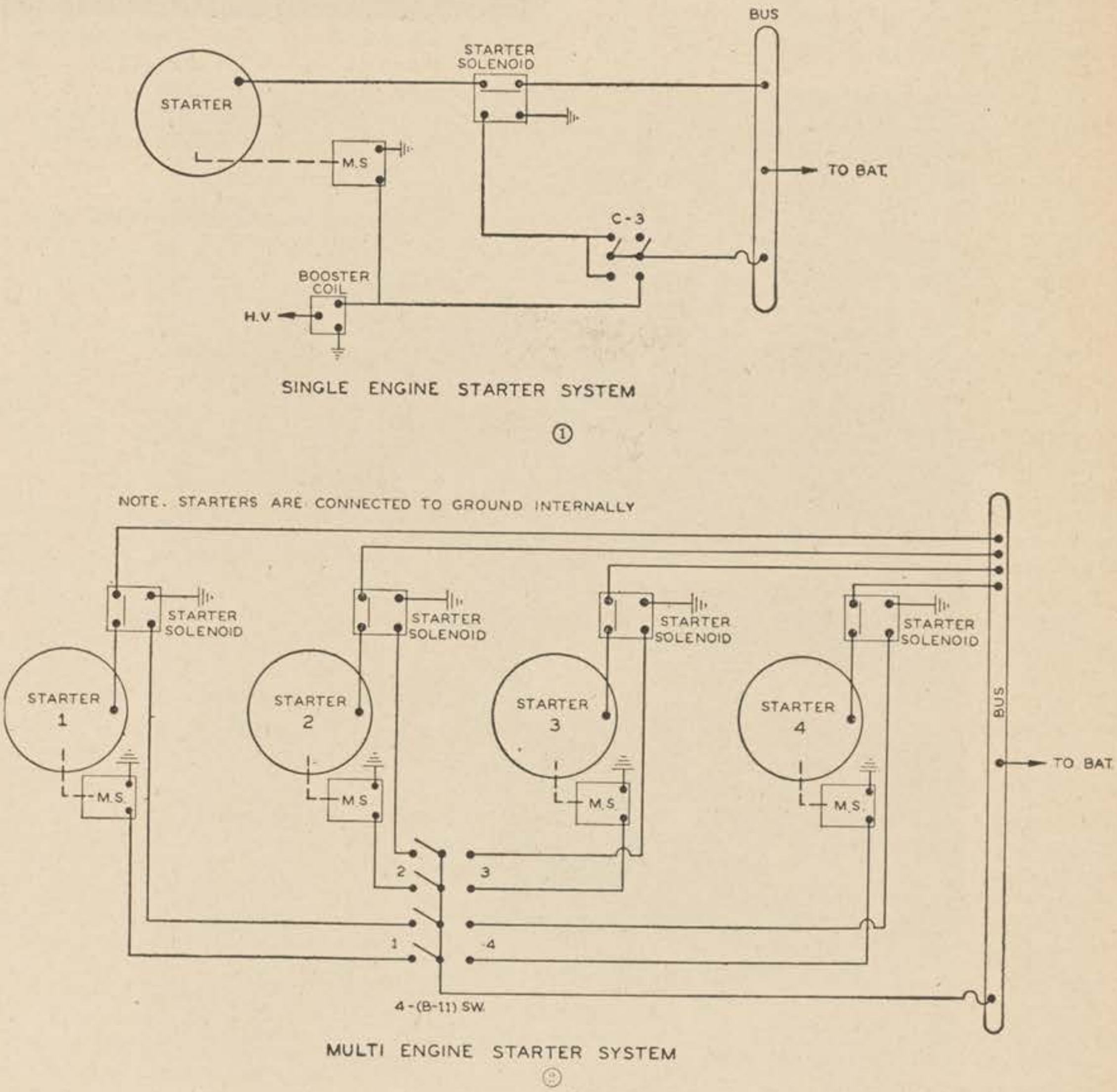


Figure 234. Conventional single and multi-engine starter systems.

(5) If operating troubles are experienced with either the starting or meshing solenoids, use proper test instruments to determine the cause, and, if necessary, replace faulty units.

c. Motor. Maintenance of a motor is concerned mainly with brushes and commutator.

(1) Remove the motor brush strap and check for worn or binding brushes. Short brushes should be replaced. New brushes are seated with a fine grade of sandpaper (No. 000) inserted between the brush and commutator and pulled in the direction of rotation. Test brush springs for correct tension.

(2) Dirty commutators and brushes are cleansed with a lint-free cloth moistened with carbon tetrachloride or undoped gasoline.

(3) Commutators are smoothed in accordance with the Technical Order for the particular starter. If the commutator is badly scarred, replace the motor or the entire starter if the motor is not detachable.

(4) Motor jaws should be checked to see that they do not bind on the shaft.

(5) If the motor is to be tested with no load, use approximately half the voltage normally required.

(6) If the motor should fail to operate, check the electrical circuits before replacement of motor or starter.

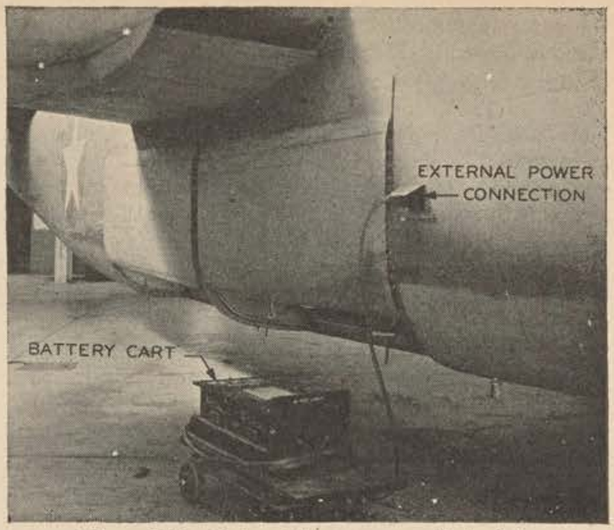


Figure 235. External power source (batteries).

Figure 236. Portable power plant and energizer in use.

SECTION XIII

ELECTRONIC TUBES

105. GENERAL. a. Electrical circuits are usually confined to closed metallic paths in which the current may flow. However, with the use of electronic tubes a current can be made to flow in a vacuum or gases. The electronic tube is sometimes called a vacuum tube, or a thermionic valve.

b. The electronic tube was originally developed for radio work. Today, a great number of different types of tubes are in use in many different types of aircraft electrical equipment such as automatic pilot, turbo-supercharger regulator, radio transmitter and receivers, interphone system, etc. Figure 237 shows some typical vacuum tubes and symbols. In the following paragraphs the fundamentals of the electronic tube and a few simple circuits containing tubes are discussed.

106. FUNDAMENTALS OF THE ELECTRONIC TUBE. a. In any conductor the elements making up the conductor have a great number of free electrons. When a current is flowing in the conductor, the electrons are said to be in motion and traveling in a definite general direction. The electrons are also in motion whenever a metal is heated. When the temperature of the metal is high enough the electrons will increase their speed and actually leave the surface of the metal. In the electronic tube, a heated filament is used to supply the electrons (fig. 238). The filament is heated by passing electric current through it. Within limits, the hotter the filament the greater the number of electrons given off. Also, to increase the number of electrons given off, the filament or cathode is usually coated with chemical compounds. With just the hot filament the electrons form in a cloud about the filament. This cloud is negatively charged because the electron is a unit of negative electricity. When this cloud of electrons (space charge) becomes dense enough, the electrons are forced back into the filament as fast as they leave it because the electron is repelled by a negative charge.

b. In some tubes, especially those designed for a-c filament operation, a heated element is used instead of the open wire filament (fig. 239). This part of the tube is called the cathode. It is usually cylindrical in shape and incloses the heater which heats the cathode to a red heat. In this case the heater is insulated from the cathode.

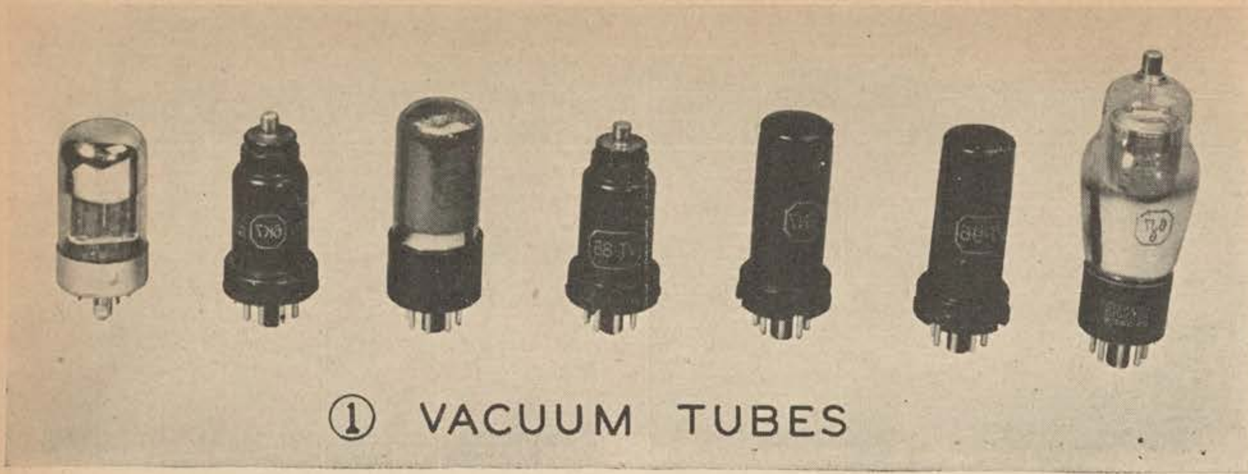
107. DIODE TUBES. a. Construction. If a plate (supplied with a positive potential) is incorporated in the tubes, the electrons given off by the filament will be attracted to the plate. This constitutes a current flow from the plate to the filament or cathode (fig. 240). The electrons, being negative charges, are attracted only to a positive object. Whenever the plate is negative, the electrons will not be attracted to the plate and no current will flow in the circuit (fig. 241).

b. Uses. The diode or 2-element tube is used principally as a rectifier. When one plate is used the tube is said to be a half-wave rectifier. See figure 242. When two plates are used the tube becomes a full-wave rectifier (fig. 243).

108. TRIODE TUBE. a. Construction. The triode tube uses, in addition to the plate and filament, a third element called the "grid," which consists of a fine wire mesh or screen between the plate and filament. See figure 244.

b. The operations of the filament and plate are the same as in the diode tube. The purpose of the grid is to control the electron flow between the filament and the plate. See figures 245 and 246. As the voltage on the grid is made more positive (less negative) the plate current will increase. Conversely as the grid voltage is made less positive (more negative), the plate current will decrease. The grid is usually negative with reference to the cathode. One method of making the grid negative is to use small battery connected in series with the grid circuit. The operating characteristics of the triode tube can best be shown from a set of curves (fig. 247). The negative voltage or bias on the grid required to reduce the plate current to zero is called the cut-off voltage. The grid current is zero until the grid is made positive. However, for positive values of grid voltage a grid current will flow. This current is usually very small because the grid has a smaller area than the plate and the plate has a greater attraction for the electrons.

c. The triode tube is manufactured in a great many different sizes and types for many uses. The most important use is as an amplifier tube. When the tube is used as an amplifier a small variation of grid voltage will produce a corresponding variation in plate current (fig. 248). The plate voltage is furnished by a high voltage battery or d-c power pack (B supply) through a series resistor or transformer primary (fig. 249). The variation of plate current will set up a varying voltage in the resistor or primary of the transformer. This voltage will then be much greater than the voltage applied to the grid. To get the desired amplification, several tubes and their circuits are usually connected in series.



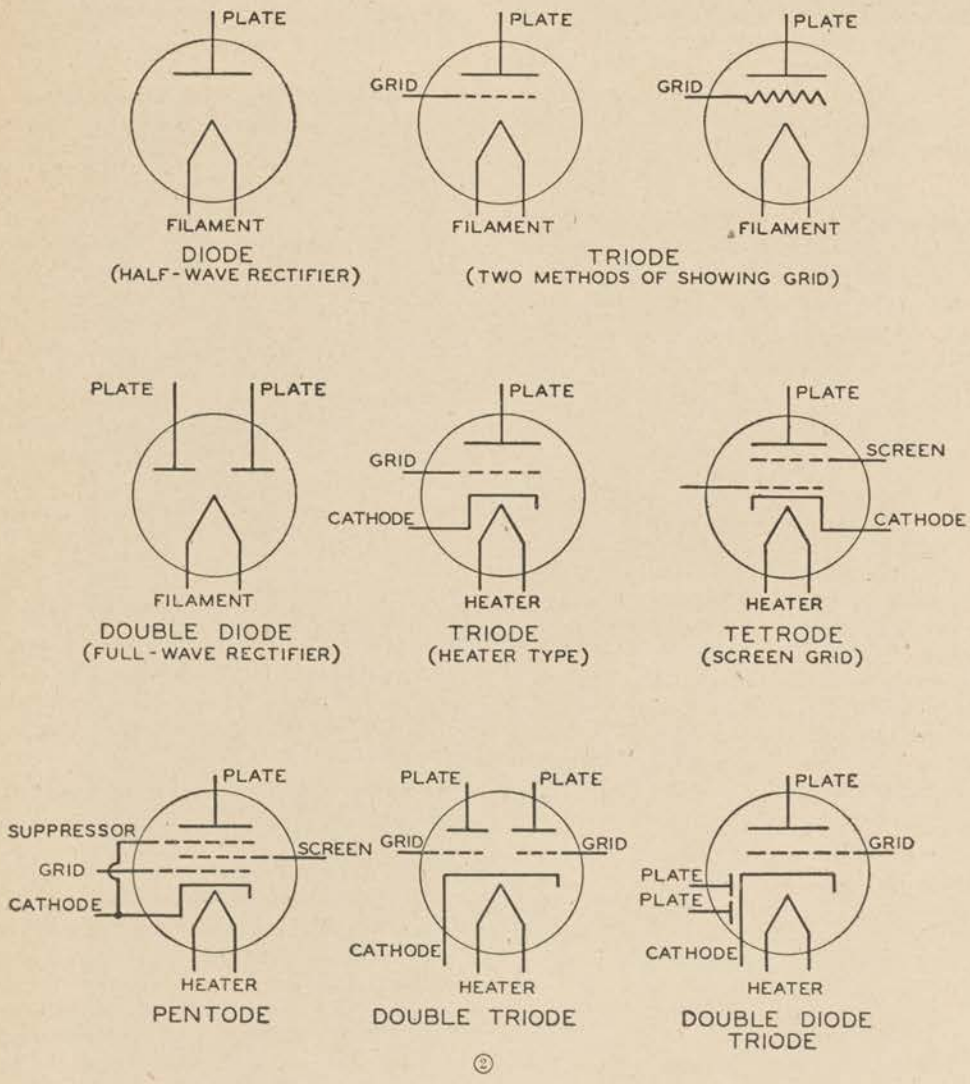


Figure 237. Typical vacuum tubes and vacuum-tube symbols.

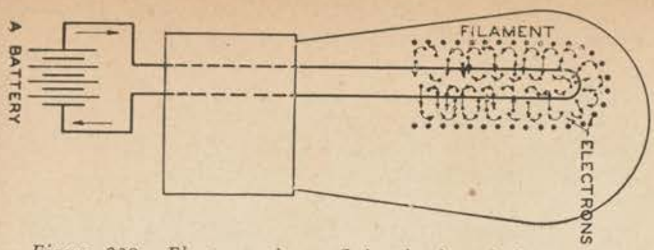


Figure 238. Electrons given off by the heated filament of a vacuum tube.

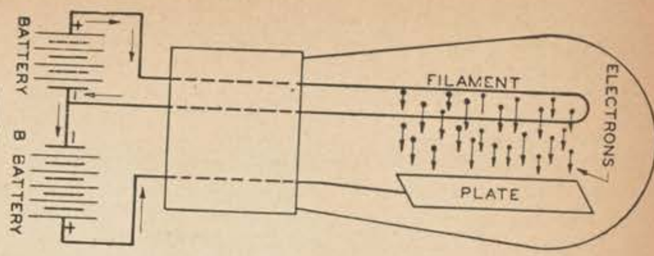


Figure 240. Electrons in a diode tube traveling toward a positive plate.

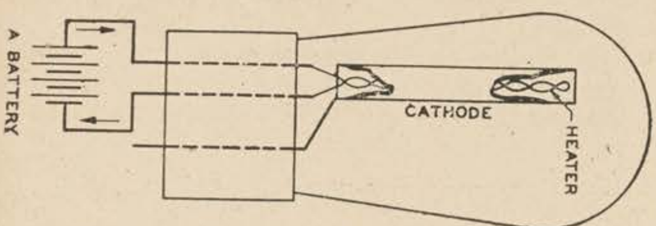


Figure 239. Tube with cathode and heater replacing the filament.

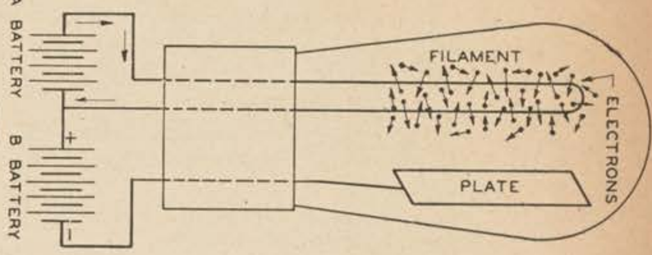


Figure 241. Electrons are not attracted by a negative plate.

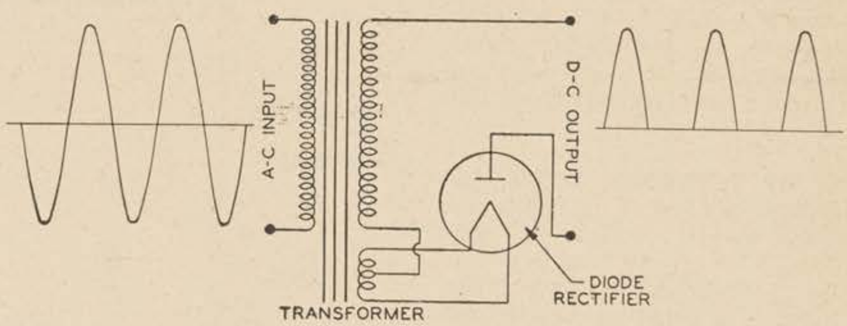


Figure 242. Half-wave rectifier circuit.

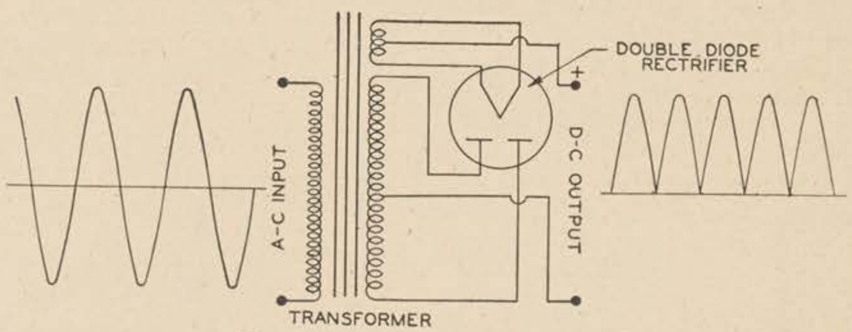


Figure 243. Full-wave rectifier circuit.

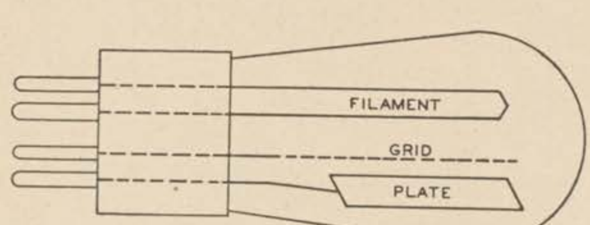


Figure 244. Parts of a triode tube.

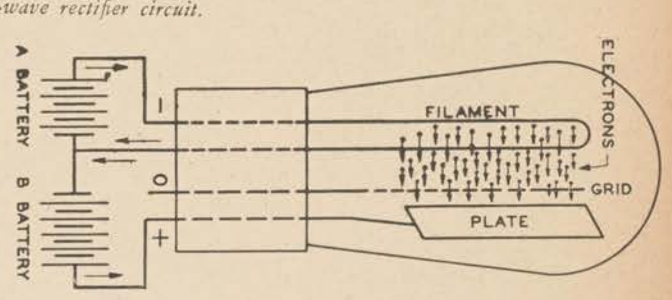


Figure 245. When the grid is at a zero potential, the electrons will flow from the filament to the plate.

109. TETRIODE TUBE. a. Construction. The operating characteristics of the triode can be improved by the addition of a fourth element—the screen grid. This grid is placed between the control grid and plate (fig. 237 ②).

b. Operating characteristics. The tetriode or screen grid tube is used for the same purposes as the triode. It has a higher amplification factor and less

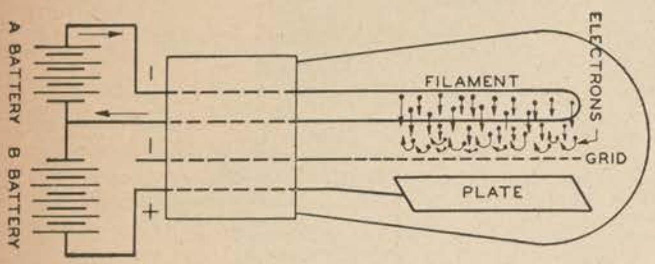


Figure 246. A grid sufficiently negative will keep all the electrons from reaching the plate.

interference between the elements of the tube. The screen grid is supplied with a steady d-c voltage slightly lower than the plate voltage. The screen grid always draws a current. However, due to its small area and the stronger attraction of the plate for the electrons, this current is quite small.

110. OTHER TYPES OF ELECTRONIC TUBES. a. The pentode tube has replaced many of the triodes and tetriodes. It uses a fifth element known as the "suppressor grid" (fig. 237②). This grid is connected to the filament or cathode. The connection may be inside the tube or in the circuit. The purpose of this element is to prevent secondary emission of the plate and further increases the shielding effect of the screen grid in the tube. The pentode has a very high amplification factor and is used to amplify very weak signals.

b. Other types of tubes include those with the characteristics of several tubes in one. Often two triodes are built into one tube. Also, a rectifier diode and an amplifier triode are often found in one tube.

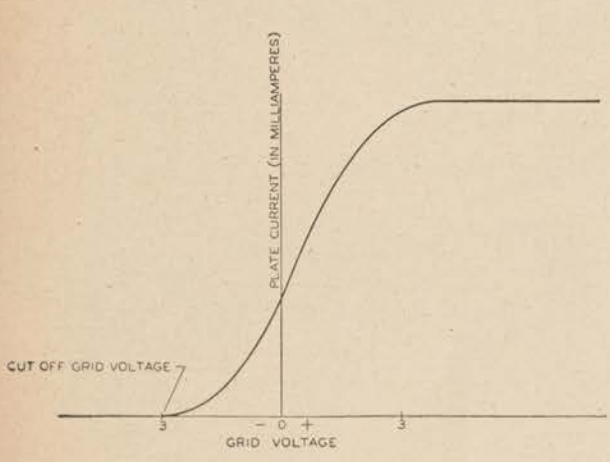


Figure 247. Characteristic curve of a triode tube-plate potential constant.

c. Another type of tube known as a "power output tube" is designed to pass a large current in the final stage of an amplifier. The "beam-power" tube is a special design of a tetrode or pentode where the elements are arranged so that the electron beam can be directed most effectively. The "beam-power" tube is very sensitive but still has a high output.

111. IDENTIFICATION OF TUBES. a. General. Electronic tubes vary in size from very small hearing-aid tubes to large radio transmitter tubes. The type of tube used in each case will be determined by the job it has to perform.

b. Numbering and lettering of tubes. Each individual tube type has a number. In considering the electronic-tube field as a whole, there is no definite

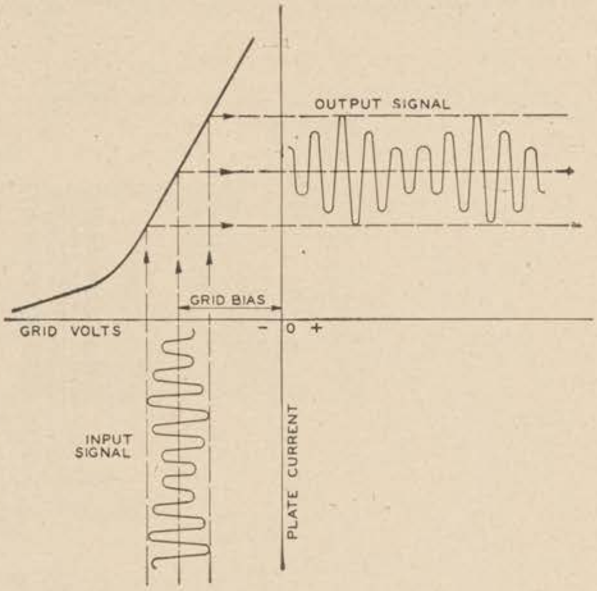


Figure 248. Graphical illustration of grid-input voltage and variations in plate current.

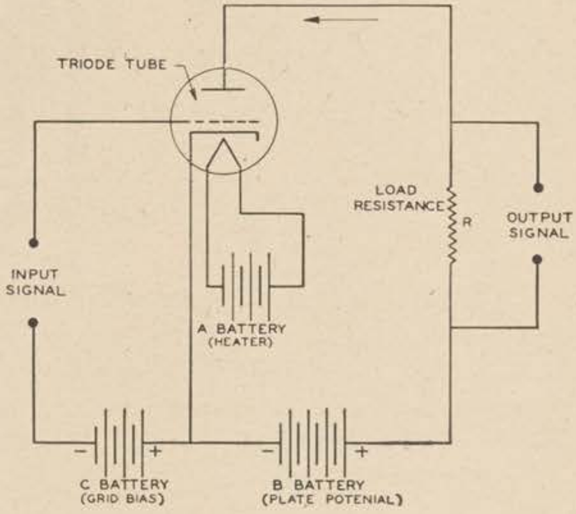


Figure 249. Simple amplifier circuit.

numbering system. However, in recent years radio tubes have been systematically identified with numbers and letters. In the older types of radio tubes where only numbers are used as 27, 45, etc., the number has no connection with the tube except as an identifying number. Generally a number and letter identification (Radio Manufacturers Association (R.M.A.) designation) will tell several things about itself. The first number indicates the approximate filament or heater voltage. The letter has nothing to do other than to identify the tube as to type. The next number designates how many elements have been brought out to terminals, but is not the number of prongs or connections on the tube. Often a letter is added on the end to designate various features such as *M* (metal tube); *G* (glass tube); *GT* (small glass); *GL* (lock-type base), etc. Tubes of different types with the same characteristics can be recognized by having certain letters and numbers the same. For example, the 7A7G, 12SA7 and 25A7GT all have the same working characteristics as indicated by the *A* and *7* which appear in each case. The *6*, *12*, and 25 indicate the approximate heater voltage. The *S* before the *A* in the case of 12SA7 indicates the tube is single ended. In this case the grid cap is eliminated and the grid is connected to a prong in the base. The 6A7G, and 12A7G are glass tubes which look alike. The 25A7GT is a small glass tube.

112. MAINTENANCE. a. General. Electronic tubes require no maintenance other than keeping them properly placed in their sockets. As the tube is sealed, no internal maintenance can be done to the tube.

b. Testers. Tube testers with switches and adjustments have been designed to test all types of tubes. As all makes of tube testers are of a different design, the instructions for each individual tester must be followed in each individual case. Tubes should be tested and replaced according to the Technical Order covering the individual piece of equipment.

LIGHTING

113. FUNCTIONS. Electric lighting serves three important functions in military aircraft; for illumination of instruments, cockpits, cabins and landing fields; for marking the position of the airplane; and for indicating certain conditions of the aircraft or its equipment by means of indicator lamps.

114. REFLECTORS AND COVER GLASSES. a. Reflectors are used in lamp assemblies to redirect the light emitted from the incandescent filament, into the desired zone. Different types of reflectors may be used depending upon the service for which the lamp assembly is intended. For example, in a landing lamp, where a concentrated beam of highest candlepower is desired, a parabolic reflector with a polished surface is used (fig. 250). In a recognition lamp assembly, from which a wide beam of light is desired, a spherical reflector with a diffusing surface is used.

b. Cover glasses protect the interior of the lamp assembly from dirt. In addition, they may be colored to produce a beam of a given color.

115. EXTERIOR LIGHTING EQUIPMENT. a. Landing lights. (1) Landing lights are extremely powerful and are directed at an angle which will give the pilot the maximum assistance in landing on unlighted airports and fields. The lights may be located midway in the leading edge of each wing (fig. 251) or streamlined into the airplane surface. The landing lights draw a high current. A relay, remotely controlled from the cockpit, may be used to control each lamp. Both the control circuits and the lamp circuits are fused for safety.

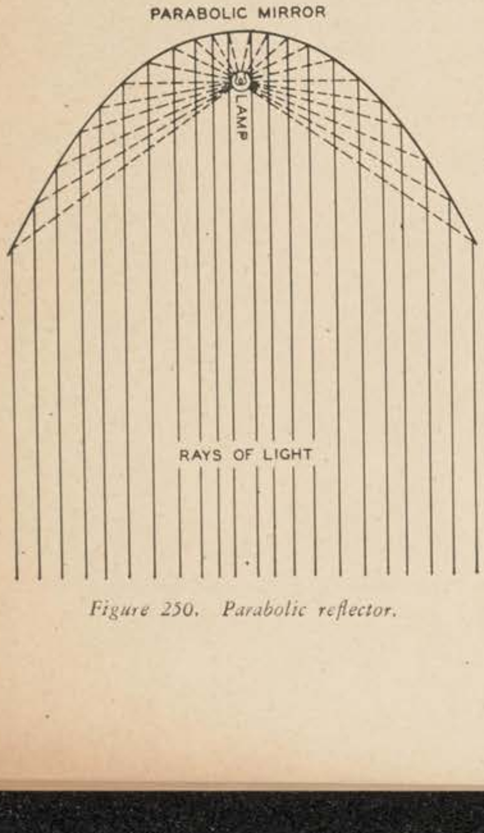


Figure 250. Parabolic reflector.

(2) In some installations, retractable landing lamps, set into the under surfaces of the wings, are used. Icing of the lamp lenses is thus greatly reduced. The installation is usually made as shown in figure 252. It is possible to lower or retract the light and to turn it off in the extended position. The landing-light motor has a split-field winding (fig. 253). The center terminal of the field is connected to one of the brushes. The other brush is grounded through the coil of a solenoid which fits a brake shoe. This brake shoe is held by spring tension against the motor shaft. The other two field terminals are connected to the outer terminals of the control switch *S* through contact points *C* and *D*. When the landing light is retracted, points *C* are pushed upon by the geared quadrant and points *D* are closed by spring tension. If switch *S* is now placed in the "lower" position, the battery current which passes through the completed motor circuit energizes the brake solenoid, withdrawing the brake shoe so that the motor may turn and the lamp will start to lower. After approximately 10 degrees of movement, contact *A* touches and rides along copper bar *B*, lighting the lamp. When fully lowered, the projection on the end of the gear quadrant opens contacts *D* thus stopping the motor and reengaging the brake. If the control switch is now placed in the "retract" position, the motor will operate in the opposite direction.

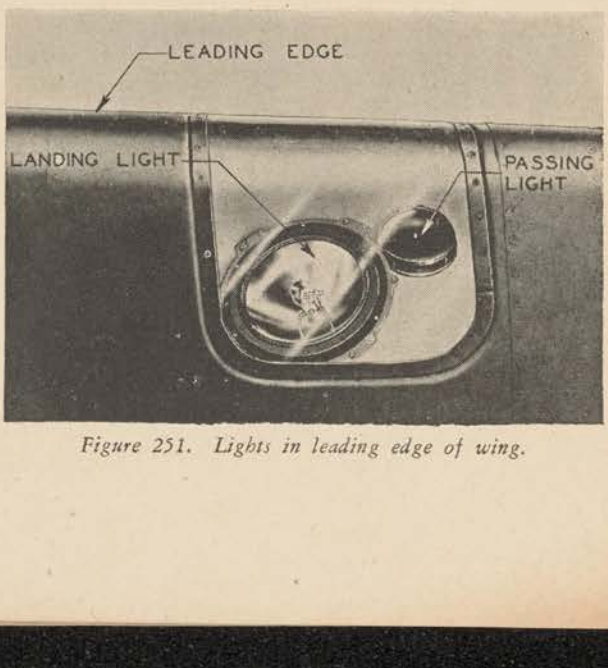


Figure 251. Lights in leading edge of wing.

b. Navigation or position lights. A set of navigation lights is the minimum exterior lighting equipment for aircraft operating at night. The set consists of one red, one green, and one white unit. On more recently built aircraft, each unit consists of one lamp streamlined into the aircraft surfaces to which it is attached. On some of the older aircraft, each unit consists of 2 lamps streamlined into the surface. The green lamp is mounted at the extreme tip of the right wing and the red lamp is similarly located on the left wing. The white lamp is usually located on the vertical stabilizer in such a position that it may be seen through a wide angle when viewed from the rear. The wing-tip lamp units are connected in parallel and are controlled by a single switch in the pilot's compartment. This switch has two "on" positions one of which is connected to the lamps through a resistor (fig. 254). This gives the pilot the choice of two intensities for the wing-tip lamps. The tail lamp is similarly connected through a separate switch.

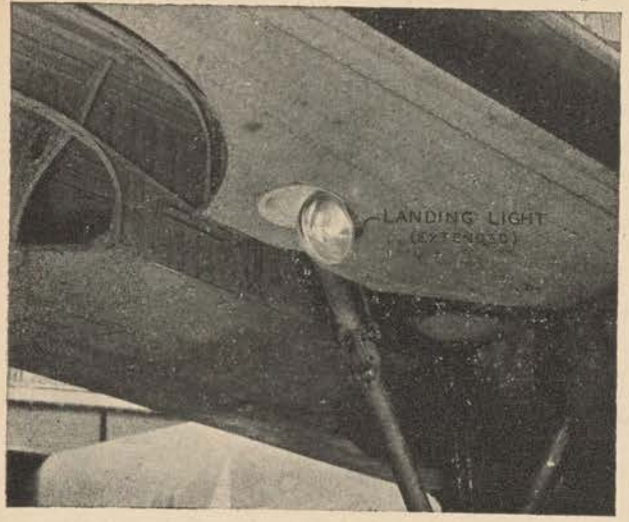


Figure 252. Landing light (extended) on under surface of wing.

c. Formation lights. Formation lights are used on certain military aircraft for night formation flying. On large aircraft, this set of lights consists of nine blue lamps. Three are installed in a straight line running along the upper surface of the fuselage and three are placed on the upper side of each wing or on the horizontal stabilizer (fig. 255). The formation lights are not visible from the ground yet they provide sufficient illumination for group maneuvers with all other lights turned off. The formation lights are controlled through a two-position switch, one position of which is connected to the lamps through a resistor thus giving the pilot the choice of two intensities.

d. Recognition lamps. Airplanes equipped for night flying are usually supplied with upward and downward recognition lights. The upward recognition light is located on the top side of the fuselage and emits a white signal visible from any position above the airplane. Three downward recognition lights are located in the bottom of the fuselage or the right wing. The downward recognition lights emit red, green, and amber signals

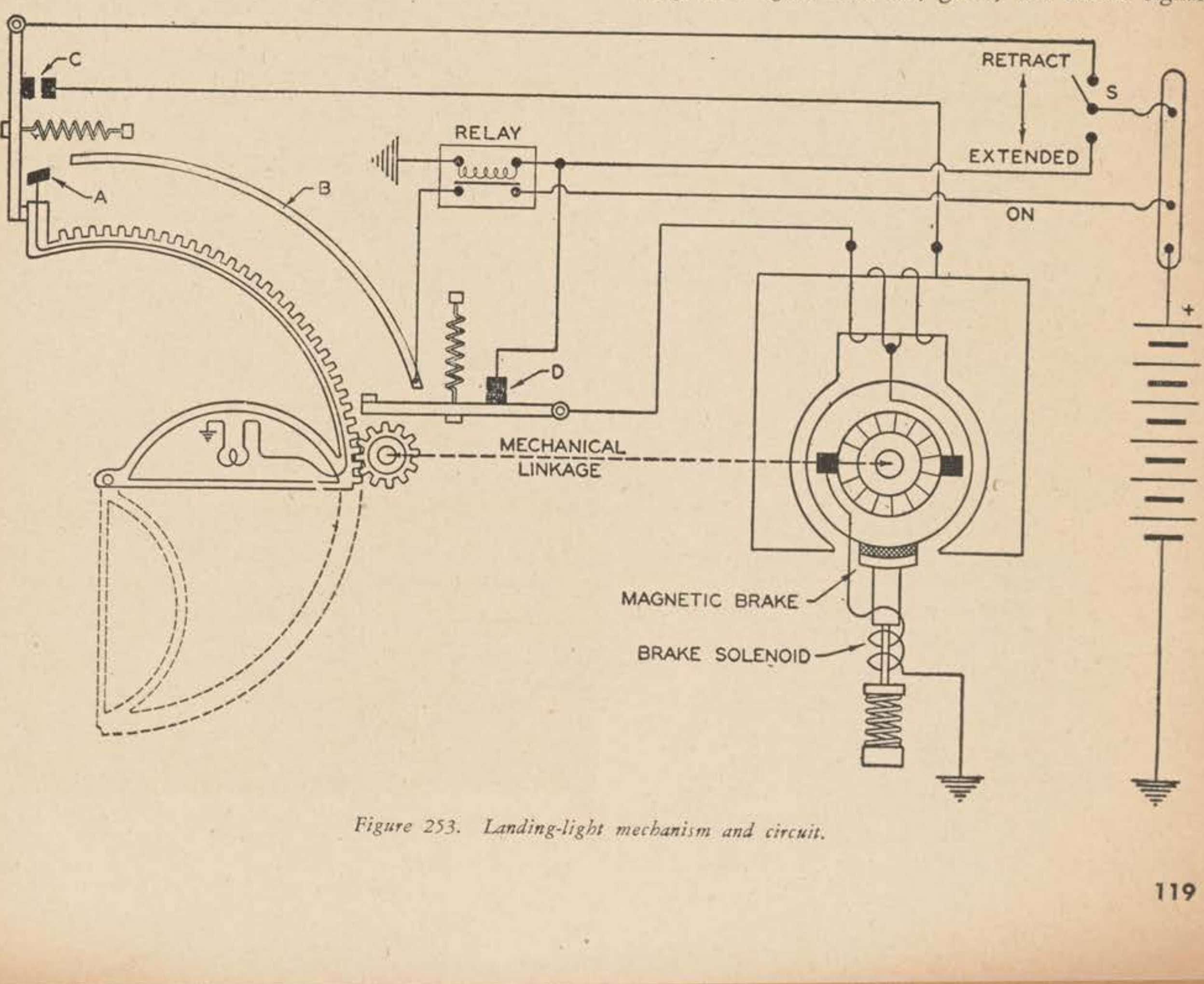


Figure 253. Landing-light mechanism and circuit.

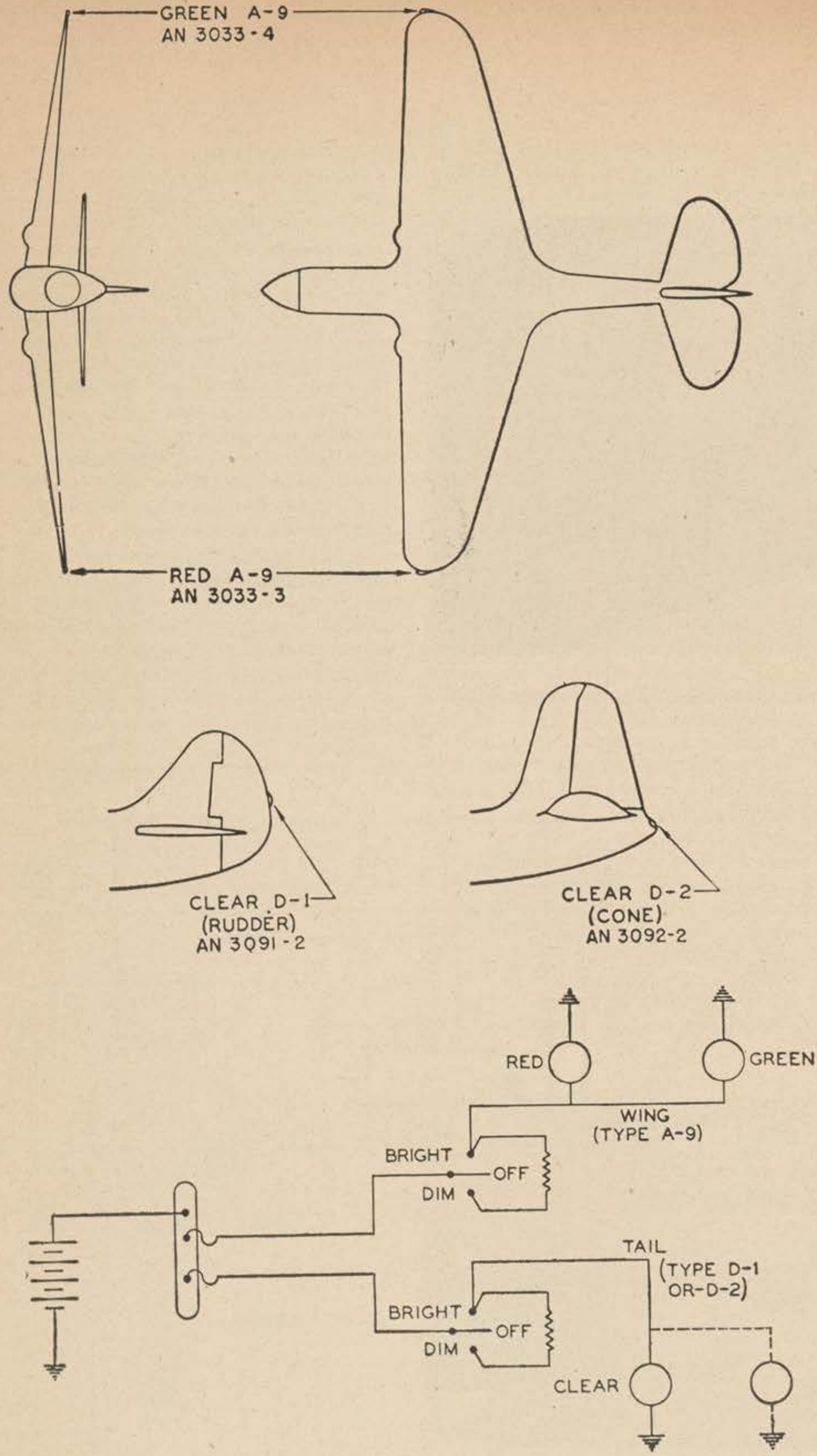


Figure 254. Navigation lights with electrical circuit.

visible from any position below the airplane. All four recognition lamps are controlled from a switch box in the cockpit and may be keyed (usually by means of a pushbutton) to give a prearranged recognition signal (fig. 256).

e. Passing lights. A passing light may be included in the lighting system for use on or near civil airways at night. The lamp (generally controlled by a simple toggle switch) is provided with a red lens and is located in the leading edge of the left wing. It is used in addition to the regular wing-tip navigation lights and as a precaution against collision when meeting other aircraft. See figure 251.

f. Formation bomb-release signal light. A formation bomb-release signal-lamp assembly is located in the tail of bombardment type of airplanes. This lamp assembly gives a white signal when the airplane is ready to release bombs and a red signal for a few seconds immediately after a bomb is released. It is used as an aid to formation bombing technique.

116. INTERIOR LIGHTING EQUIPMENT. a. Instrument and cockpit lighting. (1) Indirect lighting of the instrument panel may be provided by lamps set in the panel. The light from these lamps is distributed over the entire instrument panel by a reflector panel which has openings for observing the various instruments. This method is not widely used in Army Air Forces airplanes.

(2) Individual instrument lighting is provided on some of the older aircraft by means of small 3-volt bulbs which are mounted within the instrument case. These small lamps are operated from the generator battery system by inserting resistors in series with the lamps. The 3-volts necessary for the instrument bulbs may also be obtained from a winding on the inverter or from the auxiliary box as described in the following sub-paragraphs.

(3) Fluorescent lighting is another form of instrument or cockpit lighting. It eliminates the glare which is so common in other types of lighting. The lamp assembly (fig. 257) consists of a shell, a special lens which will pass only ultraviolet light, a screen to regulate the amount of light, and an automatic starting switch (glow lamp). A screen is used for passing visible light also. Instruments used with this type of lighting have the dial figures painted with a material which is sensitive to ultraviolet light. When the invisible ultraviolet light is directed on the instruments, the figures are outlined in a soft glow which makes them very distinct even though there is no visible light coming from the lamp. The voltage for the ultraviolet lamp may be obtained from either an inverter or a so-called auxiliary box.

(*a*) The inverter changes the direct current of the generator battery system into 110-volt alternating current with a frequency of approximately 400 cycles per second. The inverter is a special type of induction coil having a double action vibrator (fig. 258). The vibrating element sends pulsations of current, successively, in alternate directions through the primary coil, producing

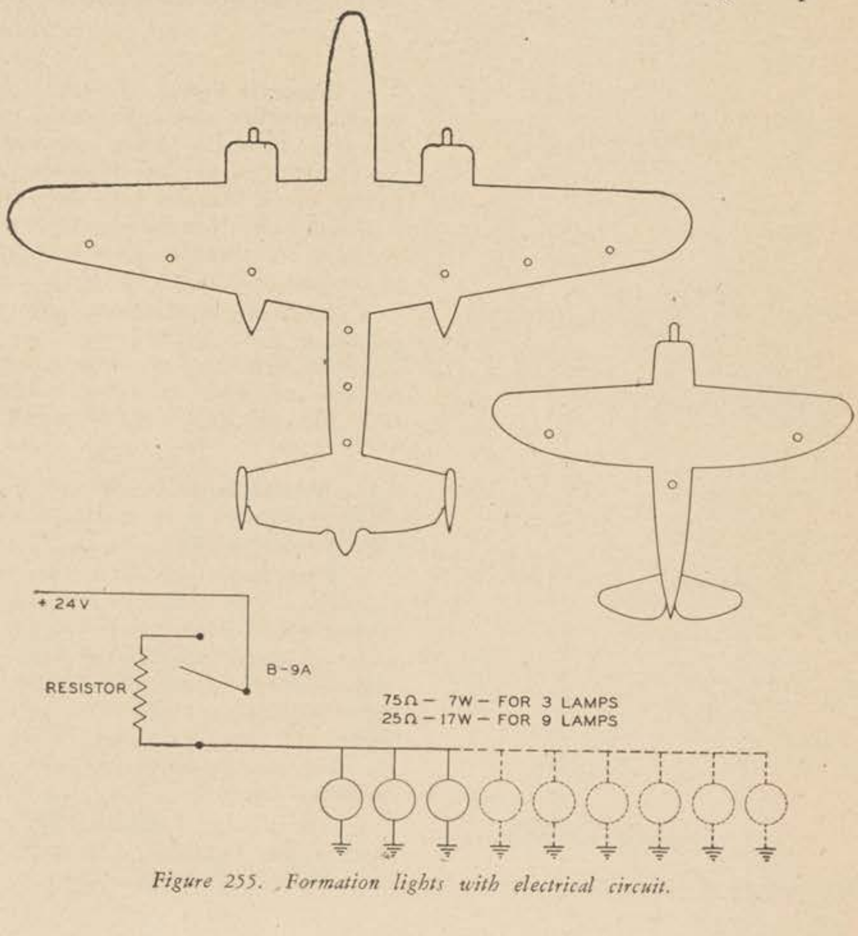


Figure 255. Formation lights with electrical circuit.

alternating current in the secondaries. One secondary operates the fluorescent lamps. Another secondary provides 3-volt a-c to operate the instrument lights. The resistors R_1, R_2 and condenser C_1 are primary circuit elements which improve the operation of the inverter. The inverter is provided with a choke coil K and condensers C_2 and C_3 as a filter system; the input and output leads are shielded to eliminate radio interference.

(*b*) When the aircraft is equipped with a central 110-volt, 400-cycle a-c power supply, the fluorescent lamps may be operated by an auxiliary box. The auxiliary box (fig. 259) includes a reactor for each fluorescent lamp and a stepdown transformer for the 3-volt instrument bulb.

(4) Another type of fluorescent lighting fixture is known as the type C-5 lamp assembly. This lamp assembly operates directly on the 28-volt direct-current system of the aircraft without the necessity of an inverter. It consists of a small fixture containing a special 4-watt, 28-volt fluorescent lamp and is equipped with a light filter which transmits only the invisible ultraviolet light; however, the filter may be opened to obtain visible light. The lamp is controlled by a combined starting switch and intensity rheostat mounted on the instrument panel (figs. 260 and 261).

(5) Many airplanes are now equipped with a small incandescent spotlight known as the type C-4 cockpit lamp assembly. The beam from this lamp assembly may be focused to either a small spot or to a wide beam of light. A red filter is provided when minimum light is desired during a bombing mission. The lamp assembly is equipped with a combined "on-off" switch and intensity control rheostat (fig. 262).

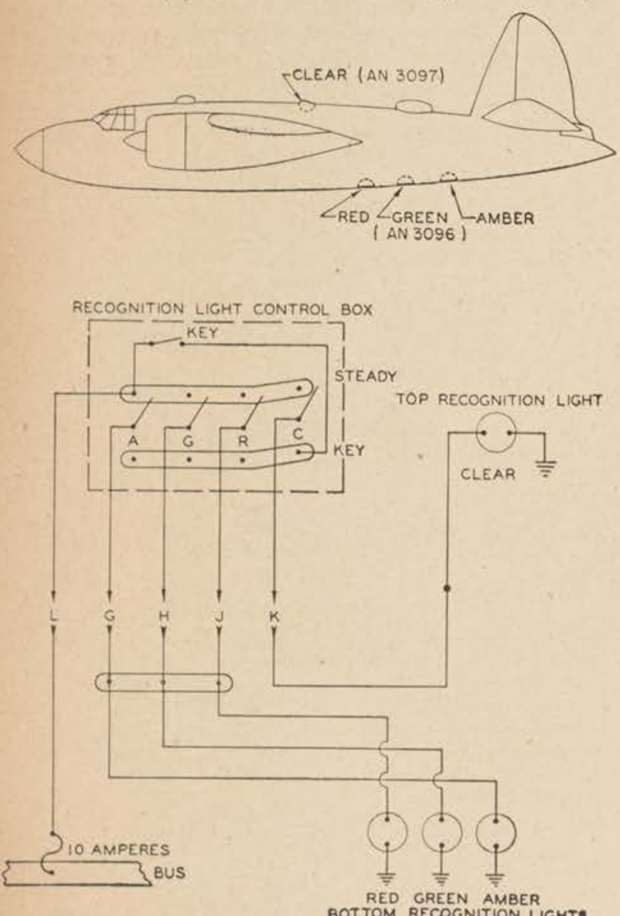


Figure 256. Recognition lights with electrical circuit.

b. Cabin and passageway lighting. The cabins and passageways are illuminated by dome lights properly located in the ceiling or sides of the airplane.

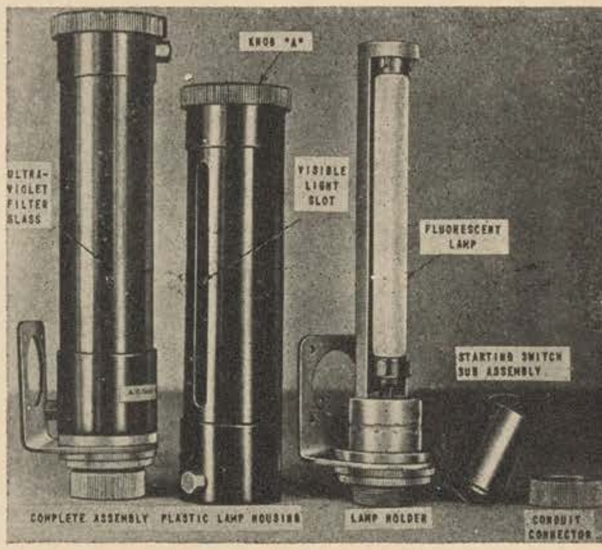


Figure 257. Cockpit lamp assembly (fluorescent).

c. Indicator lights. Indicator lights are used for various purposes such as indicating the position of landing gear, bomb-bay doors, etc. and to indicate other conditions of the airplane or its equipment. In the more recent types of indicator lamp assemblies, an arrangement is included by which the intensities of the signal may be varied to suit the pilot, by simply turning the outer cap of the lamp assembly (fig. 263).

d. Inter-communication call light. Some airplanes are now equipped with inter-communication call lights by which personnel at different stations in the airplane may signal each other. Each call light consists of an indicator light and keying switch.

117. MAINTENANCE. a. Check all visible wiring including connections, terminals, fuses, and switches for condition and security.

b. Keep lamp lenses and reflectors clean and highly polished. If a reflector is found to be cloudy, remove lacquer with acetone, polish with a mixture of lampblack and alcohol and relacquer. If it does not remove cloudiness, reflectors will be removed and turned in for replating. Inasmuch as cloudy reflectors are usually caused by an air leak around the lens, install a new gasket when the lamp is reassembled. Exercise care to insure proper focus and alinement.

c. The cause of malfunctioning of the lighting equipment may be located by systematically testing each lamp circuit with a continuity tester.

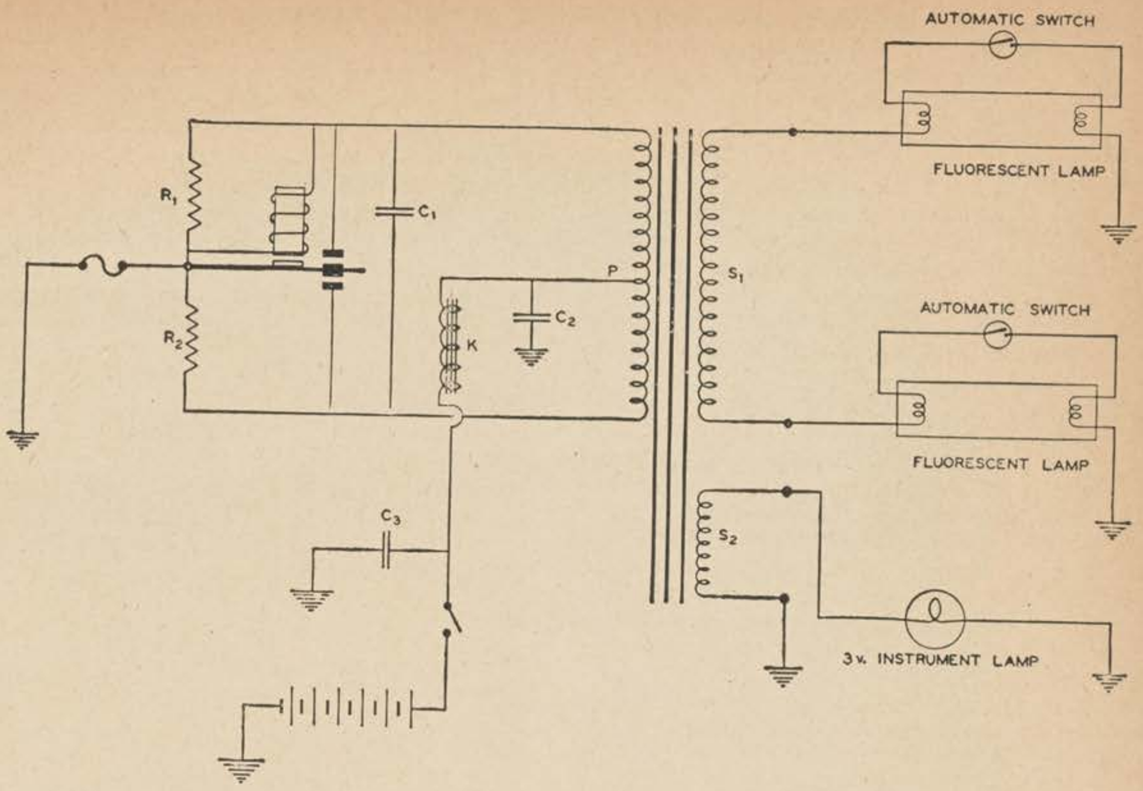


Figure 258. Inverter system for fluorescent and instrument lights.

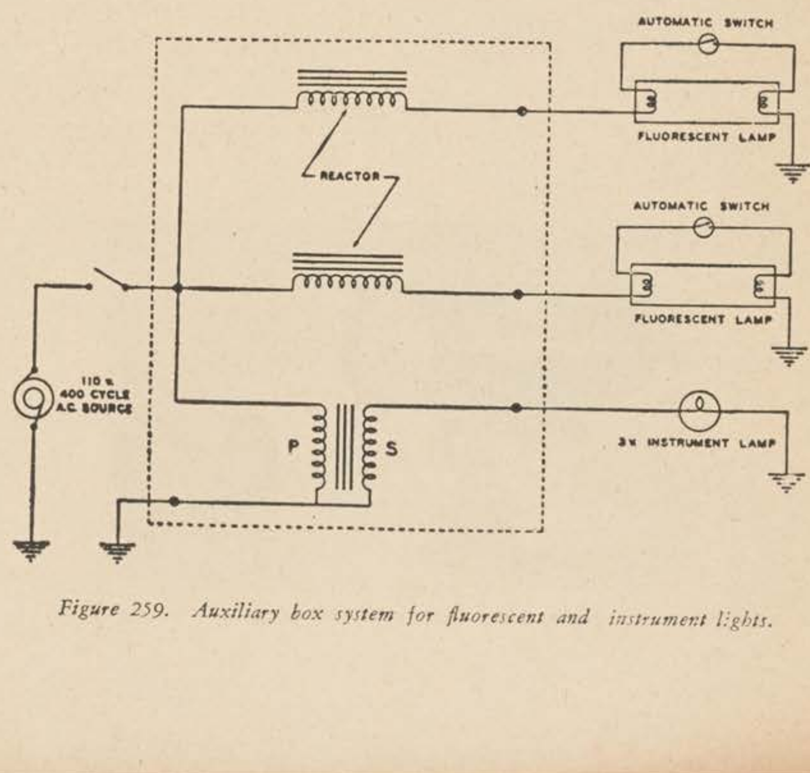


Figure 259. Auxiliary box system for fluorescent and instrument lights.

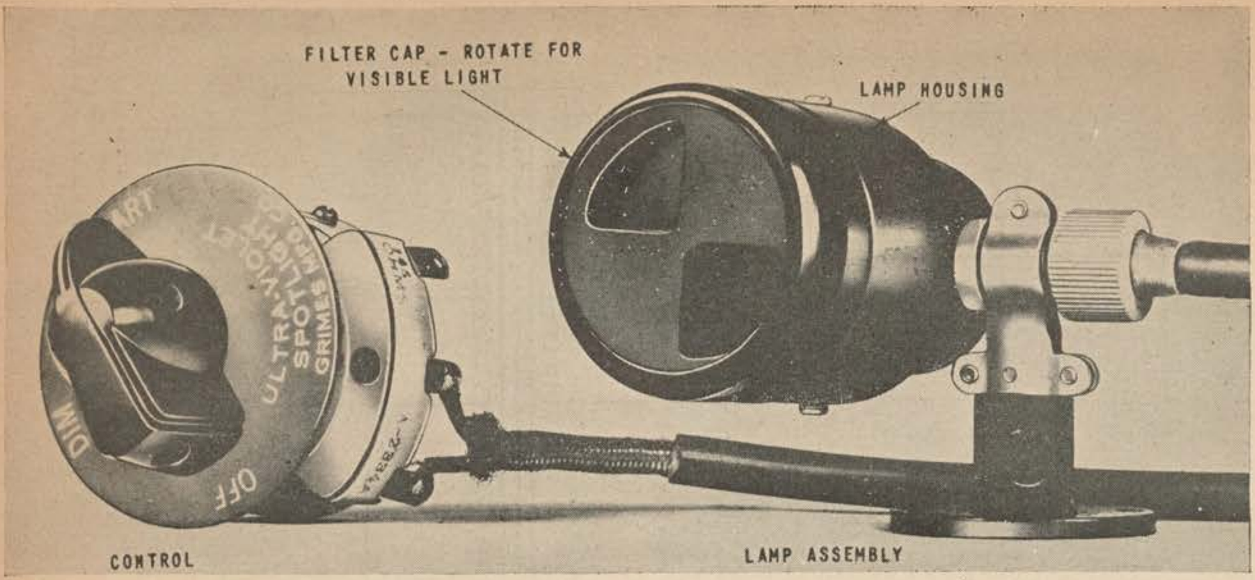


Figure 260. C–5 lamp assembly.

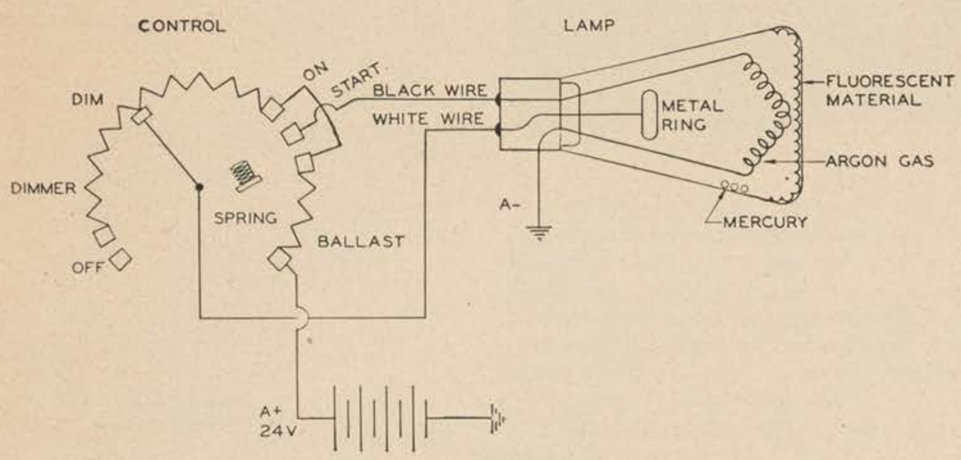


Figure 261. C–5 lamp circuit.

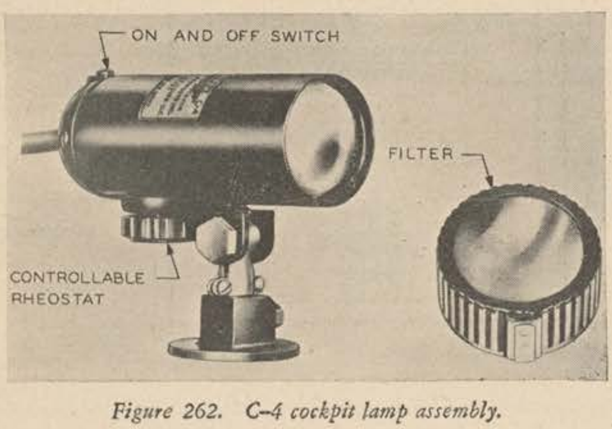


Figure 262. C–4 cockpit lamp assembly.

Figure 263. Indicator lamps and controls.

WIRING SYSTEMS

118. GENERAL WIRING FEATURES. Various types of aircraft do not have identical electrical systems, but certain typical features are in general use. The interrelation of the more common features of a power distribution system are shown in figure 264.

a. From the battery and generator, feeder lines carry current to the main bus, which is considered the central point for the distribution of electrical energy to the various electrical devices. Both the battery and generator feeders are generally provided with master or main-line switches to enable all current to be cut off in one quick operation, as may be desirable in an emergency or when testing. These switches may be controlled remotely by means of relays.

(1) The main bus is a copper bar enclosed within a metal junction box. Branch-circuit fuses are usually attached to the screw terminal of the bus; from these fuses, wires run to control switches in the cockpit and then to various electrical units located throughout the aircraft.

(2) In some installations, other buses, fed from the main bus, are located in compartments occupied by the radio operator, gunner, or other personnel, and serve as centers for the distribution of electrical energy to a special group of devices.

b. When the battery master switch is closed, any device directly connected to the main bus may be operated at any time by means of its individual switch. Certain devices, on the other hand, are connected to the main bus through a safety switch and auxiliary bus arrangement. The auxiliary bus is referred to frequently as the safety bus.

(1) Although the magnetos are entirely independent of the generator-battery system, the safety switch is often incorporated in the same assembly as the magneto switch. For example, in a single-engine safety ignition switch three of the terminals are for the magneto system, the remaining two (often designated *B* and *B. aux.* or *Bat.* and *Aux.*) serve to connect the main bus with the auxiliary bus.

(2) The pitot-tube heating element, the electric starter control, and other equipment which ordinarily should not be operated unless the aircraft is in flight or the engine is being cranked, are connected to the auxiliary bus. Thus, these devices cannot be operated by their individual control switches before the pilot has turned on the ignition preparatory to starting. Also, no damage or current waste can result because of failure of the pilot to turn off these devices at the end of a flight, provided he has shut off the ignition.

c. (1) The lead wire from the positive battery terminal proceeds first to one terminal of the motor-starter switch because the starter-motor circuit draws the heaviest current and requires conductors of very low resistance. Therefore, the battery, starter motor, and starter switch are generally located as close to each other as practicable, to allow their heavy leads to be as short as possible. The line which connects the bus to the battery may then be a lighter cable.

(2) In some installations the starter and main bus are connected to a heavy connector plug. This plug is located so as to permit easy connection to a battery cart or a ground power plant (fig. 235).

d. (1) Wires used in aircraft electrical systems carry an identifying number. This number may be prefixed with a code letter to identify the general circuit of which the wire is a part. When replacing a defective wire, no splices are permitted, and a complete new length of wire is installed, of a type, length, and size in accordance with specifications. Before the wire is installed, a band of cellulose tape is wrapped around it near each of its terminals. The identifying number is typed on the tape, and a protective coating of shellac applied. With this means of identification, a circuit can be traced and tested easily.

(2) A connector panel is a panel of insulating material provided with terminals which are insulated from each other. Each terminal serves as a convenient junction for a wire to be connected to one or more lengths of wire.

119. WIRING. a. Power cables. The power in the electrical system is transmitted from the source to the unit through a system of wires and cables. In any electrical circuit, a conducting path must be provided from the source to the unit and from the unit back to the source. In most airplanes, the return path is through the framework or other metal portion of the airplane's structure.

(1) *Cable construction.* The aircraft cable is constructed of a large number of small, tinned copper wires. The use of a large number of wires makes the finished aircraft cable more flexible. The wires are braided or twisted together and then covered with an insulating material. The insulation may be varnished cambric or any other suitable insulating material. In table IV are listed Army-Navy specifications for aircraft cables. The size of the cable is designated in the American Wire Gage number (A.W.G.). In the Army Air Forces, only even number sizes of cable are used. The size varies from No. 20 to No. 00 (2/0). The larger the number the smaller the cable. Consequently, No. 20 is the smallest

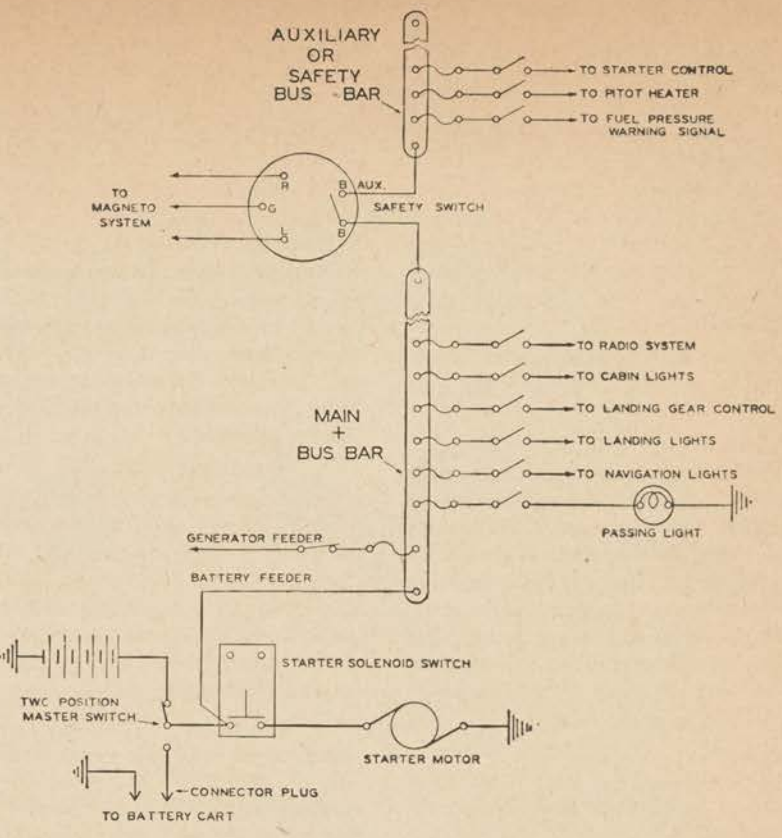


Figure 264. Typical features of power distribution system.

cable and No. 00 is the largest. The ampere rating or current rating of a cable depends upon the cross section area of the cable. The fuse capacity of any cable is the maximum current the cable will safely carry.

Table IV. Aircraft cable specifications

Wire Size A. W. G.	Resistence of cable (ohms per 1,000 ft. at 20° C.)	Rating (amperes)	Fuse Capacity (amperes)
AN–20	10.25	0.8	2
AN–18	6.44	7.0	15
AN–16	4.76	11.0	20
AN–14	2.99	16.0	30
AN–12	1.88	23.0	35
AN–10	1.10	33.0	50
AN–8	0.70	45.0	70
AN–6	0.436	65.0	100
AN–4	0.274	90.0	125
AN–2	0.179	130.0	175
AN–0	0.114	185.0	250
AN–00	0.090	220.0	300

(2) *Size of cable.* In choosing the size of cable for any particular installation the cable must be selected with the correct (*or higher*) current rating. The IR drop, in the cable, must not exceed 1 volt for continuous duty or 2 volts for intermittent duty. (28 volts are used in making any IR drop calculations). Often a certain size cable will carry a load as far as the heating effect is concerned but because of its *length,* the voltage drop in the cable becomes excessive. In this case, a larger cable must be used.

(3) *Routing of cables.* In modern tactical aircraft, conduit is eliminated, wherever possible, to facilitate the wide separation of cables. Its elimination also facilitates cable installation and maintenance and, in addition, saves weight. Where there is wide separation of cables, the airplane electrical system becomes less vulnerable to gunfire. In the individual routing of cables, particular care must be taken that the airplane structure is used to the best advantage as an electrical shield for the cable. Channels and even the surface covering of a metal airplane will provide excellent shielding effects. In replacing a cable, particular care must be taken to replace it in the exact position in which it was originally installed. No attempt should be made to reduce the length of the cable by taking what may seem to be a logical short cut.

b. Ignition cables. (1) Ignition cables need not have a high current carrying capacity, but must be able to withstand a high voltage. Hence, the greater portion of the cable is insulation.

(2) Ignition cables used in the Army Air Forces are of two sizes—the 7-mm is the standard size for nearly all original installations; a 5-mm cable is being used on

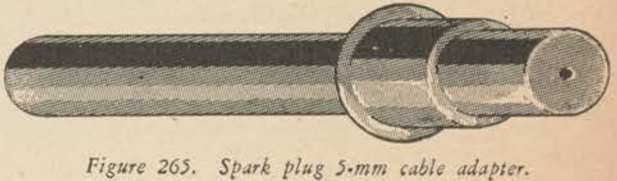


Figure 265. Spark plug 5-mm cable adapter.

some of the newer installations and to replace some of the 7-mm cable whenever a replacement is required. The 5-mm cable has a better type of insulation and its smaller size facilitates installation. If a 5-mm cable is used to replace a 7-mm cable, special adapting devices are used on each end (fig. 265).

c. Terminals and connectors. (1) A terminal is a device which can be connected to the end of a cable. It facilitates attachment of the cable to the source of power supply or to the unit which is to be operated. Terminals are of two general types; the soldered terminal and the patent solderless terminal.

(2) To facilitate removal and installation of wiring connections to electrical appliances, a conventional connector is used.

(*a*) *Types and construction.* Connector types are numerous. Plug assemblies are of two types: straight or 90°. Receptacle assemblies may be of the wall-mounting, box mounting, and integral-mounting types. To identify the receptable from the plug, the receptacle is always the fixed portion of the connector and the plug is the movable part. Army-Navy specification numbers and letters identify a connector's type, style, and arrangement. For example, a commonly used connector may be identified as an AN3106–28–58 plug with an AN3102–28–5P receptacle.

AN—Army-Navy
3106—Specification number for plug
3102—Specification number for receptacles
28—Size of the shell
5—Contact arrangement
P—Pin contacts
S—Socket contacts

The connector mentioned is used on a 28-volt, 100-ampere generator system. Figure 266 shows the parts and proper nomenclature of the connector.

(*b*) *Maintenance.* If a connector is to be replaced in a circuit, disassembling, soldering, and assembling must be properly done (fig. 267).

d. Junction panels. In the modern airplane, cables are run from one end of the airplane to the other through several junction boxes. Provision must be made to replace and inspect these various cables. If the cables were in one piece, from the source to the unit, greater difficulty would be encountered in replacing the cable; hence, terminal boxes and strips are provided for the connection of the cables. Cables are never spliced between junctions; if a cable is damaged, it is removed and replaced with a new one.

e. Shielding. Shielding is the enclosing of cables or electrical units with metal. The purpose of shielding is to *cause* the high-frequency voltage (interference) to be induced *in the shield* rather than in the adjacent units. Shielding is used where one unit is to be protected from the effects of a high frequency current in a unit near it or where a cable is to be protected from radio frequency noise. An example of this would be the flexible, metal covering about the radio antenna.

f. Bonding. (1) *Construction.* A bond is usually made up of a flexible metal strap provided with a terminal at each end. The bond can be made of either aluminum or tinned copper wire. However, care must be taken not to place two dissimilar metals in contact with one another. Brass, bronze, copper, and steel in contact with aluminum will result in corrosion, especially when in the presence of moisture.

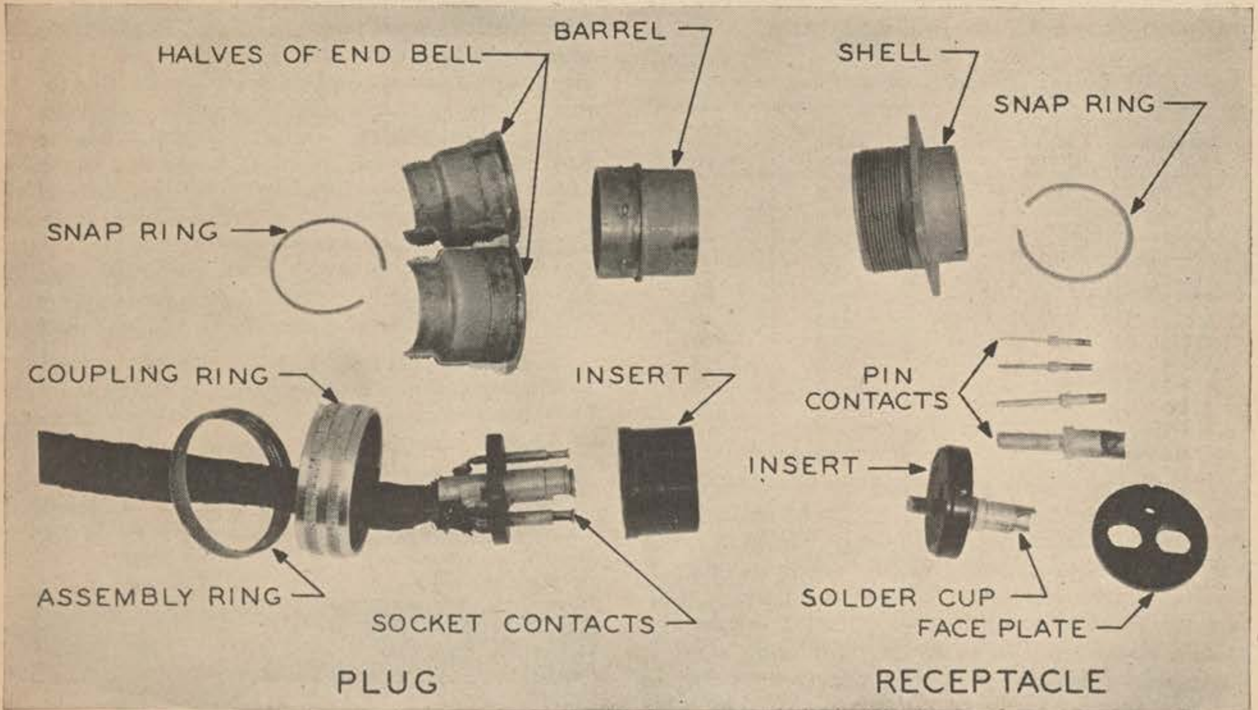
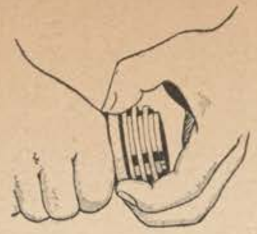
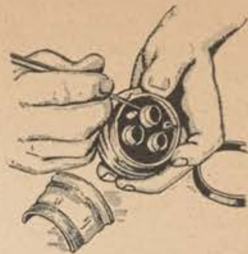


Figure 266. Cable connector plug.

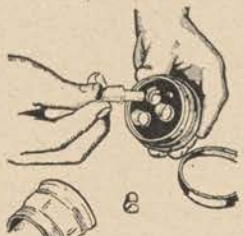


WHEN DIS-ASSEMBLING AN CONNECTORS, GRASP THE SPLIT END FIRMLY OVER THE BOSSES WHILE UNSCREWING ASSEMBLY RING.

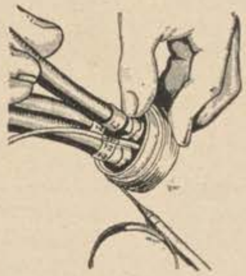
WITH ASSEMBLY RING REMOVED, BOTH HALVES OF END BELL ARE LIFTED OFF, EXPOSING TERMINAL ENDS AS SHOWN ABOVE.



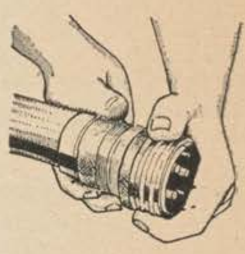
THE SPRING CLIP WHICH LOCKS LARGE TERMINALS IN PLACE IN THE BAKELITE FILLER IS PRIED UP AND THEN SLIPPED OFF.



LARGE TERMINALS ARE THEN GIVEN A QUARTER-TURN AND LIFTED OUT OF THE BAKELITE INSERT. THEY ARE THEN READY TO SOLDER.



LARGE TERMINALS ARE REPLACED IN THE BAKELITE INSERT AFTER THE WIRES ARE SOLDERED. TERMINAL IS GIVEN A QUARTER-TURN AND LOCKING CLIP IS THEN REPLACED.



BOTH HALVES OF END BELL ARE REPLACED AND LOCKED TOGETHER BY ASSEMBLY RING. CONDUIT IS ATTACHED BY COUPLING NUT.

DISASSEMBLY AND ASSEMBLY

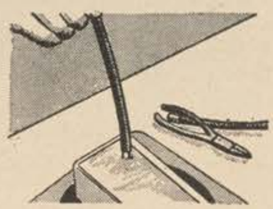
① *Disassembly and assembly.*

LARGE TERMINAL IS THEN CAREFULLY TAPED BEFORE DIPPING IN SOLDER POT, TO PREVENT THE SOLDER FROM ADHERING TO CONTACT END.

TERMINAL IS DIPPED INTO SOLDER POT TO TIN SOLDERING CUP AND FILL CUP WITH SOLDER BEFORE INSERTING END OF CABLE.

CABLE END IS WOUND WITH WIRE TO HOLD SMALL WIRES OF THE CABLE TOGETHER WHILE SOLDERING INTO LARGE TERMINAL.

THE LARGE TERMINAL AND END OF CABLE ARE THEN BROUGHT TOGETHER IN THE SOLDER POT, FORCING LARGE CABLE INTO THE SOLDER CUP.



END OF CABLE IS ALSO DIPPED INTO SOLDER POT TO TIN THE EXPOSED WIRES BEFORE INSERTING INTO SOLDER CUP OF THE LARGE TERMINAL.

WITH LARGE TERMINALS REMOVED IT IS EASY TO SOLDER SMALL TERMINALS THAT STILL REMAIN IN THE BAKELITE INSERT.

SOLDERING

② *Soldering.*

Figure 267. Maintenance of connector plug.

(2) *Uses of bonding.* Bonds are used to tie together electrically any parts of the metal structure of the airplane which are not already an integral part of the airplane. Any part of an airplane which is movable or is connected by a hinge, etc., should be bonded to the main structure of the airplane. This usually can be done with a bond only a few inches in length. Some of the most important units which require bonding are engine to mount, ailerons to wing, radio to the airplane structure, cowling flaps to the support, and conduit to airplane structure.

(3) *Maintenance.* Maintenance requirements are that the bond be intact and make a good electrical connection at all times. In replacing a bond, care must be taken to make a good metal contact. If, in preparing the surface for the bonding connection, the surface has to be cleaned with sandpaper, care must be taken not to damage the original finish on the metal. Bonds should be placed in such a position as not to interfere with the operation of the unit and not be damaged or broken loose because of the motion or vibration of the unit.

120. ELECTRICAL SYSTEM PROTECTION. a. General. Various devices and arrangements of circuits are used to protect the electrical system of aircraft from damage and failure.

b. Fuses. A fuse is a strip of metal bridging the ends of two wires in a circuit, the metal having a very low melting point. Most fuses are made of an alloy of tin and bismuth; however, some are made of copper. If the fuse is made of copper it is called a current limiter. The current limiter is used in sectionalizing the airplane circuit. A fuse will melt and break the circuit whenever the current becomes excessive, whereas a current limiter will stand considerable overload for a short time. There are a number of types of fuses. The ones most used in the Army Air Forces are the "plug-in" type or the "clip" type. The capacity of the fuse will always be slightly higher than the anticipated load on the circuit.

c. Circuit breakers. (1) A circuit breaker is a manually operated switch which has a mechanical tripping device; it will break the circuit when the current reaches a predetermined value. The circuit breaker is often used in place of a fuse and it may eliminate the use of a switch (fig. 268). The circuit breaker can be made to control a number of circuits as shown in the diagram. Several types of circuit breakers are used by the Army Air Forces. The magnetic type operates by the pull of an electromagnet on a small armature which, in turn, trips the breaker.

(2) Another type of circuit breaker is the thermal-

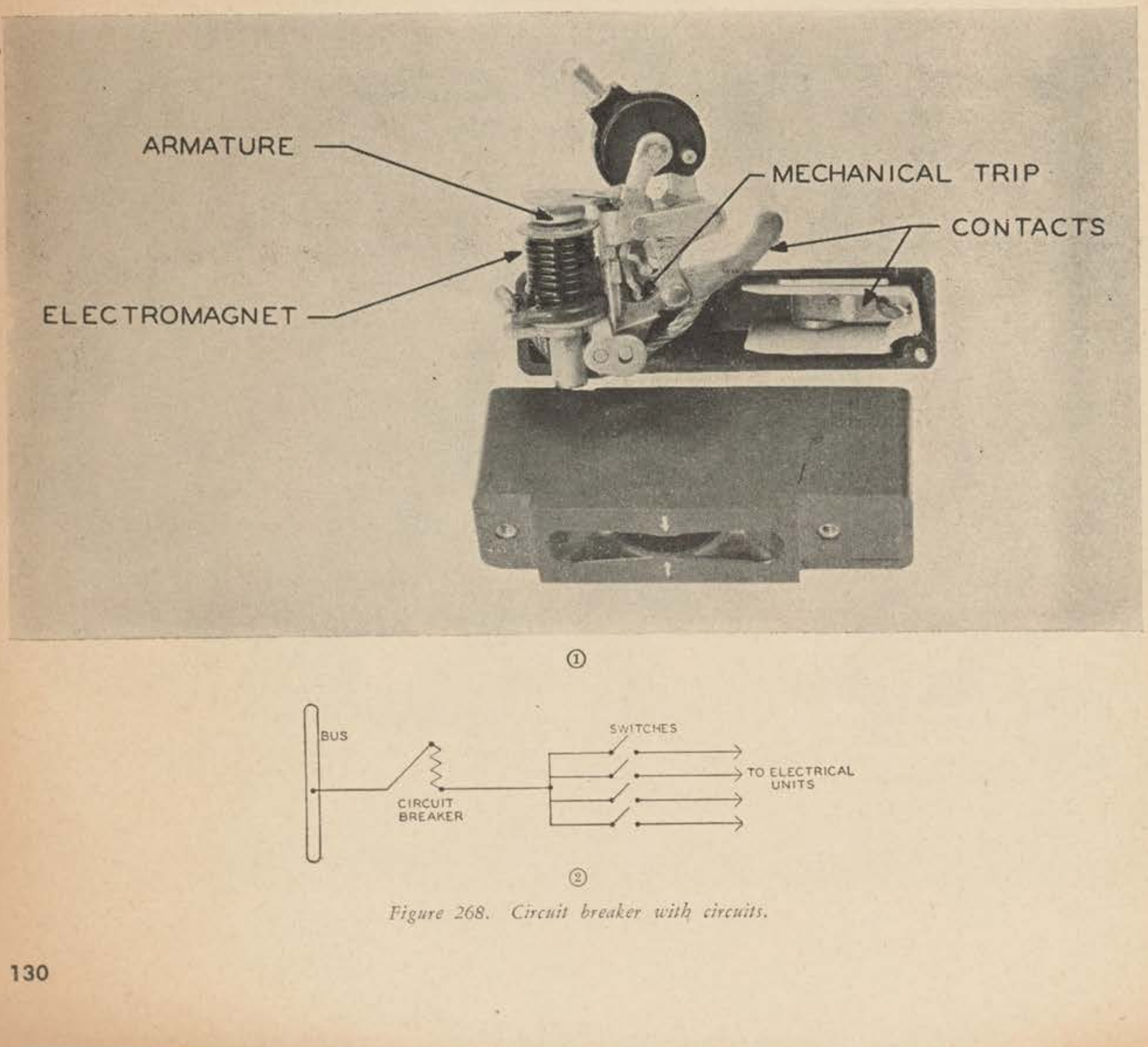


Figure 268. Circuit breaker with circuits.

overload breaker or switch. When a bi-metallic strip becomes heated, it will bend away from a catch on the switch lever and permit the switch to trip open. If a circuit breaker is used, the switch must be turned all the way "off" then back to the "on" position to put the circuit back in operation. If the overload is still present, the circuit breaker will again trip without damage to the circuit.

d. Circuit protectors. A circuit protector is a device which automatically opens the circuit whenever the temperature of the *unit* becomes excessively high. It has two positions, automatic "off" and automatic "on." If there is a fault which will cause the temperature of a motor to become excessively high (a locked rotor, for example) the circuit will be broken intermittently. This may permit the motor to break loose and complete its operation. The operation of the circuit protector is accomplished by a bi-metal disk or strip which will bend and break contact when it is heated. On cooling, the bi-metal disk will assume its original position and close the contacts.

e. Sectionalization. Sectionalization is a proposed plan for the arrangement of an electric circuit which provides alternate paths for an electric unit to receive its power (fig. 269). At each junction current limiters are placed in the circuit. Fuses and circuit breakers can be used in place of current limiters; however, the circuit will not function as well. Circuit breakers have the advantage of not requiring replacement. Since sectionalization provides an alternate electrical path to a device, it could be especially valuable to aircraft in combat. If an electrical path feeding a unit such as a gun turret has been broken by gunfire, the turret can be fed by another path and will continue to operate. If a path has a fault such as a short circuit, the circuit will be so arranged that current from two or three lines will feed into the current limiter installed in the line having the short circuit, and will break the circuit. Therefore, the faulty line will be cut from the circuit. The power will then be transmitted to the unit intended to be operated.

121. WIRING DIAGRAMS. a. The manufacturer of the particular aircraft furnishes a wiring diagram of the electrical system. This wiring diagram is in blueprint form and is kept in the data compartment of the aircraft so as to be available at all times. The wiring diagram is helpful to the mechanic when making inspections, testing circuits, and replacing electrical equipment. A small part of an aircraft wiring diagram is shown in figure 270.

b. The type and serial number of the aircraft and various explanatory notes are given on the blueprint. The wiring diagram is sub-divided by dashed lines to indicate, in a general way, the main sections of the aircraft. Dashed lines may also denote a junction box or other inclosure and in some instances mechanical linkage.

c. In addition to many of the common symbols shown in figure 7, various other symbols, as shown in figure 271, appear on aircraft wiring diagrams to designate items of electrical equipment. A reference number is assigned to each separate item and printed (frequently underlined) near the symbol which represents the item.

(1) A table of equipment is given on the blueprint and each item of equipment is listed numerically. Information, for each item, includes its serial number, name or description, quantity required, Army Air Forces type, etc. Tabulation of equipment shown in part in figure 272 includes some of the items shown symbolically in figure 270.

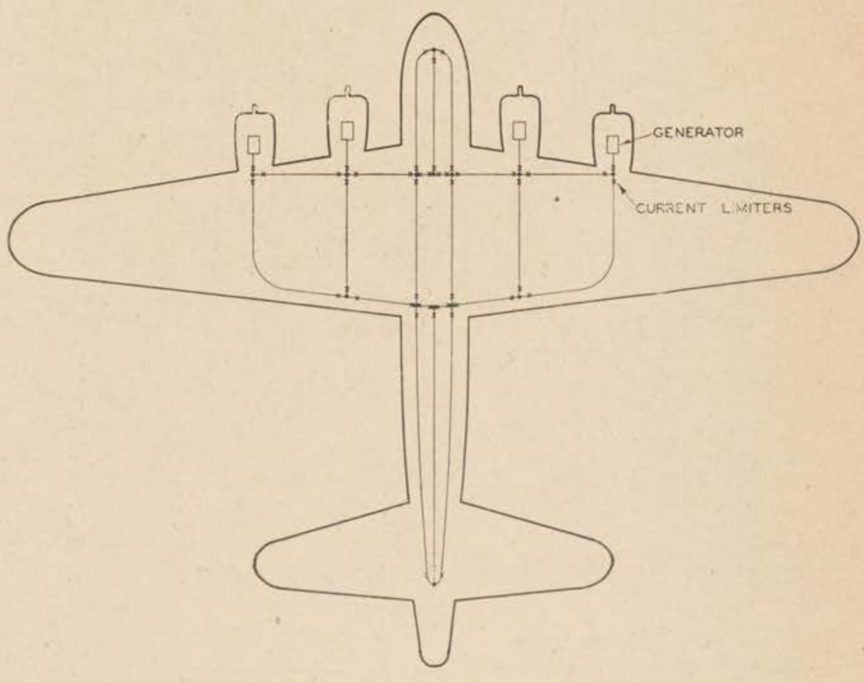


Figure 269. Profused diagram for sectionalization.

(2) The table equipment should be consulted to identify a symbol and/or to insure that the correct type of equipment will be obtained when replacement is required.

d. Cables which connect various units are indicated by solid lines, vertical or horizontal. For identification, the same serial number which appears on the cable in the aircraft is printed somewhere along the line which represents the cable on the diagram.

(1) A wire table, shown in part in figure 272, is also given on the blueprint, and it lists the cables numerically. Information for each cable may include its length, size, and types of terminal lugs.

(2) The wire table should be consulted when a cable in the aircraft is to be traced or when a defective cable is to be replaced. When replacement is made, the numbers must be put on the new cable just as they were on the cable which was replaced.

e. Conduit is generally represented on wiring diagrams by a single solid line. At each end of the line a bracket is drawn to include all the separate cables entering or leaving the conduit. All cables entering a conduit at one point must leave it at another point but not necessarily in the same order of entry. Care must be exercised not to confuse conduit and cable lines. A conduit line may or may not have an equipment number but it will never have a cable number.

f. (1) Occasionally, a unit (or group of units) appears in a separate sketch. Figure 273① illustrates a conventional method used to show the relationship between the sketch and the main body of the wiring diagram.

(2) Some wiring diagrams use a complete "code" in order to avoid many wire crossings (figure 273②). The full length of a cable is not drawn; only a small length extending from its terminals is shown. At each terminal of an item of equipment, various code numbers are given. The wire connected to a terminal is represented by a number. Another number adjacent to the cable number designates the item of equipment to which the cable connects. When tracing a cable on such diagrams, the item of equipment is located first and then the terminal to which the cable (which is being traced) connects.

g. The service instructions in the Technical Order for a particular aircraft may contain diagrams of specific circuits assembled from the complete wiring diagram. Figures 274 and 275 are examples of such assembled diagrams. An individual circuit diagram is especially helpful when the mechanic is concerned with one particular circuit only. The service instructions may also contain equipment and cable tabulations compiled from the blueprint.

(1) When an assembled diagram, as contained in service instructions, is not available or when it is desired to further simplify a specific part of a circuit, a detailed diagram may be used. Typical details of a wiring diagram are illustrated in figure 276. The essential features of the generator-battery circuit may be simplified by following the connections from the proper terminals. The cable, from the *A* terminal on the voltage regulator to the *A* terminal on the generator, passes through two lengths of conduit, a pull box, and a connector plug; one short line may be used to indicate this connection. By use of this method, the features of the circuit may be simplified to the extent shown in figure 277.

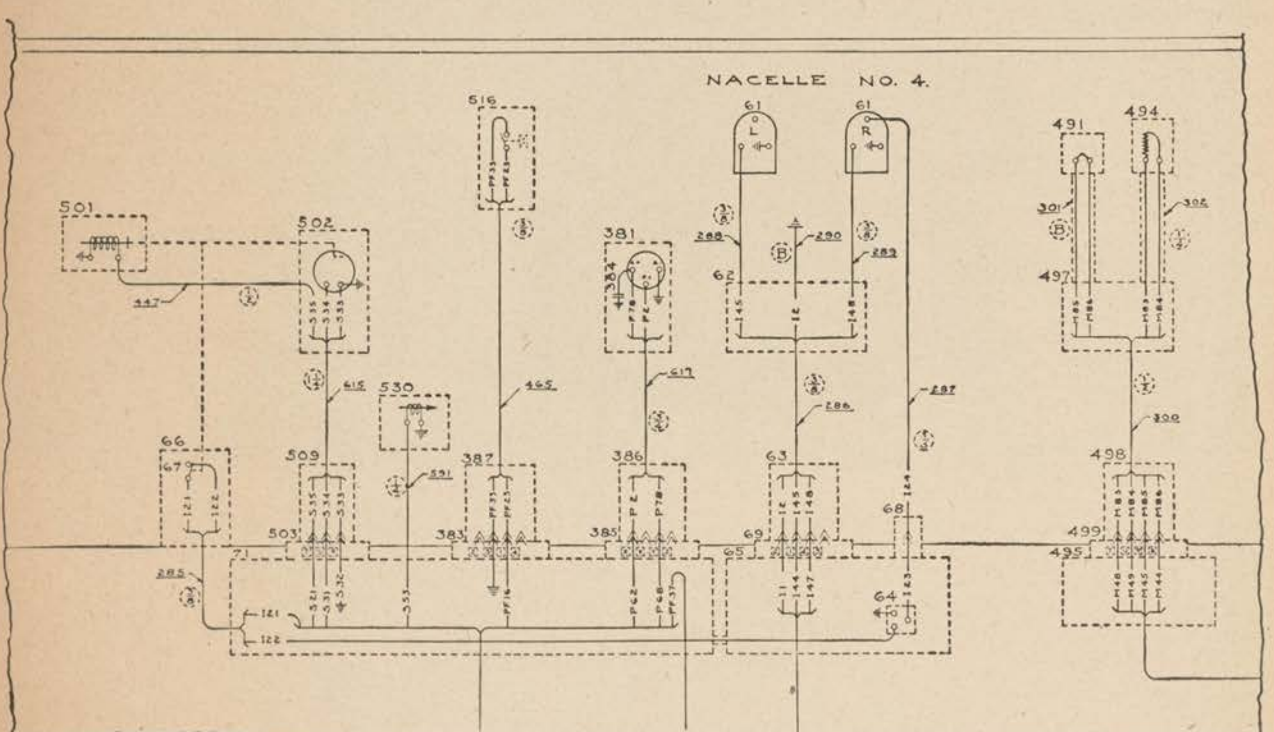


Figure 270. Part of an aircraft wiring diagram.

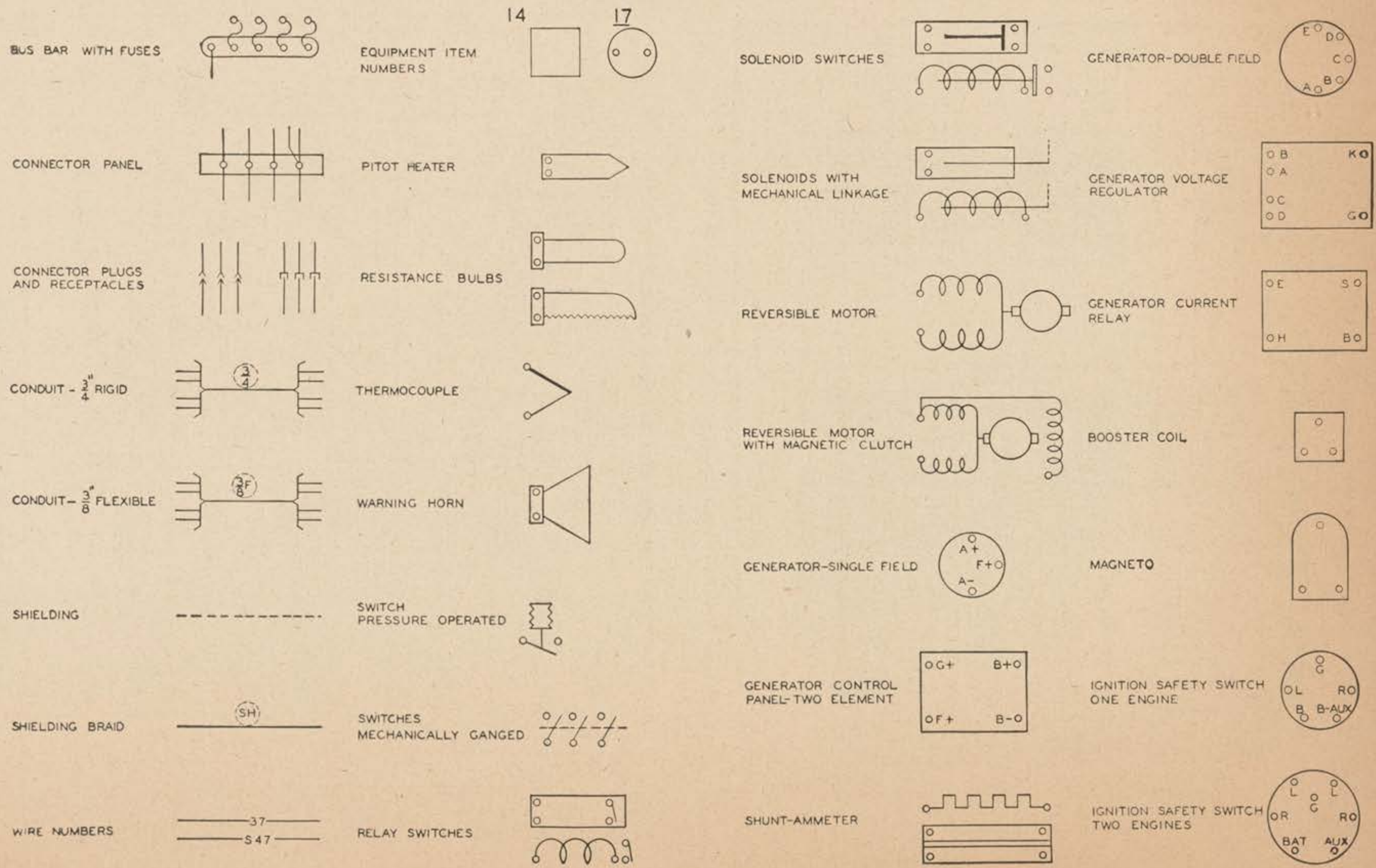


Figure 271. Conventional symbols used on aircraft wiring diagrams.

TABLE OF EQUIPMENT					
NO	DESCRIPTION	REQ	TYPE	PART NO	INST DWG No
61	MAGNETO--BENDIX-SCINTILLA	8	SF9LI	10-5377	15-5900
62	SHIELD-ENGINE PULL	4	BAC	3-1056912	6-8107-1
63	PLUG-IGNITION PULL	4	BREEZE	35A4273	15-5284
64	COIL-BOOSTER	4	A-1	2520	———
65	SHIELD OUTBRD IGNITION	2	BAC	311256	6-7692
66	SHIELD BOOSTER SWITCH(OUTBD)	2	BAC	21-9627	[illegible]
67	SWITCH-BOOSTER	4	B-G-B	AN 3016	9-2917
68	SOCKET-HIGH TENSION	4	BREEZE	E-1117-1-20	6-7692
69	SOCKET-IGNITION	4	"	35A4269	6-7692
70	SHIELD-INBRD IGNITION	2	BAC	3-11256	6-7690
71	SHIELD-STARTER CONNECTOR OUTBRD	2	"	3-11251	6-7692

381	GENERATOR-ENGINE Nos 2-3 & 4	3	E-7	F-64463-2	15-5900
382	PLUG	4	BREEZE	35A4273	15-5284
383	SOCKET	4	"	35A4269	———
384	CAPACITOR	7	B-1	Spec 50131	———
385	SOCKET-GENERATOR	3	BREEZE	35B5168	3-11255
386	PLUG-GENERATOR	3	"	36A2203-2	15-5284

491	THERMOCOUPLE-UNIT	4	W.A.C.	62508	62102
494	RESISTANCE BULB-CARB AIR TEMP	4	F-2	Spec 27823	15-5900
495	SHIELD-OUTBRD THERMOCOUPLE	2	BAC	3-10569-4 3-10569-12	3-11377
496	SHIELD-INBRD "	2	"	"	3-11969
497	SHIELD-ENGINE PULL	4	"	"	6-8107
498	PLUG	4	BREEZE	35A2533	15-5284
499	SOCKET	4	"	35A2539	3-11969
501	SOLENOID-STARTER MESHING	4	A-1A	C-53635	9-2917
502	STARTER	4	C-21	F-42331	15-5900
503	SOCKET	4	BREEZE	36A1881	———
505	SOLENOID-STARTER	4	A-5A	C-53540	———
509	PLUG	4	BREEZE	36A1874	15-5284
515	MOTOR-PROPELLER FEATHERING PUMP	4	PESCO	417770	15-4726
516	SWITCH- " PRESSURE CUT-OUT	4	HAMILTON	53574	15-5900

WIRE TABLE		
IGNITION		
WIRE NO	SIZE	LENGTH
I 1	16	264
I 2	16	48
I 21	18	312
I 22	18	48
I 23	HT	6
I 24	HT	36
I 45	16	72
I 48	16	72

WIRE TABLE		
D.C. POWER		
WIRE NO	SIZE	LENGTH
P 2	18	60
P 62	18	372
P 68	6	120
P 78	6	60

WIRE TABLE		
STARTER CONTROL		
WIRE NO	SIZE	LENGTH
S 21	10	372
S 23	16	288
S 24	2	96
S 31	2	120
S 33	2	48
S 34	2	48
S 35	10	84

Figure 272. Tabulation of equipment and wire.

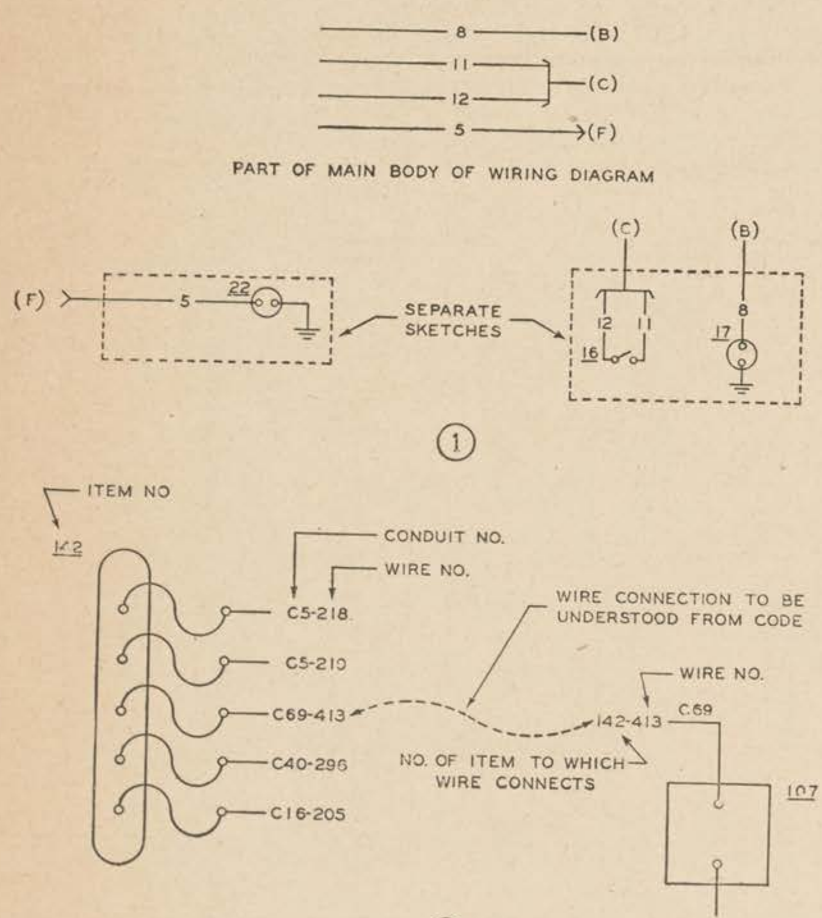


Figure 273. Wiring-diagram code conventions.

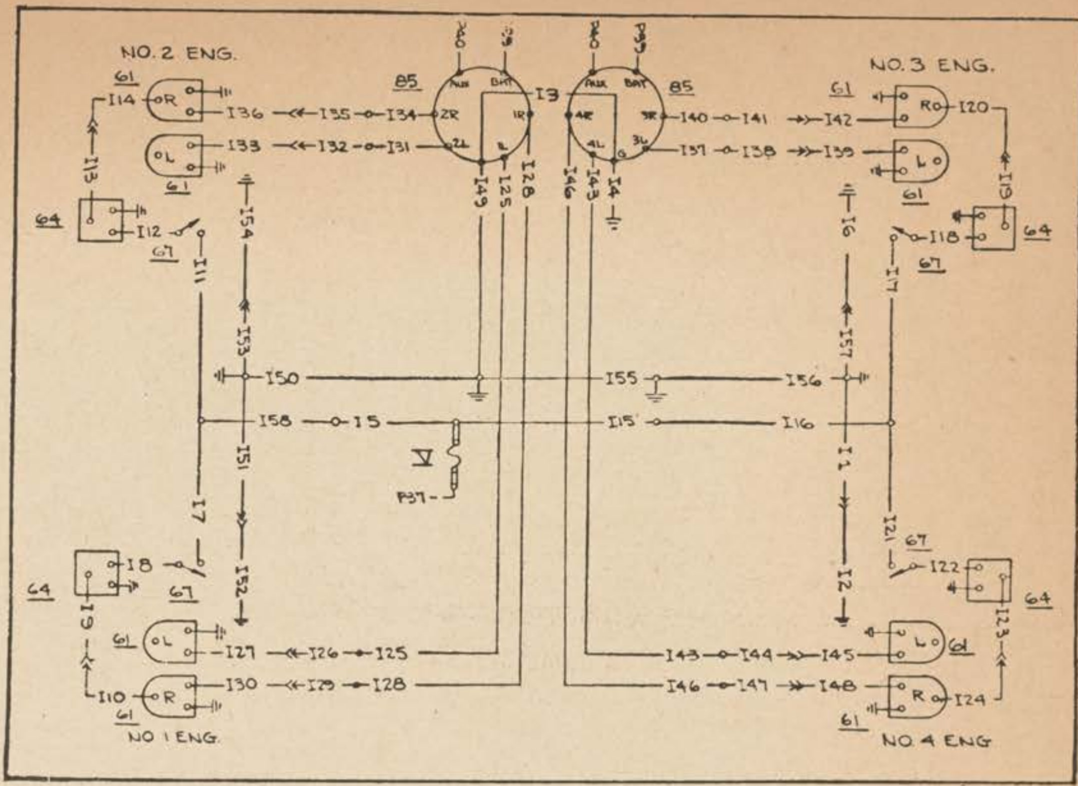


Figure 274. Ignition circuits assembled from complete wiring diagram.

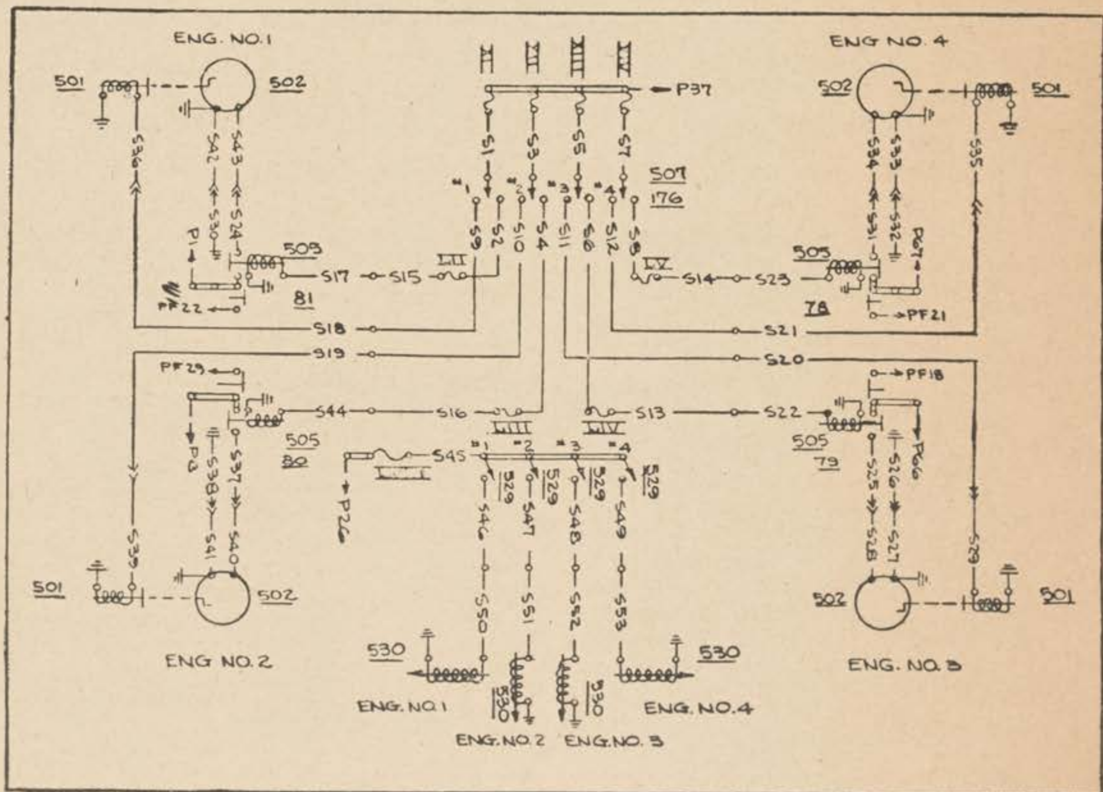


Figure 275. Starting circuits assembled from complete wiring diagram.

(2) An approximate lay-out of the basic items of a single-engine aircraft electrical system is shown in figure 278. A diagram of this direct-line type is particularly helpful when a comparative study is to be made of the electrical features of new models of aircraft. The simplified diagram may be drawn from the wiring blueprint or the diagrams in the service instructions.

122. CIRCUIT TESTING. If trouble develops in an electrical device, there are two general causes—the device itself may be at fault (burned out, damaged mechanically, etc.) or that part of the circuit leading to or from the device may be at fault. Continuity testing refers to the checking process used to determine whether or not there is a complete electrical circuit.

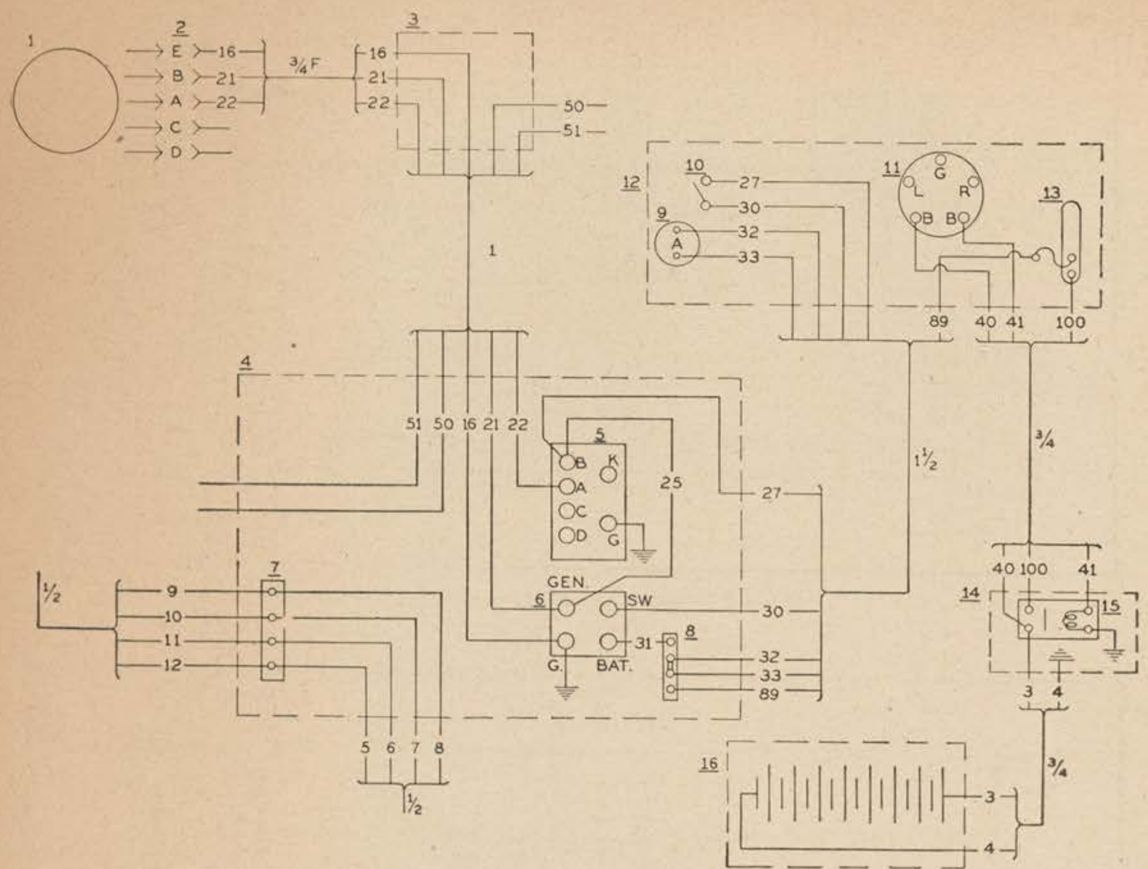


Figure 276. Detailed wiring diagram of generator system.

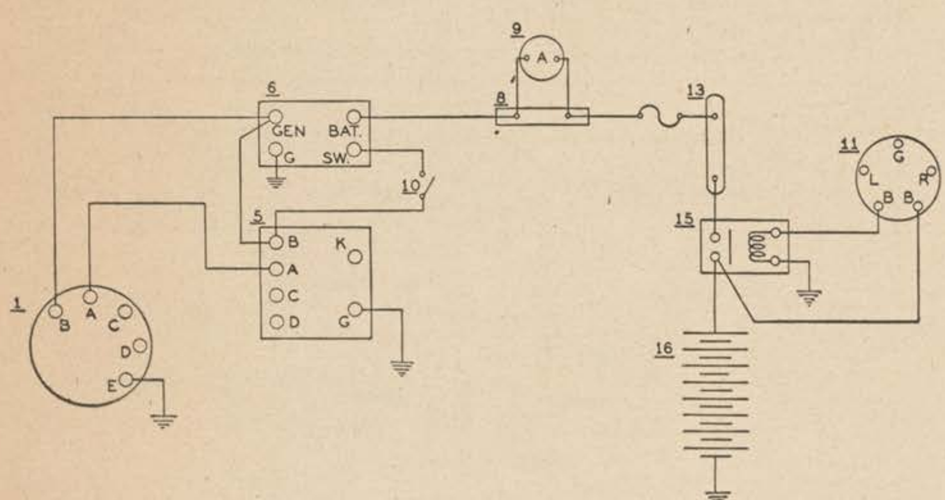
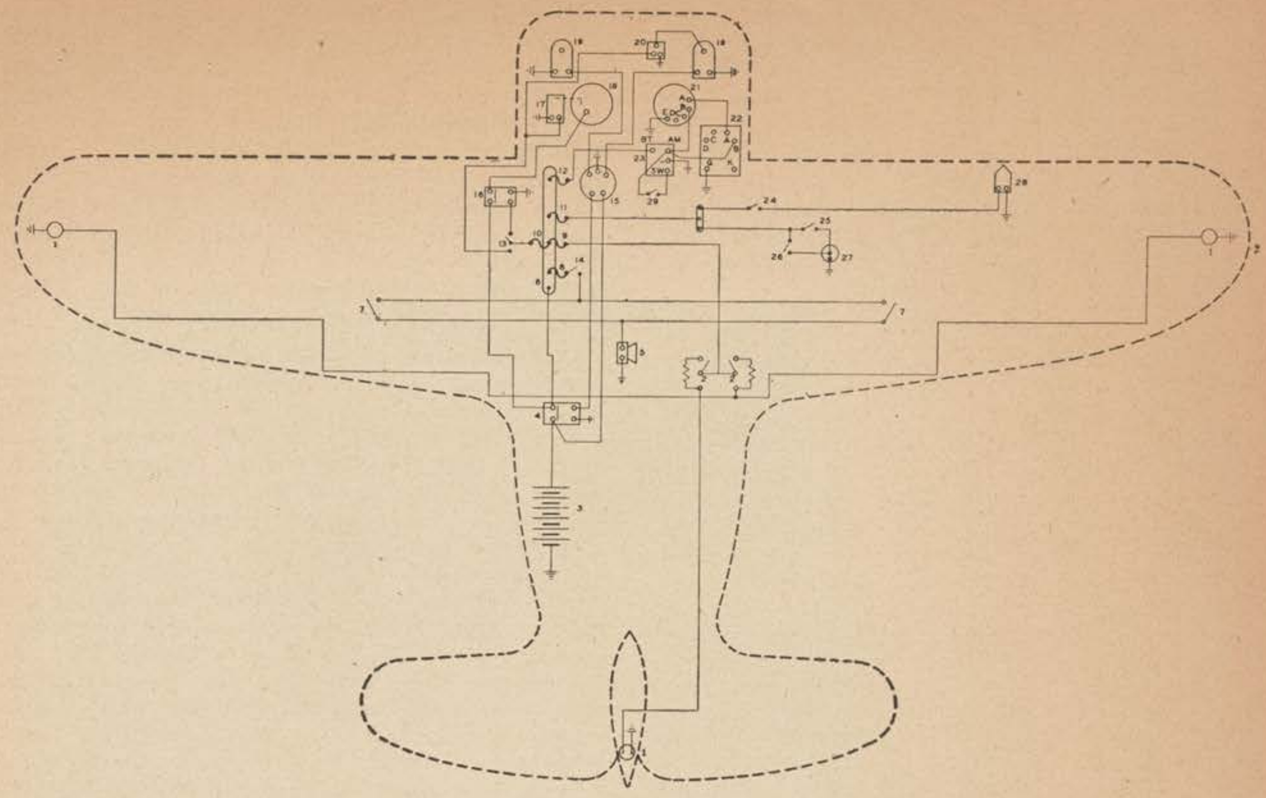


Figure 277. Simplified wiring diagram of generator system.



1. Position light.
2. Switch, position light.
3. Battery.
4. Relay battery.
5. Warning horn.
6. Horn.
7. Switch, landing-gear warning.
8. Fuse, landing-gear warning.
9. Fuse, position light.
10. Fuse, starter.
11. Fuse, fuel-pressure warning and pitot heater.
12. Fuse, generator.
13. Switch, starter.
14. Switch, throttle.
15. Switch, ignition.
16. Relay, starter.
17. Solenoid, starter meshing.
18. Starter.
19. Magneto.
20. Booster coil.
21. Generator.
22. Voltage regulator.
23. Relay switch.
24. Switch, pitot heater.
25. Switch, fuel-pressure warning.
26. Switch, fuel-pressure test.
27. Fuel-pressure warning light.
28. Pitot heater.
29. Switch, generator.

Figure 278. Wiring diagram and approximate layout of basic electrical items.

a. The circuits illustrated in ①, ②, and ③ of figure 279 include a portable type of continuity tester wherein dry cells are used as a source of voltage. A lamp within the portable tester serves as the indicator.

(1) If the alligator clips of the tester unit were touched together, a complete circuit would be established and the lamp would be lighted. If, as shown in figure 279①, the clips are brought into contact with the terminals of the resistor (or coils, etc.) under test and the lamp does not light, an open circuit in the resistor is indicated. This test is conclusive only if the resistance of the unit under test is sufficiently low to permit the lamp to light. If the resistance is too high (more than approximately 10 ohms) a voltmeter (mounted on the panel of the tester) can be connected in the circuit in place of the lamp. If no deflection of the voltmeter pointer occurs, an open circuit is indicated.

(2) In figure 279② the tester indicates the presence of a short circuit across the terminals of a switch which is the "open" position.

(3) To determine whether a length of wire is grounded at some point between its terminals, the wire is disconnected at each end; one test clip is hooked to the wire and the other clip is grounded as shown in figure 279③. If the wire is grounded, the lamp will light.

(4) When the methods of continuity testing outlined are applied to installations on the aircraft, the disconnection of a number of wires may be necessary.

b. To test for open circuits in wiring and equipment installed in aircraft, the aircraft storage battery may be used as a source of voltage and a voltmeter with long flexible leads used to test the circuit. This method of circuit testing may be illustrated by reference to a simple aircraft circuit containing a 12-volt battery, fuse, switch, and landing map. The following procedure may be applied to any branch circuit which is fed by the battery.

(1) First, draw a simple wiring diagram of the circuit involved, as shown in ④ of figure 279. For this purpose, the wiring blueprint or the service instruction diagrams should be consulted.

(2) If the lamp lights when the switch is closed, the indication to be expected in each position of the volt-

meter is shown by the voltmeter symbols in figure 279(4). If the lamp does not light, check the battery for normal voltage. The negative test clip of the voltmeter is attached to any convenient ground connection; the positive test clip is connected to the battery end of the fuse. If the voltmeter reads zero, it must then be determined whether the battery is at fault or whether the battery leads to ground or fuse are at fault. If the reading of the voltmeter is approximately 12 volts, no defect is indicated up to this point and the test may be continued along the circuit.

(3) The negative clip is kept connected to ground. The positive clip is moved from point to point along the circuit with the diagram for a guide; test each unit and length of wire (by attachment of positive clip to its terminal) until the first zero reading is obtained. An open circuit is indicated between the last point at which voltage was indicated and the point of first zero reading. This is illustrated in figure 279(5) by an open fuse, in figure 279(6) by an open lamp filament, and in figure 279(7) by an open lamp-to-ground connection.

(4) When testing a lamp, it is to be noted that in figure 279(7) the voltmeter reads 12 volts when the positive clip is connected to either terminal of the lamp. This means that there is no potential difference across the lamp. This is reasonable, because no current is flowing through the lamp. (Actually, the voltmeter does allow some current to flow through it but this is not enough to light the lamp.)

c. An ammeter should not be used in the methods of continuity testing described in this section because the ammeter has a very low resistance which would short-circuit the battery and damage the meter.

123. SOLDERING. a. General. Soldering is joining of two metals by the use of a third metal which has a lower melting point. The third metal is commonly called solder. For aircraft electrical use, solder is usually composed of 50 percent tin and 50 percent lead. The solder may be melted by an electric soldering copper or a soldering copper heated by a blow torch.

b. Preparation. To make a good soldering job on aircraft wiring, proper equipment, proper heating temperature, and cleanliness are of primary importance. The soldering copper should be in good condition. If the soldering copper has been heated excessively and is slightly pitted, it should be filed. Do not attempt to use a deeply pitted copper. It should go through a reconditioning process before using. If a soldering copper appears to be in good condition, it should next be tinned. Tinning may be accomplished by heating the soldering copper so that heat can be noticed when bringing the copper within 6 inches of the cheek. Then dip the soldering copper point in a paste flux or rub the point on a block of pine wood containing resin. Apply enough solder to cover the surface of the point. After the soldering copper is properly tinned, the two units to be soldered should be prepared (cleanliness cannot be overstressed). If a conductor is to be soldered to a

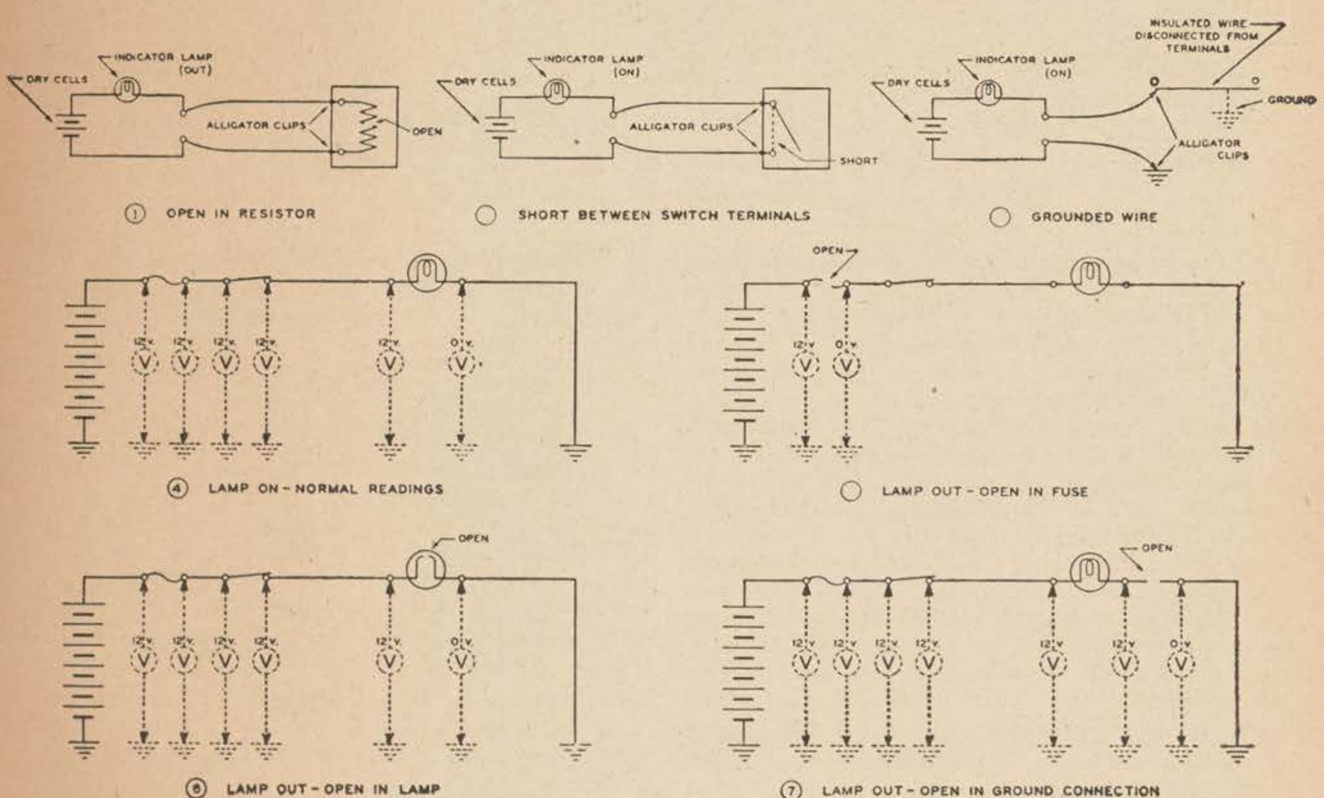


Figure 279. Continuity testing.

terminal lug, remove the insulation and scrape all foreign matter from the wire, and apply a little soldering paste. Attach the conductor and terminal lug together and heat them with the soldering copper. CAUTION IN HEATING COPPER: If color is noticed on the terminal or wire, the solder will not stick properly. Heat the units as shown in figure 280. After the soldering job is complete, the soldered units should be insulated. Soldering of plug and receptacle connector is explained in paragraph 119.

Figure 280. Soldering a lug on a cable.

AUXILIARY SYSTEMS

124. WARNING SIGNAL SYSTEM. Landing-gear warning signals warn the pilot to lower the landing gear when preparing to land and notify him whether or not the landing gear is down and locked.

a. A diagram of a warning signal system is shown in figure 281. A switch is linked with each landing wheel so that when the wheel is not down and locked, the switch is closed. The spring *S* in the relay normally holds contact points C_1 closed. When the throttle is closed beyond a set point, the throttle lever closes a switch which is mounted on the throttle control. If either wheel is not down and locked, the circuit to the horn is completed and the horn will sound. In the event that the pilot has no intention of landing, he momentarily closes the horn-release relay switch, which energizes the relay, opening contacts C_1, silences the horn, and closes contacts C_2. The horn-release relay switch is thus shunted, the relay remains energized, and the horn is inoperative when the momentary-contact switch is released. When the pilot reopens the throttle, the throttle switch is opened, and the relay is de-energized, permitting contacts C_1 to reclose. When he again closes the throttle, the horn will sound.

b. The signal system shown in figure 282 illustrates a combination horn and signal-light landing-gear warning system. The wheel switches are double-throw type and have no neutral position, consequently one circuit or the other is always completed. If either wheel is not down and locked, the red lamps are lighted; in addition, the warning horn will operate when the throttle is closed beyond a set point. (A horn release relay may be added to the system.) The green signal lamps are lighted only when both wheels are down and locked. The signal lamps may be dimmed, for night flying, by means of dimmer resistors. A test switch is incorporated to determine if the horn is operative.

125. INVERTERS. The function of the inverter is to change the d-c power, provided by the airplane, to a-c power for equipment which will function only on a-c current. Alternating current is used for the operation of fluorescent lights, autosyn instruments, turbo-supercharger control, and other special equipment.

a. Principles. (1) The vibrator type inverter switches a direct current intermittently through the primary coil of a transformer. This action creates an a-c voltage in the secondary coil. The switching arrangement is usually called a vibrator.

(2) The rotary inverter consists of a d-c motor which drives an alternator (a-c generator). The frequency is governed by the speed of the motor and the voltage output is governed by the strength of the alternator's field. See figure 283. However, in some inverters, complicated winding arrangements have been used in order to gain the desired frequency and voltage control, where the motor and alternator are interconnected. Only the rotary inverters of a simple design will be treated in this section.

b. Construction. One type of rotary inverter is constructed with a motor armature at one end of the shaft and the rotating part of the alternator at the other end of the same shaft. The field frame contains the field coils of the motor and the starter coils of the alternator. The motor brushes are located at the motor end of the frame. The rotary inverter is built in a number of different sizes. The size is always determined by the power output of the unit. The v.a. (volt-ampere) is the unit used to rate the alternator at a certain power factor; an example of this is the 400-cycle, 750-v.a. inverter. This output is delivered at two voltages; 26 and 115 volts; the 26-volt output being 250-v.a. at 40-percent power factor and the 115-volt output, 500-v.a. at 90-percent power factor. The circuit of the inverter is shown in figure 284. The circuit shows a set of points shunted by a resistor and controlled by a centrifugal governor which regulates the frequency of the alternator.

c. Trouble shooting. In trouble shooting the individual inverter, refer to the Technical Order covering inverters.

d. Maintenance. The maintenance of inverters will be limited to brush replacement and general care. The bearings are sealed at assembly and will never require lubrication. Other services on the inverter require special tools and should be done by qualified mechanics only.

126. ELECTRONIC TURBO-SUPERCHARGER CONTROL. a. General. This control system is a device which permits the manual selection of a desired manifold pressure and which automatically maintains the desired manifold pressure within the limits of the turbo-supercharger by regulating the position of the turbo waste gate. The complete system consists of a bridge circuit, amplifier, and a waste-gate motor. The power to operate the system is furnished by a 115-volt, 400-cycle alternator or inverter.

b. Bridge circuit. The bridge circuit is a system of potentiometers connected across transformer secondaries. These potentiometers are controlled by a manual pressure selector, the carburetor inlet pressure, a governor, and

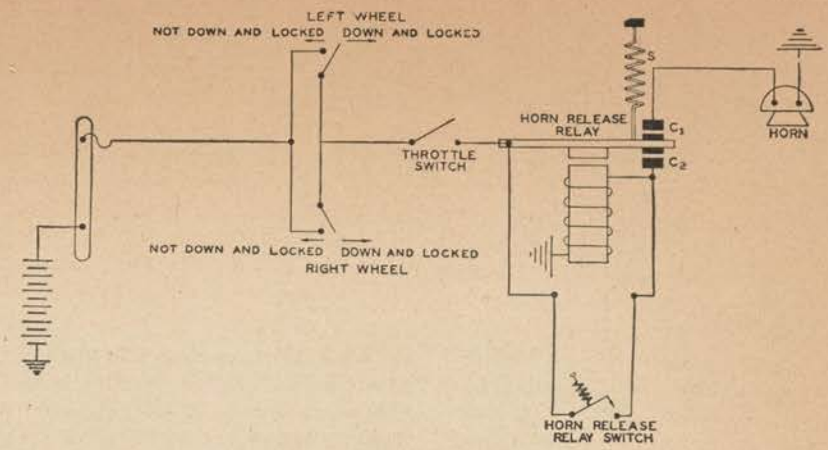


Figure 281. Landing-gear warning-horn system.

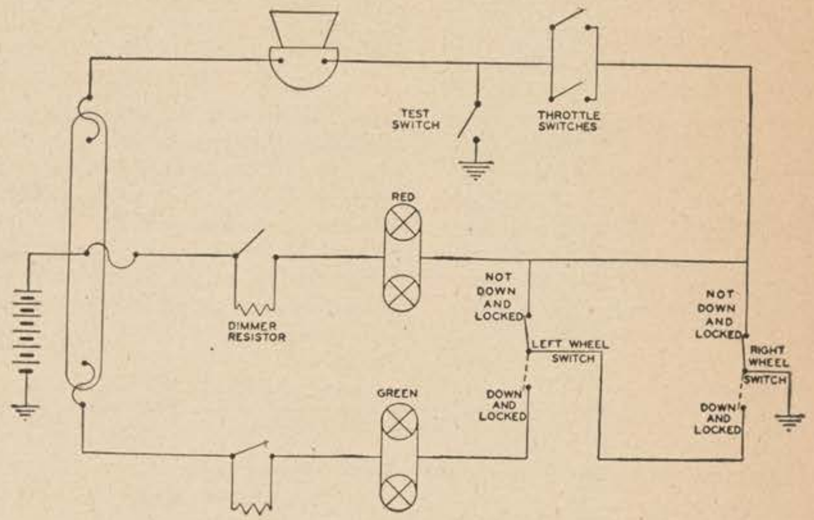


Figure 282. Horn and signal-light landing-gear warning system.

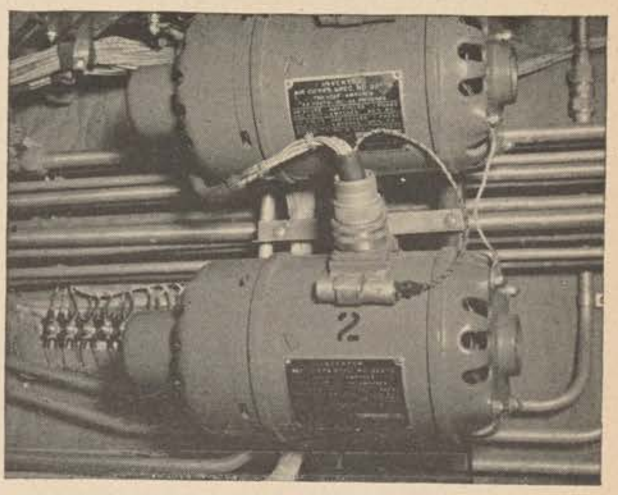


Figure 283. Inverters installed in an airplane.

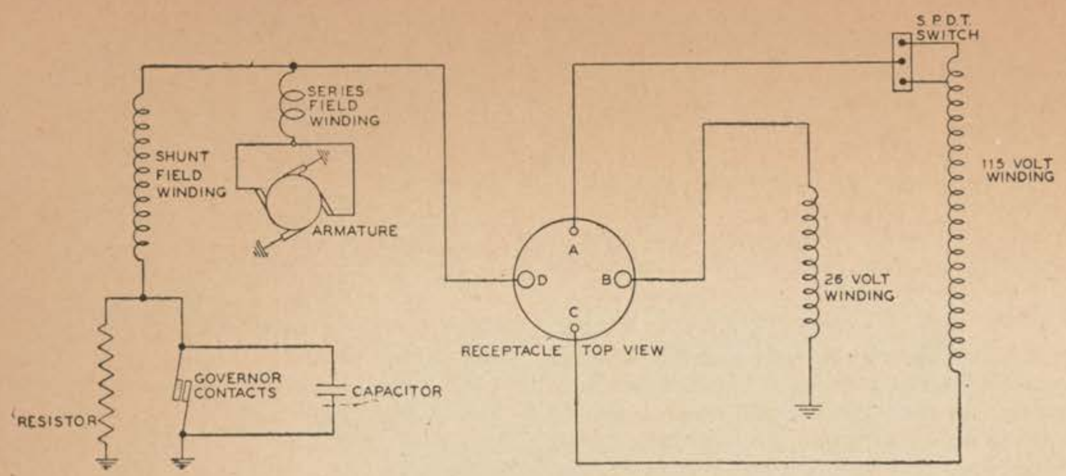


Figure 284. Circuit diagram of rotary inverter.

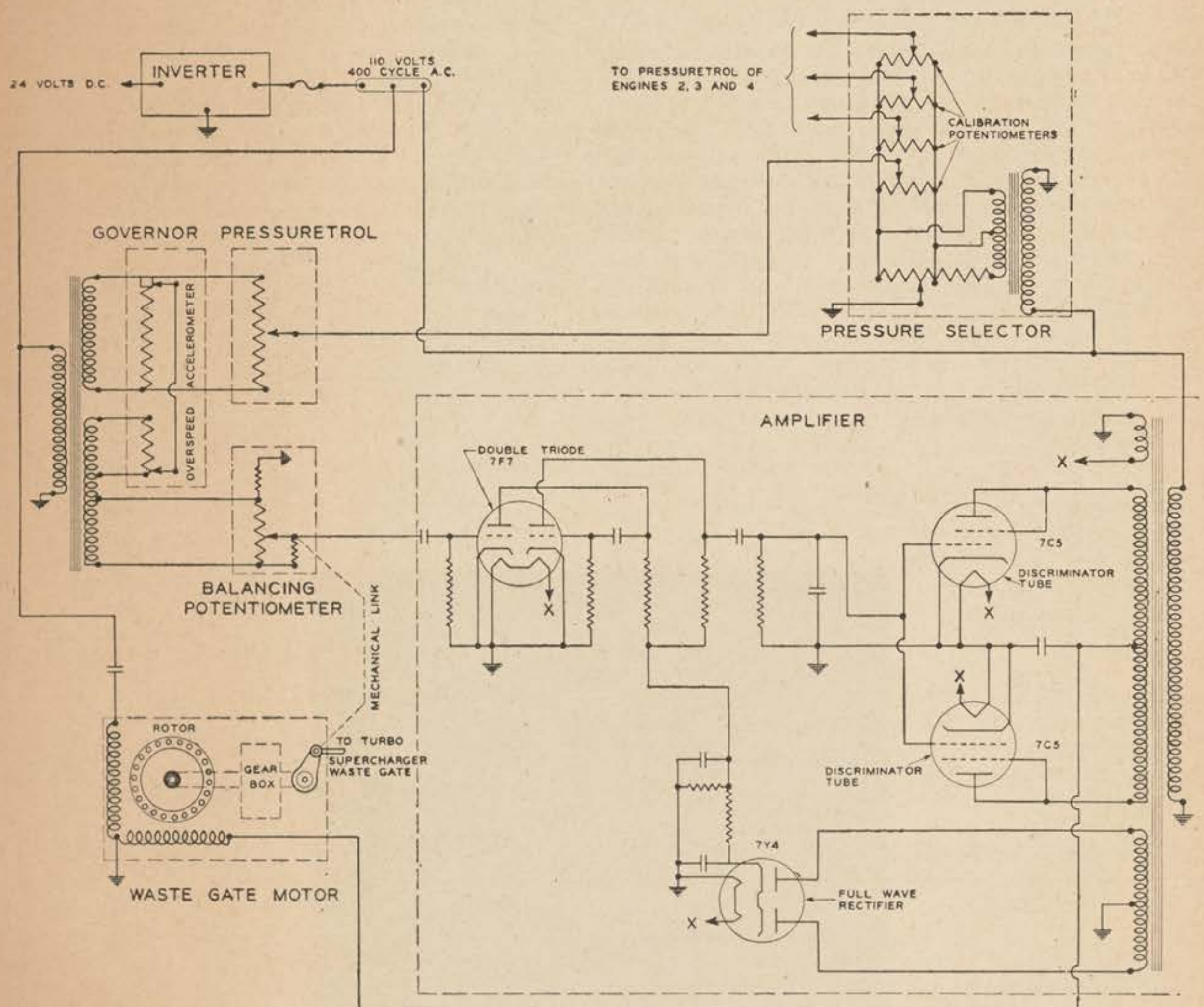


Figure 285. Turbo-supercharger regulator circuit.

the movement of the waste-gate motor. The manifold pressure selector is a potentiometer manually controlled to select the desired manifold pressure. In this unit are mounted the calibrating potentiometers used to equalize the manifold pressure on all engines. The pressuretrol potentiometer is operated by a bellows controlled by the carburetor inlet pressure. The accelerometer and over-speed potentiometers are controlled by a governor driven by the turbo. The balance potentiometer is operated by the waste-gate movement. The function of the bridge circuit is to furnish the amplifier with an a-c potential of varying value.

c. Amplifier. The amplifier builds up the incoming signal from the bridge through a double triode tube (7F7) and delivers this amplified signal to the paralleled grids of the two 7C5 discriminator tubes (fig. 285). The 7C5 tube which has a positive plate when the grids are positive will pass a current to one winding of the waste-gate motor. The two tubes pass current 180° out of phase with each other or of opposite instantaneous polarity which depends on the input signal. The 7Y4 tube is a full-wave rectifier which furnishes d-c voltage to the plates of the 7F7 amplifier tube.

d. Turbo waste-gate motor. The waste-gate motor is a small two-phase motor. One phase (line-excited field winding) is supplied by the inverter through a series condenser and the other phase (amplifier-excited field winding) by the amplifier. The phasing of current supplied by the amplifier with the other phase supplied by the transformer is determined by the two discriminator tubes, resulting in motor rotation in one direction or the other. The synchronous speed of the motor is 12,000 r.p.m., but due to slippage inherent in a squirrel-cage motor, its actual r.p.m. is much lower. The torque of the motor is increased through a system of gearing to approximately 50 inch-pounds at the crank arm. The crank arm is connected to the waste gate through suitable rods and levers.

e. Maintenance. In servicing the electronic turbo-supercharger control system, particular care must be taken to keep all leads in their proper order. All potentiometers *must* be kept free of dust, dirt, finger marks, and other foreign materials. Lubrication for the potentiometers must be strictly in accord with Technical Orders. Crossing of leads or poor connections between potentiometers and wipers will cause the entire system to malfunction.

127. AMPLIDYNE. a. Amplidyne is the name given to a special control system of an electric motor through a motor generator set.

b. The principle of the amplidyne circuit is to control the field current in a generator driven by a constant-speed motor from the battery supply; the generator drives a shunt motor which is used to operate auxiliary equipment (fig. 286). The advantage of controlling the field of the generator which drives the motor is that a very small controlling device can be used since only a very low current is required to excite the generator field. If the controlling device were placed in line controlling the motor, considerable current would have to be handled. The amplidyne principle is used to operate gun turrets.

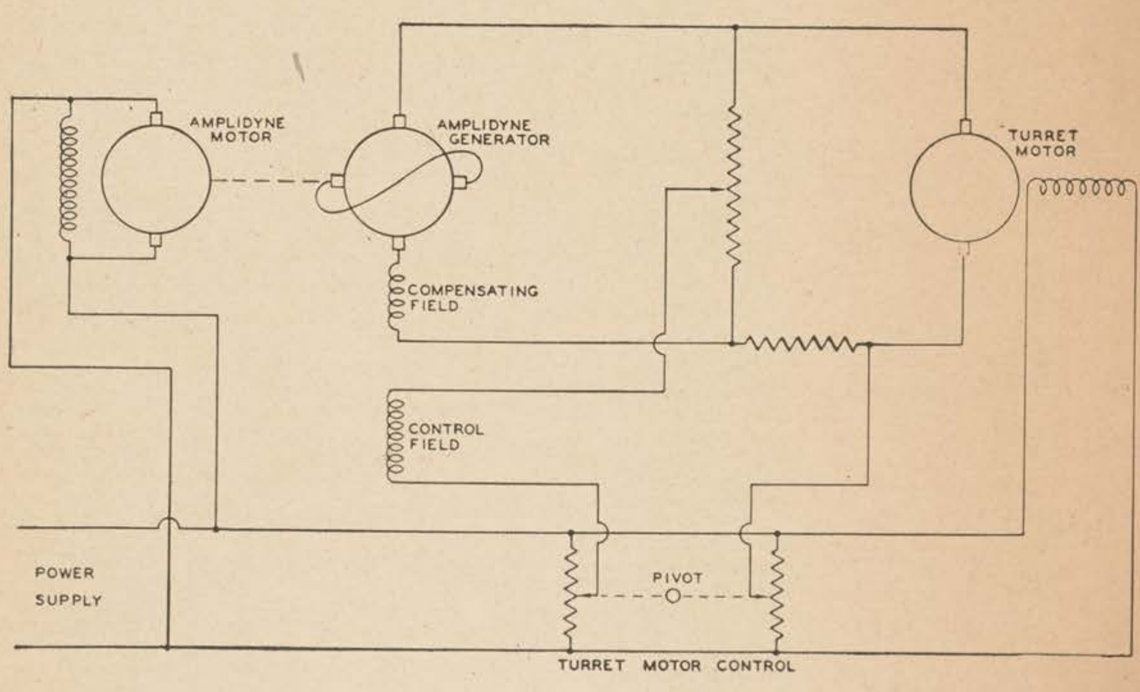


Figure 286. Amplidyne circuit for a turret.

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