Chapter 4

Engine Ignition & Electrical Systems

Reciprocating Engine Ignition Systems

The basic requirements for reciprocating engine ignition systems are similar, regardless of the type of engine. All ignition systems must deliver a high-tension spark across the electrodes of each spark plug in each cylinder of the engine in the correct firing order. At a predetermined number of degrees ahead of the top dead center position of the piston, as measured by crankshaft travel in degrees of rotation, the spark occurs in the cylinder. The potential output voltage of the system must be adequate to arc the gap in the spark plug electrodes under all operating conditions. The spark plug is threaded into the cylinder head with the electrodes exposed to the combustion area of the engine's cylinder.

Ignition systems can be divided into two classifications: magneto-ignition systems or electronic Full Authority Digital Engine Control (FADEC) systems for reciprocating engines. Ignition systems can also be subclassified as either single or dual magneto-ignition systems. The single magneto-ignition system, usually consisting of one magneto and the necessary wiring, was used with another single magneto on the same engine. Dual magnetos generally use one rotating magnet that feeds two complete magnetos in one magneto housing. An example of each type is shown in *Figure 4-1*.

Aircraft magneto-ignition systems can be classified as either high-tension or low-tension. The low-tension magneto system, covered in a later section of this chapter, generates a low-voltage that is distributed to a transformer coil near each spark plug. This system eliminates some problems inherent in the high-tension system that was containing the high-voltage until it passed through the spark plug. The materials that were used for ignition leads could not withstand the high-voltage and were prone to leak to ground before the spark would get to the cylinder. As new materials evolved and shielding was developed, the problems with high-tension magnetos were overcome. The high-tension magneto system is still the most widely used aircraft ignition system.

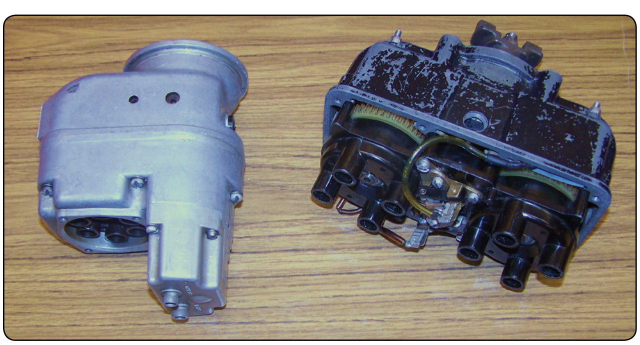


Figure 4-1. *Single and dual magnetos.*

Some very old antique aircraft used a battery-ignition system. In this system, the source of energy is a battery or generator, rather than a magneto. This system was similar to that used in most automobiles at the time. *Figure 4-2* shows a simplified schematic of a battery-ignition system.

Magneto-Ignition System Operating Principles

The magneto, a special type of engine-driven alternating current (AC) generator, uses a permanent magnet as a source of energy. By the use of a permanent magnet (basic magnetic field), coil of wire (concentrated lengths of conductor), and relative movement of the magnetic field, current is generated in the wire. At first, the magneto generates electrical power by the engine rotating the permanent magnet and inducing a current to flow in the coil windings. As current flows through the coil windings, it generates its own magnetic field that surrounds the coil windings. At the correct time, this current flow is stopped and the magnetic field collapses across a second set of windings in the coil and a high-voltage is generated. This is the voltage used to arc across the spark plug gap. In both cases, the three basic things needed to generate electrical power are present to develop the high-voltage that forces a spark to jump across the spark plug gap

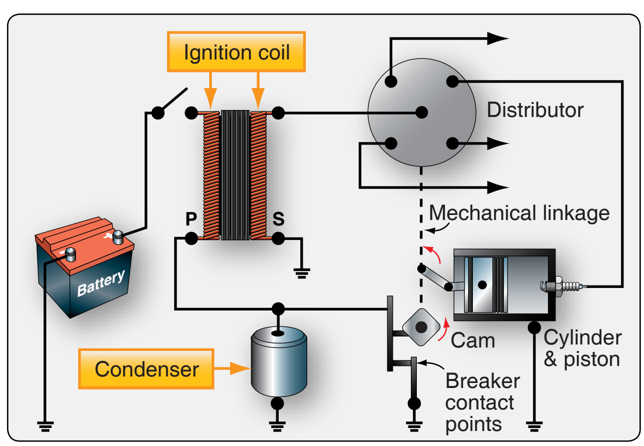


Figure 4-2. *Battery-ignition system.*

in each cylinder. Magneto operation is timed to the engine so that a spark occurs only when the piston is on the proper stroke at a specified number of crankshaft degrees before the top dead center piston position.

High-Tension Magneto System Theory of Operation

The high-tension magneto system can be divided, for purposes of discussion, into three distinct circuits: magnetic, primary electrical, and secondary electrical circuits.

Magnetic Circuit

The magnetic circuit consists of a permanent multi-pole rotating magnet, a soft iron core, and pole shoes. *[Figure 4-3]* The magnet is geared to the aircraft engine and rotates in the gap between two pole shoes to furnish the magnetic lines of force (flux) necessary to produce an electrical voltage. The poles of the magnet are arranged in alternate polarity so that the flux can pass out of the north pole through the coil core and back to the south pole of the magnet. When the magnet is in the position shown in *Figure 4-3A*, the number of magnetic lines of force through the coil core is maximum because two magnetically opposite poles are perfectly aligned with the pole shoes.

This position of the rotating magnet is called the full register position and produces a maximum number of magnetic lines of force, flux flow clockwise through the magnetic circuit and from left to right through the coil core. When the magnet is moved away from the full register position, the amount of flux passing through the coil core begins to decrease. This occurs because the magnet's poles are moving away from the pole shoes, allowing some lines of flux to take a shorter path through the ends of the pole shoes.

As the magnet moves farther from the full register position, more lines of flux are short circuited through the pole shoe ends. Finally, at the neutral position 45° from the full register position, all flux lines are short circuited, and no flux flows through the coil core. *[Figure 4-3B]* As the magnet moves from full register to the neutral position, the number of flux lines through the coil core decreases in the same manner as the gradual collapse of flux in the magnetic field of an ordinary electromagnet.

The neutral position of the magnet is where one of the poles of the magnet is centered between the pole shoes of the magnetic circuit. As the magnet is moved clockwise from this position, the lines of flux that had been short circuited through the pole shoe ends begin to flow through the coil core again. But this time, the flux lines flow through the coil core in the opposite direction. *[Figure 4-3C]* The flux flow reverses as the magnet moves out of the neutral position because the north pole of the rotating permanent magnet is opposite the right pole shoe instead of the left. *[Figure 4-3A]*

When the magnet is again moved a total of 90°, another full register position is reached with a maximum flux flow in the opposite direction. The 90° of magnet travel is shown in *Figure 4-4,* where a curve shows how the flux density in the coil core, without a primary coil around the core, changes as the magnet is rotated.

Figure 4-4 shows that as the magnet moves from the full register position 0°, flux flow decreases and reaches a zero value as it moves into the neutral position 45°. While the magnet moves through the neutral position, flux flow reverses and begins to increase as indicated by the curve below the

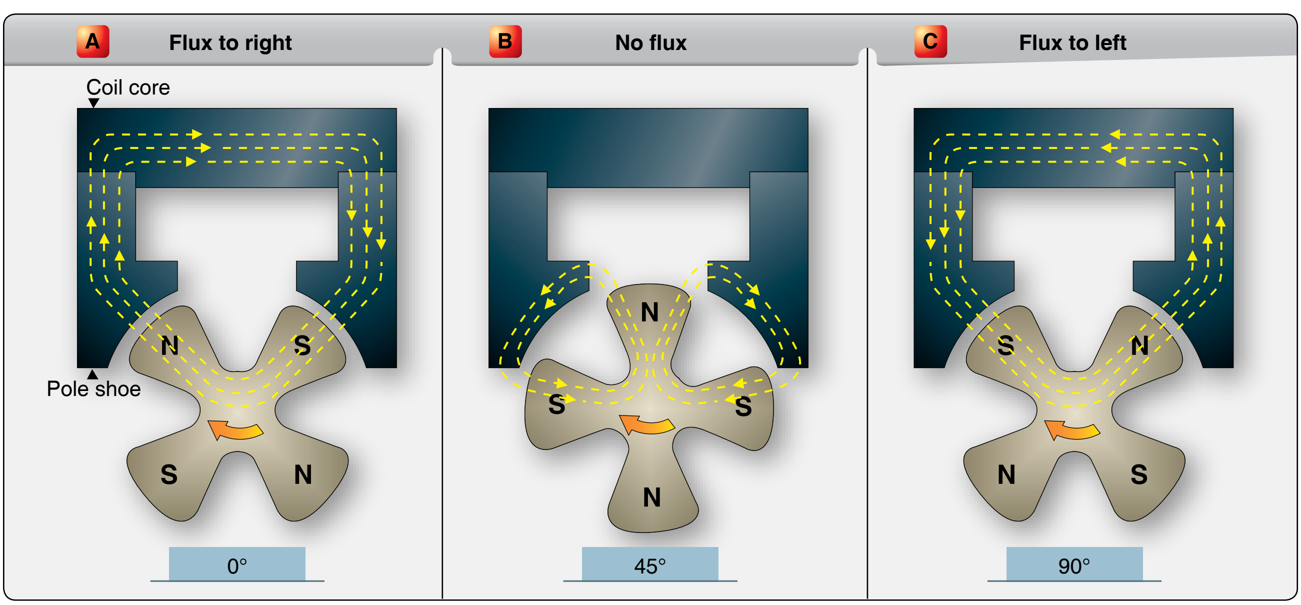


Figure 4-3. *Magnetic flux at three positions of the rotating magnet.*

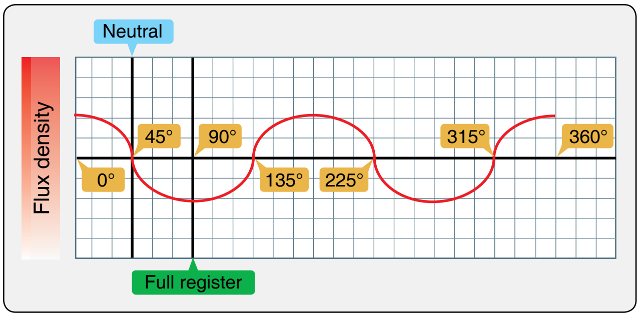


Figure 4-4. *Change in flux density as magnet rotates.*

horizontal line. At the 90° position, another position of maximum flux is reached. Thus, for one revolution 360° of the four pole magnet, there are four positions of maximum flux, four positions of zero flux, and four flux reversals.

This discussion of the magnetic circuit demonstrates how the coil core is affected by the rotating magnet. It is subjected to an increasing and decreasing magnetic field and a change in polarity each 90° of magnet travel.

When a coil of wire as part of the magneto's primary electrical circuit is wound around the coil core, it is also affected by the varying magnetic field.

Primary Electrical Circuit

The primary electrical circuit consists of a set of breaker contact points, a condenser, and an insulated coil. *[Figure 4-5]* The coil is made up of a few turns of heavy copper wire, one end is grounded to the coil core and the other end to the ungrounded side of the breaker points. *[Figure 4-5]* The primary circuit is complete only when the ungrounded breaker point contacts the grounded breaker point. The third unit in the circuit, the condenser (capacitor), is wired in parallel with the breaker points. The condenser prevents arcing at the points when the circuit is opened and hastens the collapse of the magnetic field about the primary coil.

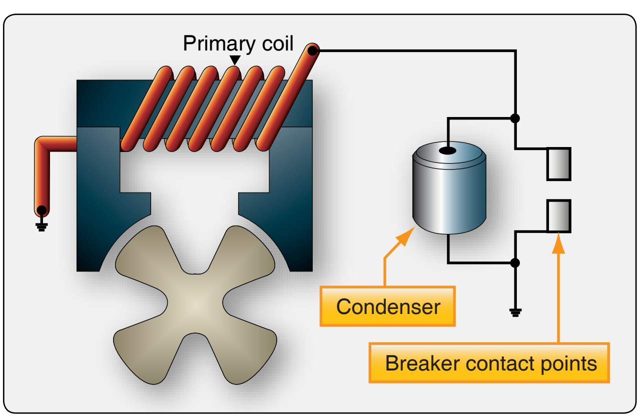


Figure 4-5. *Primary electrical circuit of a high-tension magneto.*

The primary breaker closes at approximately full register position. When the breaker points are closed, the primary electrical circuit is completed and the rotating magnet induces current flow in the primary circuit. This current flow generates its own magnetic field, which is in such a direction that it opposes any change in the magnetic flux of the permanent magnet's circuit.

While the induced current is flowing in the primary circuit, it opposes any decrease in the magnetic flux in the core. This is in accordance with Lenz's Law that states: "An induced current always flows in such a direction that its magnetism opposes the motion or the change that induced it." (For a review of Lenz's Law, refer to the Aviation Maintenance Technician—General Handbook, FAA-H-8083-30). Thus, the current flowing in the primary circuit holds the flux in the core at a high value in one direction until the rotating magnet has time to rotate through the neutral position to a point a few degrees beyond neutral. This position is called the E-gap position (E stands for efficiency).

There are three basic events required to fire a spark plug when its piston is in the prescribed position:

1. the magneto must be in the E-gap position,
2. the breaker contact points must be open, and
3. the distributor must be aligned correctly.

With the magnetic rotor in E-gap position and the primary coil holding the magnetic field of the magnetic circuit in the opposite polarity, a very high rate of flux change can be obtained by opening the primary breaker points. Opening the breaker points stops the flow of current in the primary circuit and allows the magnetic rotor to quickly reverse the field through the coil core. This sudden flux reversal produces a high rate of flux change in the core, that cuts across the secondary coil of the magneto (wound over and insulated from the primary coil), inducing the pulse of high-voltage electricity in the secondary needed to fire a spark plug. As the rotor continues to rotate to approximately full register position, the primary breaker points close again and the cycle is repeated to fire the next spark plug in firing order. The sequence of events can now be reviewed in greater detail to explain how the state of extreme magnetic stress occurs.

With the breaker points, cam, and condenser connected in the circuit as shown in *Figure 4-6*, the action that takes place as the magnetic rotor turns is depicted by the graph curve in *Figure 4-7*. At the top (A) of *Figure 4-7*, the original static flux curve of the magnets is shown. Shown below the static flux curve is the sequence of opening and closing the magneto breaker points. Note that opening and closing the breaker points is timed by the breaker cam. The points close

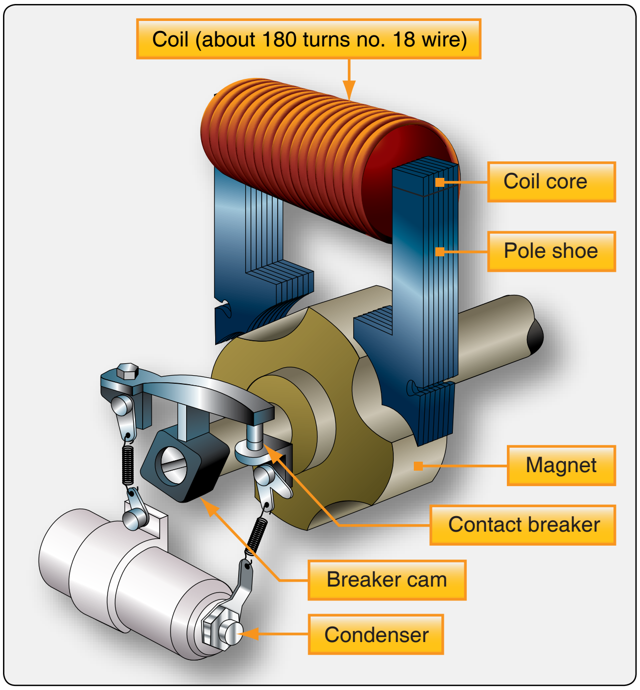


Figure 4-6. *Components of a high-tension magneto circuit.*

when a maximum amount of flux is passing through the coil core and open at a position after neutral. Since there are four lobes on this particular cam (there are some magnetos with cams that have only two lobes), the breaker points close and open in the same relation to each of the four neutral positions of the rotor magnet. Also, the point opening and point closing intervals are approximately equal.

Starting at the maximum flux position marked 0° at the top of *Figure 4-7*, the sequence of events in the following paragraphs occurs.

As the magnet rotor is turned toward the neutral position, the amount of flux through the core starts to decrease. *[Figure 4-7D]* This change in flux linkages induces a current in the primary winding. *[Figure 4-7C]* This induced current creates a magnetic field of its own that opposes the change of flux linkages inducing the current. Without current flowing in the primary coil, the flux in the coil core decreases to zero as the magnet rotor turns to neutral and starts to increase in the opposite direction (dotted static flux curve in *Figure 4-7D*). But, the electromagnetic action of the primary current prevents the flux from changing and temporarily holds the field instead of allowing it to change (resultant flux line in *Figure 4-7D*).

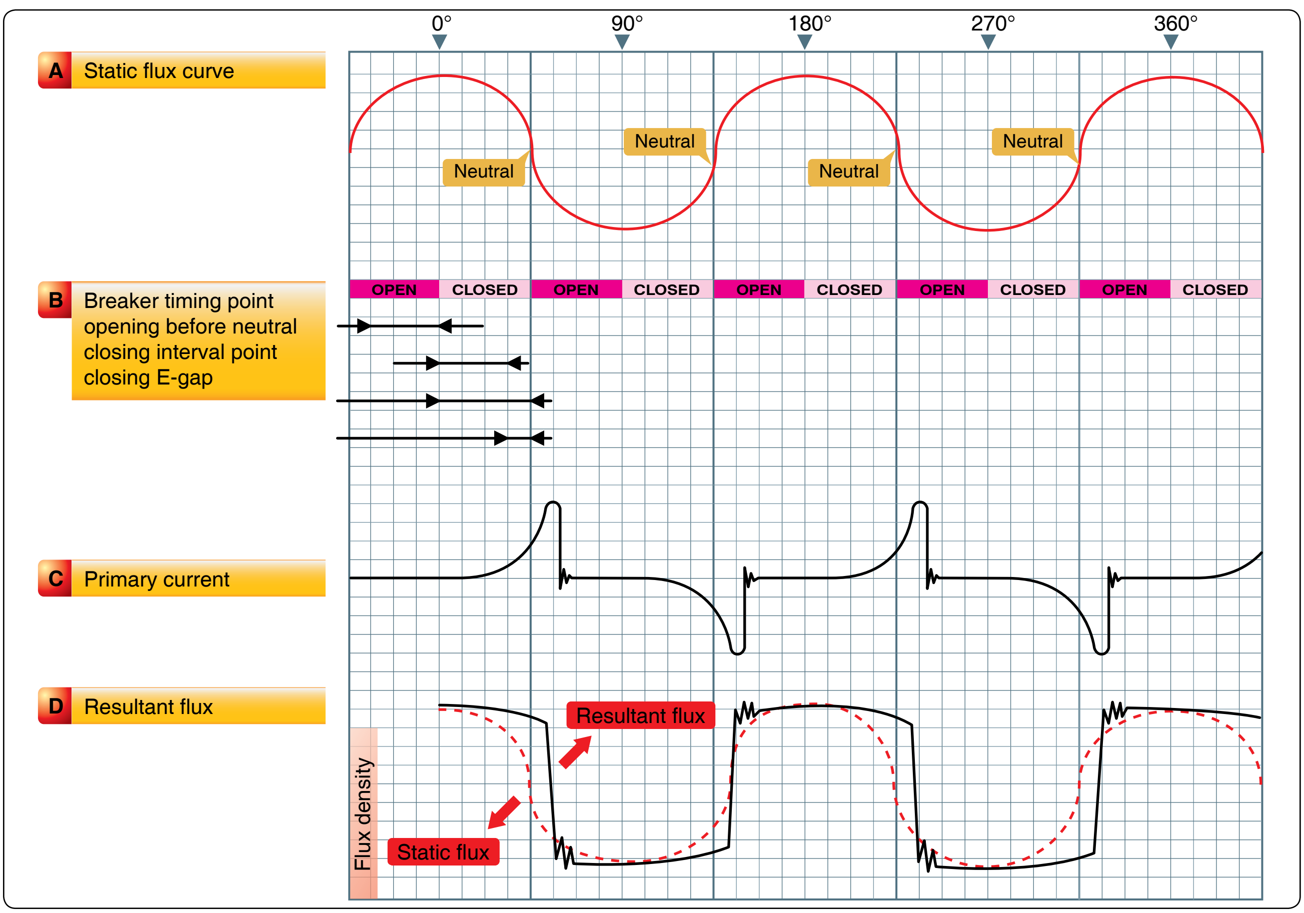


Figure 4-7. *Magneto flux curves.*

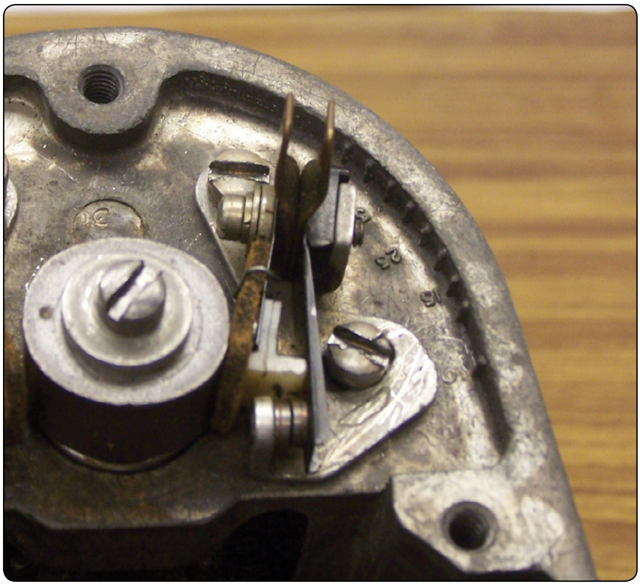


Figure 4-8. *Pivotless type breaker assembly and cam.*

As a result of the holding process, there is a very high stress in the magnetic circuit by the time the magnet rotor has reached the position where the breaker points are about to open. The breaker points, when opened, function with the condenser to interrupt the flow of current in the primary coil, causing an extremely rapid change in flux linkages. The high-voltage in the secondary winding discharges across the gap in the spark plug to ignite the air-fuel mixture in the engine cylinder. Each spark actually consists of one peak discharge, after which a series of small oscillations takes place.

They continue to occur until the voltage becomes too low to maintain the discharge. Current flows in the secondary winding during the time that it takes for the spark to completely discharge. The energy or stress in the magnetic circuit is completely dissipated by the time the contacts close for the production of the next spark. Breaker assemblies, used in high-tension magneto-ignition systems, automatically open and close the primary circuit at the proper time in relation to piston position in the cylinder to which an ignition spark is being furnished. The interruption of the primary current flow is accomplished through a pair of breaker contact points made of an alloy that resists pitting and burning.

Most breaker points used in aircraft ignition systems are of the pivotless type in which one of the breaker points is movable and the other stationary. *[Figure 4-8]* The movable breaker point attached to the leaf spring is insulated from the magneto housing and is connected to the primary coil. *[Figure 4-8]* The stationary breaker point is grounded to the magneto housing to complete the primary circuit when the points are closed and can be adjusted so that the points can open at the proper time.

Another part of the breaker assembly is the cam follower, which is spring-loaded against the cam by the metal leaf spring. The cam follower is a Micarta block or similar material that rides the cam and moves upward to force the movable breaker contact away from the stationary breaker contact each time a lobe of the cam passes beneath the follower. A felt oiler pad is located on the underside of the metal spring leaf to lubricate and prevent corrosion of the cam.

The breaker-actuating cam may be directly driven by the magneto rotor shaft or through a gear train from the rotor shaft. Most large radial engines use a compensated cam that is designed to operate with a specific engine and has one lobe for each cylinder to be fired by the magneto. The cam lobes are machine ground at unequal intervals to compensate for the elliptical path of the articulated connecting rods. This path causes the pistons top dead center position to vary from cylinder to cylinder with regard to crankshaft rotation. A compensated 14-lobe cam, together with a two-, four-, and eight-lobe uncompensated cam, is shown in *Figure 4-9*.

The unequal spacing of the compensated cam lobes, although it provides the same relative piston position for ignition to occur, causes a slight variation of the E-gap position of the rotating magnet and thus a slight variation in the high-voltage impulses generated by the magneto. Since the spacing between each lobe is tailored to a particular cylinder of a particular engine, compensated cams are marked to show

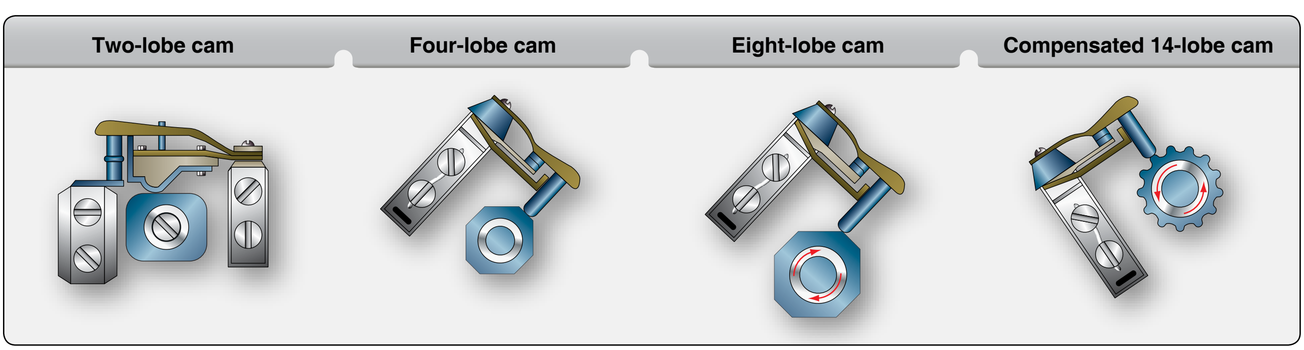


Figure 4-9. *Typical breaker assemblies.*

the series of the engine, the location of the master rods, the lobe used for magneto timing, the direction of cam rotation, and the E-gap specification in degrees past neutral of magnet rotation. In addition to these markings, a step is cut across the face of the cam, that, when aligned with scribed marks on the magneto housing, places the rotating magnet in the E-gap position for the timing cylinder. Since the breaker points should begin to open when the rotating magnet moves into the E-gap position, alignment of the step on the cam with marks in the housing provides a quick and easy method of establishing the exact E-gap position to check and adjust the breaker points.

Secondary Electrical Circuit

The secondary circuit contains the secondary windings of the coil, distributor rotor, distributor cap, ignition lead, and spark plug. The secondary coil is made up of a winding containing approximately 13,000 turns of fine, insulated wire; one end of which is electrically grounded to the primary coil or to the coil core and the other end connected to the distributor rotor. The primary and secondary coils are encased in a non-conducting material. The whole assembly is then fastened to the pole shoes with screws and clamps.

When the primary circuit is closed, the current flow through the primary coil produces magnetic lines of force that cut across the secondary windings, inducing an electromotive force. When the primary circuit current flow is stopped, the magnetic field surrounding the primary windings collapses, causing the secondary windings to be cut by the lines of force. The strength of the voltage induced in the secondary windings, when all other factors are constant, is determined by the number of turns of wire. Since most high-tension magnetos have many thousands of turns of wire in the secondary coil windings, a very high-voltage, often as high as 20,000 volts, is generated in the secondary circuit. The high-voltage induced in the secondary coil is directed to the distributor, which consists of two parts: revolving and stationary. The revolving part is called a distributor rotor and the stationary part is called a distributor block. The rotating part, which may take the shape of a disc, drum, or finger, is made of a non-conducting material with an embedded conductor. The stationary part consists of a block also made of non-conducting material that contains terminals and terminal receptacles into which the ignition lead wiring that connects the distributor to the spark plug is attached. This high-voltage is used to jump the air gap of electrodes of the spark plug in the cylinder to ignite the air-fuel mixture.

As the magnet moves into the E-gap position for the No. 1 cylinder and the breaker points just separate or open, the distributor rotor aligns itself with the No. 1 electrode in the distributor block. The secondary voltage induced as the breaker points open enters the rotor where it arcs a small air gap to the No. 1 electrode in the block.

Since the distributor rotates at one-half crankshaft speed on all four-stroke cycle engines, the distributor block has as many electrodes as there are engine cylinders, or as many electrodes as cylinders served by the magneto. The electrodes are located circumferentially around the distributor block so that, as the rotor turns, a circuit is completed to a different cylinder and spark plug each time there is alignment between the rotor finger and an electrode in the distributor block. The electrodes of the distributor block are numbered consecutively in the direction of distributor rotor travel. *[Figure 4-10]*

The distributor numbers represent the magneto sparking order rather than the engine cylinder numbers. The distributor electrode marked "1" is connected to the spark plug in the No. 1 cylinder; distributor electrode marked "2" to the second

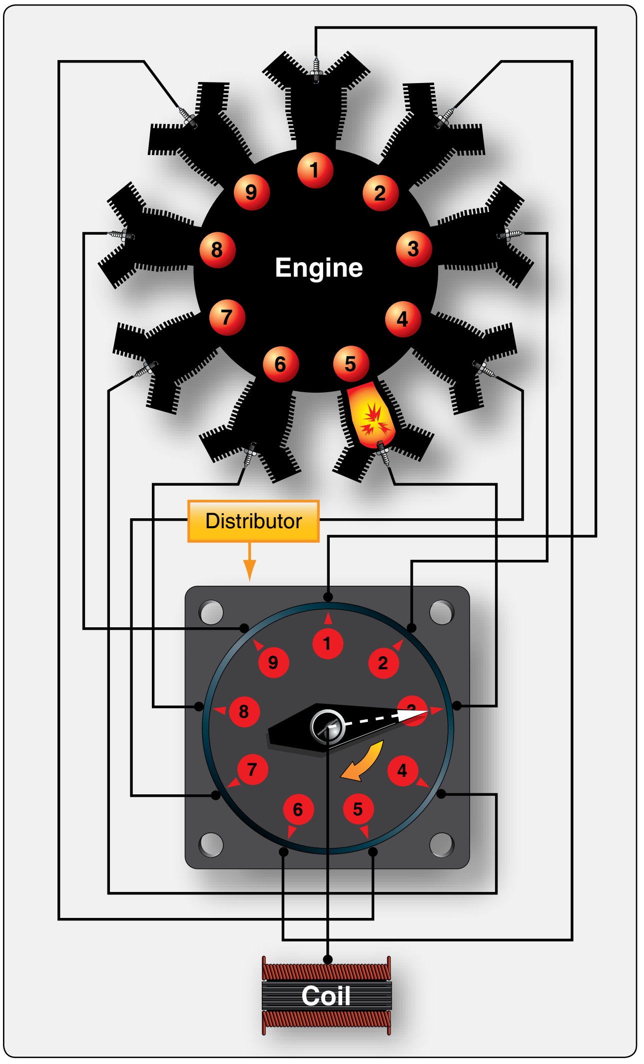


Figure 4-10. *Relation between distributor terminal numbers and cylinder numbers.*

cylinder to be fired; distributor electrode marked “3” to the third cylinder to be fired, and so forth.

In *Figure 4-10*, the distributor rotor finger is aligned with the distributor electrode marked “3,” which fires the No. 5 cylinder of a nine-cylinder radial engine. Since the firing order of a nine-cylinder radial engine is 1-3-5-7-9-2-4-6-8, the third electrode in the magneto sparking order serves the No. 5 cylinder.

Magneto & Distributor Venting

Since magneto and distributor assemblies are subjected to sudden changes in temperature, the problems of condensation and moisture are considered in the design of these units. Moisture in any form is a good conductor of electricity. If absorbed by the nonconducting material in the magneto, such as distributor blocks, distributor fingers, and coil cases, it can create a stray electrical conducting path. The high-voltage current that normally arcs across the air gaps of the distributor can flash across a wet insulating surface to ground, or the high-voltage current can be misdirected to some spark plug other than the one that should be fired. This condition is called flashover and usually results in cylinder misfiring. This can cause a serious engine condition called pre-ignition, which can damage the engine. For this reason, coils, condensers, distributors, and distributor rotors are waxed so that moisture on such units stand in separate beads and do not form a complete circuit for flashover.

Flashover can lead to carbon tracking, which appears as a fine pencil-like line on the unit across which flashover occurs. The carbon trail results from the electric spark burning dirt particles that contain hydrocarbon materials. The water in the hydrocarbon material is evaporated during flashover, leaving carbon to form a conducting path for current. When moisture is no longer present, the spark continues to follow the carbon track to the ground. This prevents the spark from getting to the spark plug, so the cylinder does not fire.

Magnetos cannot be hermetically sealed to prevent moisture from entering a unit, because the magneto is subject to pressure and temperature changes in altitude. Thus, adequate drains and proper ventilation reduce the tendency of flashover and carbon tracking. Good magneto circulation also ensures that corrosive gases produced by normal arcing across the distributor air gap, such as ozone, are carried away. In some installations, pressurization of the internal components of the magnetos and other various parts of the ignition system is essential to maintain a higher absolute pressure inside the magneto and to eliminate flashover due to high altitude flight. This type of magneto is used with turbocharged engines that operate at higher altitudes. Flashover becomes more likely at high altitudes because of the lower air pressure, which makes it easier for the electricity to jump air gaps. By pressurizing the interior of the magneto, the normal air pressure is maintained and the electricity or the spark is held within the proper areas of the magneto even though the ambient pressure is very low.

Even in a pressurized magneto, the air is allowed to flow through and out of the magneto housing. By providing more air and allowing small amounts of air to bleed out for ventilation, the magneto remains pressurized. Regardless of the method of venting employed, the vent bleeds or valves must be kept free of obstructions. Further, the air circulating through the components of the ignition system must be free of oil since even minute amounts of oil on ignition parts result in flashover and carbon tracking.

Ignition Harness

The ignition lead directs the electrical energy from the magneto to the spark plug. The ignition harness contains an insulated wire for each cylinder that the magneto serves in the engine. *[Figure 4-11]* One end of each wire is connected to the magneto distributor block and the other end is connected to the proper spark plug. The ignition harness leads serve a dual purpose. It provides the conductor path for the high-tension voltage to the spark plug. It also serves as a shield for stray magnetic fields that surround the wires as they momentarily carry high-voltage current. By conducting these magnetic lines of force to the ground, the ignition harness cuts down electrical interference with the aircraft radio and other electrically sensitive equipment.

A magneto is a high frequency radiation emanating (radio wave) device during its operation. The wave oscillations produced in the magneto are uncontrolled and cover a wide range of frequencies and must be shielded. If the magneto and ignition leads were not shielded, they would form antennas and pick up the random frequencies from the ignition system.

Figure 4-11. *A high-tension ignition harness.*

The lead shielding is a metal mesh braid that surrounds the entire length of the lead. The lead shielding prevents the radiation of the energy into the surrounding area.

Capacitance is the ability to store an electrostatic charge between two conducting plates separated by a dielectric. Lead insulation is called a dielectric, meaning it can store electrical energy as an electrostatic charge. An example of electrostatic energy storage in a dielectric is the static electricity stored in a plastic hair comb. When shielding is placed around the ignition lead, capacitance increases by bringing the two plates closer together. Electrically, the ignition lead acts as a capacitor and has the ability to absorb and store electrical energy. The magneto must produce enough energy to charge the capacitance caused by the ignition lead and have enough energy left over to fire the plug.

Ignition lead capacitance increases the electrical energy required to provide a spark across the plug gap. More magneto primary current is needed to fire the plug with the shielded lead. This capacitance energy is discharged as fire across the plug gap after each firing of the plug. Reversing the polarity during servicing by rotating the plugs to new locations, the plug wear is equalized across the electrodes. The very center of the ignition lead is the high-voltage carrier surrounded by a silicone insulator material that is surrounded by a metal mesh, or shielding, covered with a thin silicone rubber coating that prevents damage by engine heat, vibration, or weather.

A sectional view of the typical ignition lead is shown in *Figure 4-12*. Ignition leads must be routed and clamped correctly to avoid hot spots on the exhaust and vibration points as the leads are routed from the magneto to the individual cylinders. Ignition leads are normally of the all-weather type and are hard connected at the magneto distributor and affixed to the spark plug by threads. The shielded ignition lead spark plug terminal is available in all-weather ¾ inch diameter and ⅝ inch diameter barrel ignition lead nut. *[Figure 4-13]* The ⅝ – 24 plug takes a ¾ wrench on the lead nut and the ¾ – 20 plug takes a ⅞ wrench on the lead nut. The ¾ inch all-weather design utilizes a terminal seal that results in greater terminal well insulation. This is recommended because the lead end of the spark plug is completely sealed from moisture.

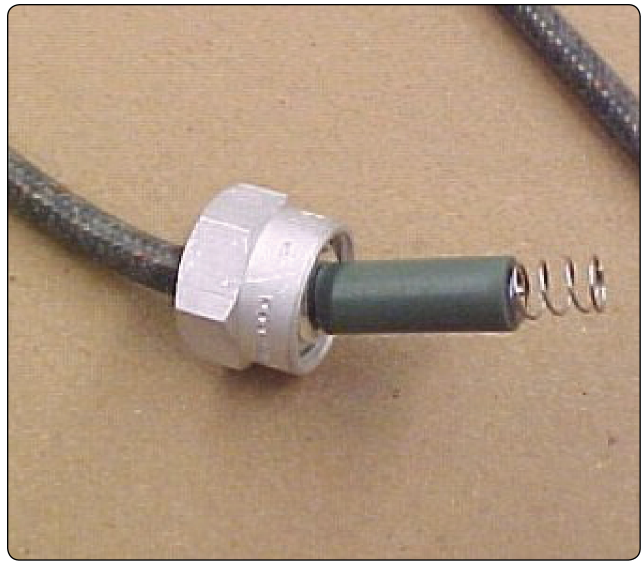


Figure 4-13. *Ignition lead spark plug end.*

An older radial engine type of ignition harness is a manifold formed to fit around the crankcase of the engine with flexible extensions terminating at each spark plug. A typical high-tension ignition harness is shown in *Figure 4-14*. Many older single-row radial engine aircraft ignition systems employ a dual-magneto system, in which the right magneto supplies the electric spark for the front plugs in each cylinder, and the left magneto fires the rear plugs.

Ignition Switches

All units in an aircraft ignition system are controlled by an ignition switch. The type of switch used varies with the number of engines on the aircraft and the type of magnetos used. All switches, however, turn the system off and on in much the same manner. The ignition switch is different in at least one respect from all other types of switches: when the ignition switch is in the off position, a circuit is completed through the switch to ground. In other electrical switches, the off position normally breaks or opens the circuit.

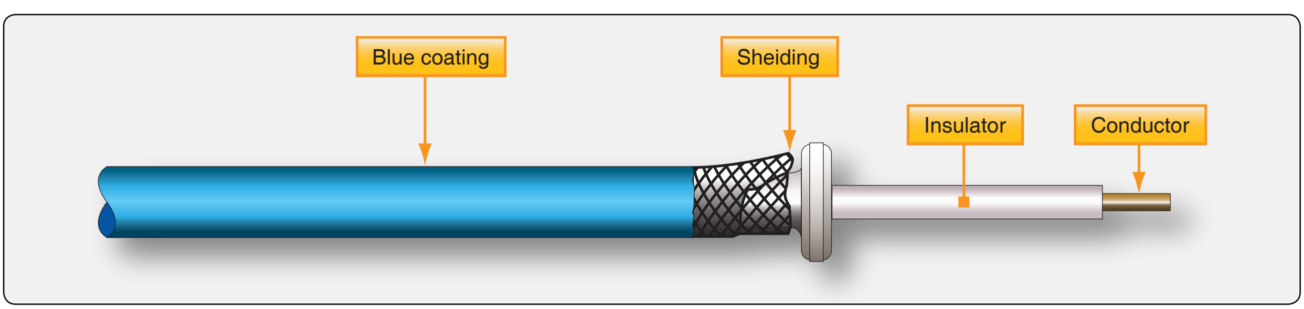


Figure 4-12. *Ignition lead.*

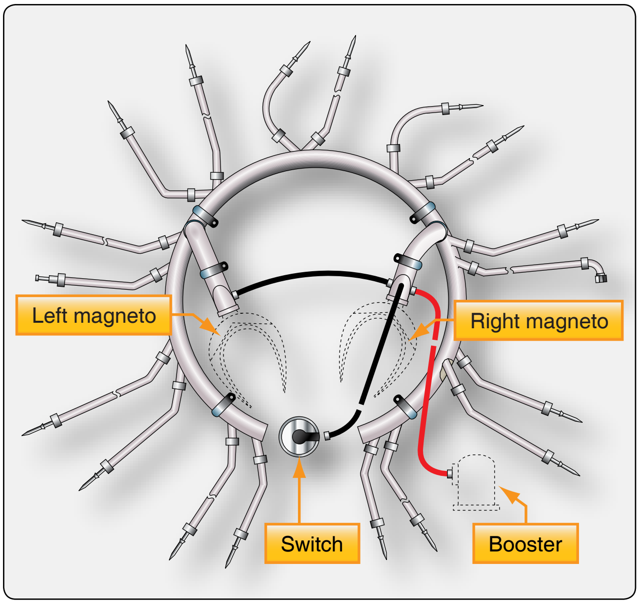


Figure 4-14. *Accessory-mounted nine cylinder engine ignition harness.*

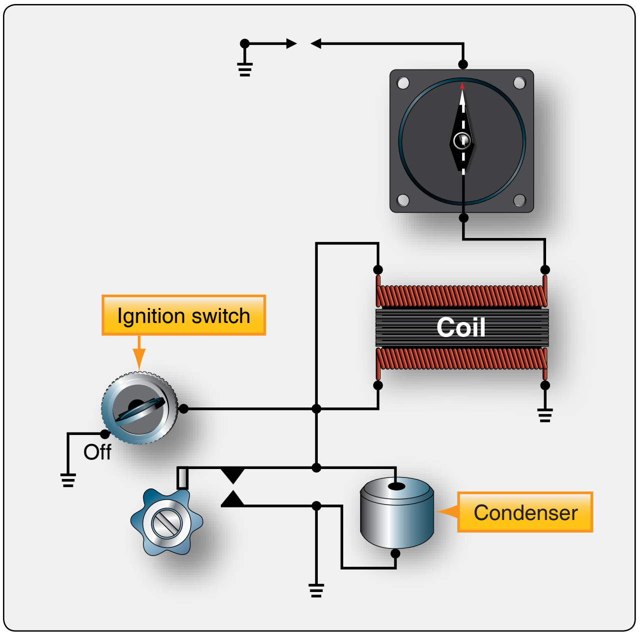


Figure 4-15. *Typical ignition switch in off position.*

The ignition switch has one terminal connected to the primary electrical circuit between the coil and the breaker contact points. The other terminal of the switch is connected to the aircraft ground structure. As shown in *Figure 4-15*, two ways to complete the primary circuit are:

1. Through the closed breaker points to ground and
2. Through the closed ignition switch to ground.

Figure 4-15 shows that the primary current is not interrupted when the breaker contacts open since there is still a path to ground through the closed, or off, ignition switch. Since primary current is not stopped when the contact points open, there can be no sudden collapse of the primary coil flux field and no high-voltage induced in the secondary coil to fire the spark plug.

As the magnet rotates past the electrical gap (E-gap) position, a gradual breakdown of the primary flux field occurs. But that breakdown occurs so slowly that the induced voltage is too low to fire the spark plug. Thus, when the ignition switch is in the off position with the switch closed, the contact points are as completely short-circuited as if they were removed from the circuit, and the magneto is inoperative.

When the ignition switch is placed in the on position, switch open, the interruption of primary current and the rapid collapse of the primary coil flux field is once again controlled or triggered by the opening of the breaker contact points. *[Figure 4-16]* When the ignition switch is in the on position, the switch has absolutely no effect on the primary circuit.

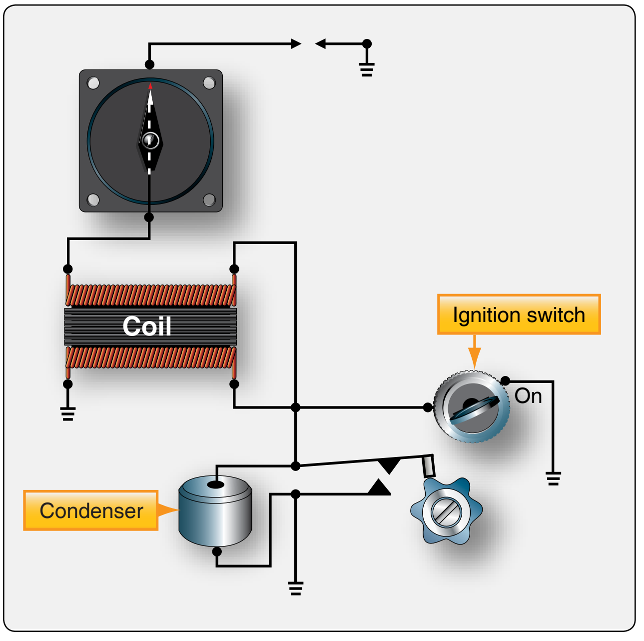


Figure 4-16. *Typical ignition switch in on position.*

The ignition/starter switch, or magneto switch, controls the magnetos on or off and can also connect the starter solenoid for turning the starter. When a starting vibrator, a box that emits pulsating direct current (DC), is used on the engine, the ignition/starter switch is used to control the vibrator and retard points. This system is explained in detail later in this chapter. Some ignition starter switches have a push to prime feature during the starting cycle. This system allows additional fuel to spray into the intake port of the cylinder during the starting cycle.

Single & Dual High-Tension System Magnetos

High-tension system magnetos used on aircraft engines are either single or dual type magnetos. The single magneto design incorporates the distributor in the housing with the magneto breaker assembly, rotating magnet, and coil. *[Figure 4-17]* The dual magneto incorporates two magnetos contained in a single housing. One rotating magnet and a cam are common to two sets of breaker points and coils. Two separate distributor units are mounted in the magneto. *[Figure 4-18]*

Magneto Mounting Systems

Flange-mounted magnetos are attached to the engine by a flange around the driven end of the rotating shaft of the magneto. *[Figure 4-19]* Elongated slots in the mounting flange permit adjustment through a limited range to aid in timing the magneto to the engine. Some magnetos mount by the flange and use clamps on each side to secure the magneto to the engine. This design also allows for timing adjustments. Base mounted magnetos are only used on very old or antique aircraft engines.

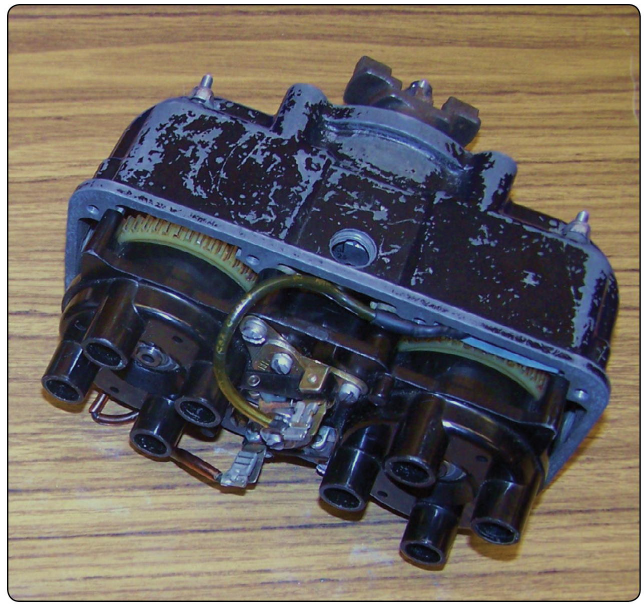


Figure 4-18. *A dual magneto with two distributors.*

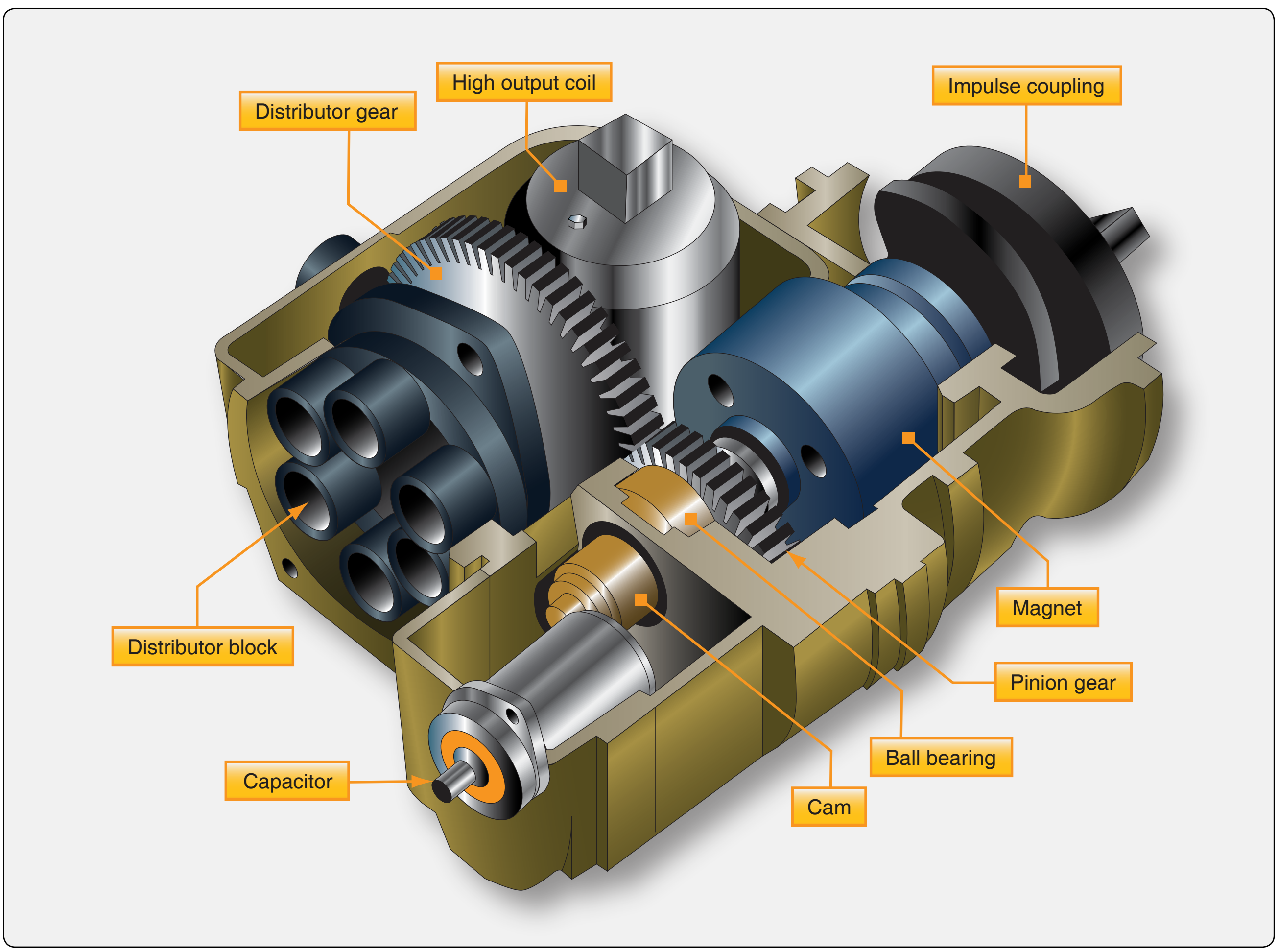


Figure 4-17. *Magneto cutaway.*

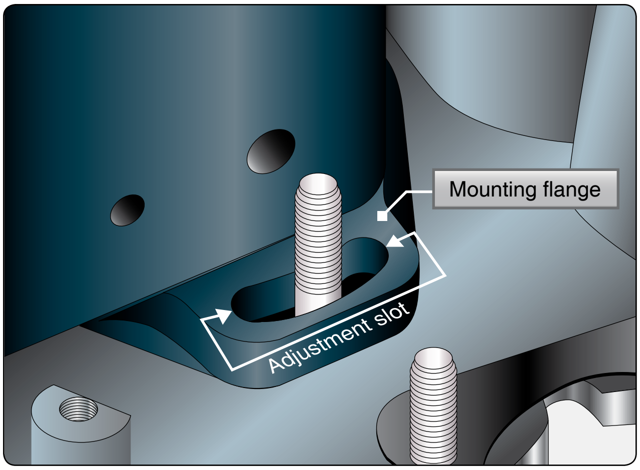


Figure 4-19. *Magneto mounting flange.*

High- & Low-Tension Magneto Systems

High-tension ignition systems have undergone many refinements and improvements in design. This includes new electronic systems that control more than just providing ignition to the cylinders. High-tension voltage presents certain problems with carrying the high-voltage from the magneto internally and externally to the spark plugs. In early years, it was difficult to provide insulators that could contain the high-voltage, especially at high altitudes when the air pressures were reduced. Another requirement of high-tension systems was that all weather and radio-equipped aircraft have ignition wires enclosed in shielding to prevent radio noise due to high-voltages. Many aircraft were turbosupercharged and operated at increased high altitudes. The low pressure at these altitudes would allow the high-voltage to leak out even more. To meet these problems, low-tension ignition systems were developed.

Electronically, the low-tension system is different from the high-tension system. In the low-tension system, low-voltage is generated in the magneto and flows to the primary winding of a transformer coil located near the spark plug. There, the voltage is increased to high by transformer action and conducted to the spark plug by very short high-tension leads. *[Figure 4-20]*

The low-tension system virtually eliminates flashover in both the distributor and the harness because the air gaps within the distributor have been eliminated by the use of a brush-type distributor, and high-voltage is present only in short leads between the transformer and spark plug.

Although a certain amount of electrical leakage is characteristic of all ignition systems, it is more pronounced on radio-shielded installations because the metal conduit is at ground potential and close to the ignition wires throughout their entire length. In low-tension systems, however, this leakage is reduced considerably because the current throughout most of the system is transmitted at a low-voltage potential. Although

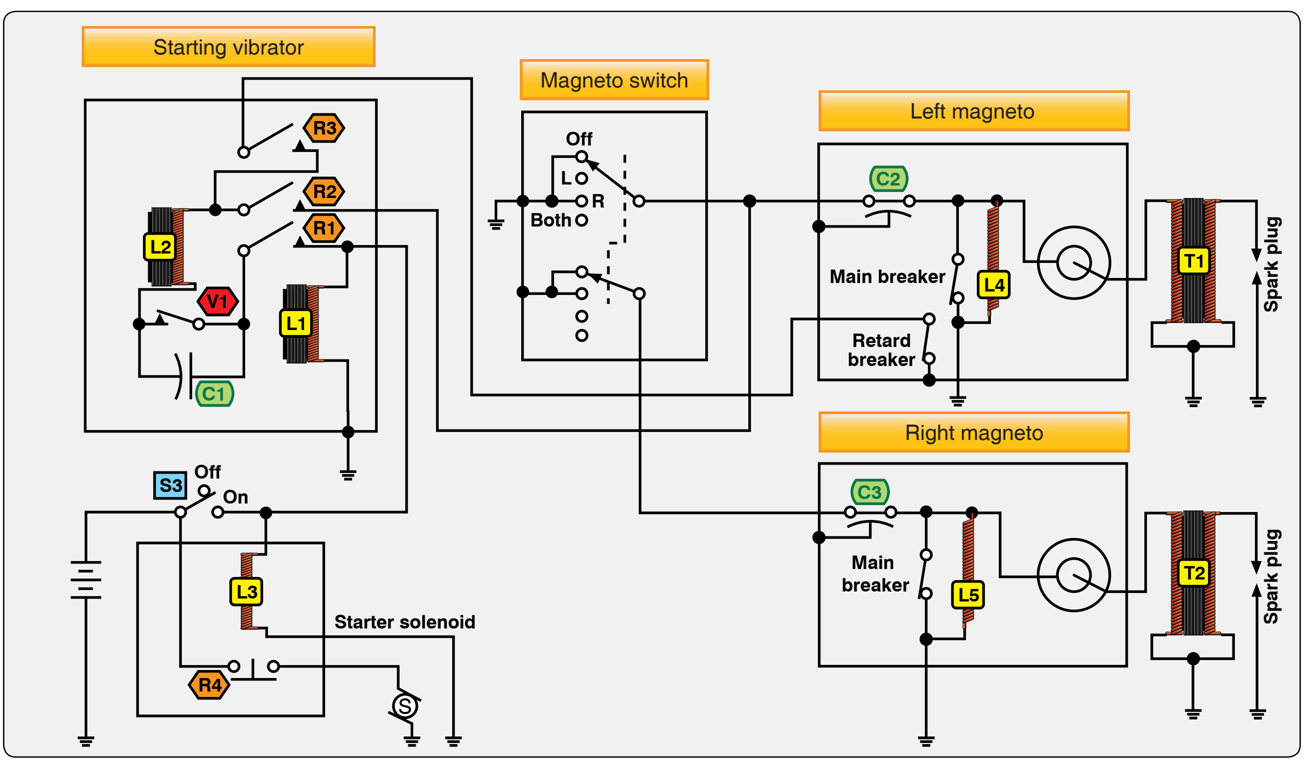


Figure 4-20. *Simplified low-tension ignition system schematic.*

the leads between the transformer coils and the spark plugs of a low-tension ignition system are short, they are high-tension high-voltage conductor, and are subject to the same failures that occur in high-tension systems. Low-tension ignition systems have limited use in modern aircraft because of the excellent materials and shielding available to construct high-tension ignition leads and the added cost of a coil for each spark plug with the low-tension system.

Types of DC Generators

There are three types of DC generators: series wound, parallel (shunt) wound, and series-parallel (compound) wound. The appropriate generator is determined by the connections to the armature and field circuits with respect to the external circuit. The external circuit is the electrical load powered by the generator. In general, the external circuit is used for charging the aircraft battery and supplying power to all electrical equipment being used by the aircraft. As their names imply, windings in series have characteristics different from windings in parallel.

Series Wound DC Generators

The series generator contains a field winding connected in series with the external circuit. *[Figure 4-21]* Series generators have very poor voltage regulation under changing load, since the greater the current is through the field coils to the external circuit, the greater the induced EMFs and the greater the output voltage is. When the aircraft electrical load is increased, the voltage increases; when the load is decreased, the voltage decreases.

Since the series wound generator has such poor voltage and current regulation, it is never employed as an airplane generator. Generators in airplanes have field windings, that are connected either in shunt or in compound formats.

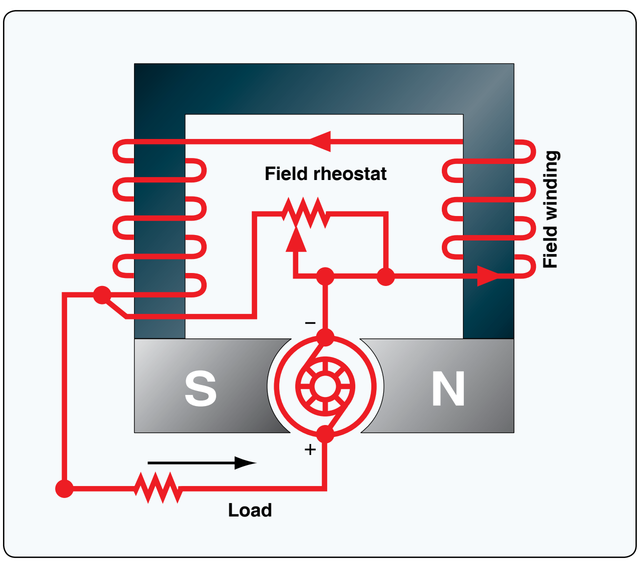


Figure 4-21. *Diagram of a series wound generator.*

Parallel (Shunt) Wound DC Generators

A generator having a field winding connected in parallel with the external circuit is called a shunt generator. *[Figure 4-22]* It should be noted that, in electrical terms, shunt means parallel. Therefore, this type of generator could be called either a shunt generator or a parallel generator.

In a shunt generator, any increase in load causes a decrease in the output voltage, and any decrease in load causes an increase output voltage. This occurs since the field winding is connected in parallel to the load and armature, and all the current flowing in the external circuit passes only through the armature winding (not the field).

As shown in *Figure 4-22A*, the output voltage of a shunt generator can be controlled by means of a rheostat inserted in series with the field windings. As the resistance of the field circuit is increased, the field current is reduced; consequently, the generated voltage is also reduced. As the field resistance is decreased, the field current increases and the generator output increases. In the actual aircraft, the field rheostat would be replaced with an automatic control device, such

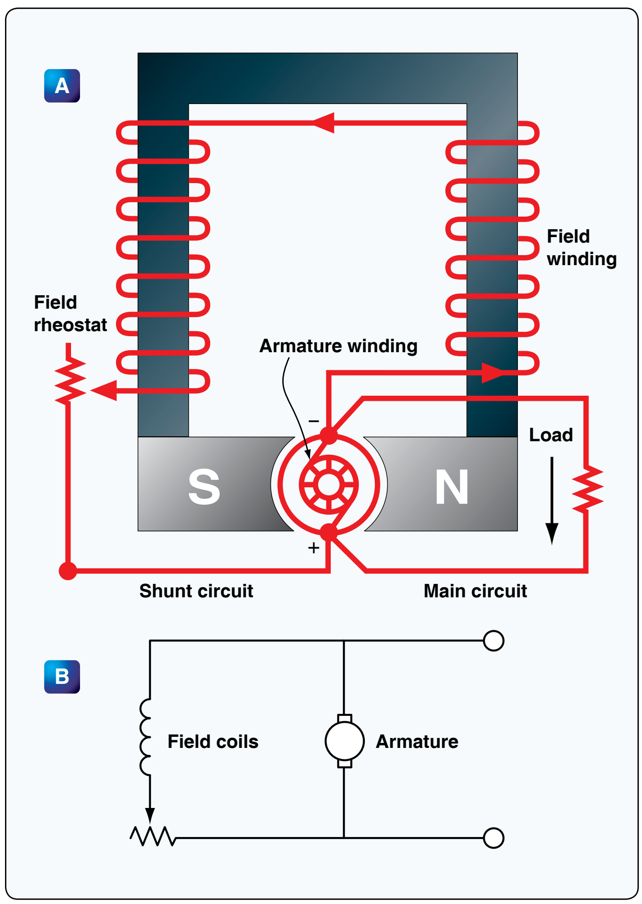


Figure 4-22. *Shunt wound generator.*

as a voltage regulator.

Compound Wound DC Generators

A compound wound generator employs two field windings one in series and another in parallel with the load. *[Figure 4-23]*

This arrangement takes advantage of both the series and parallel characteristics described earlier. The output of a compound wound generator is relatively constant, even with changes in the load.

Generator Ratings

A DC generator is typically rated for its voltage and power output. Each generator is designed to operate at a specified voltage, approximately 14 or 28 volts. It should be noted that aircraft electrical systems are designed to operate at one of these two voltage values. The aircraft's voltage depends on which battery is selected for that aircraft. Batteries are either 12 or 24 volts when fully charged. The generator selected must have a voltage output slightly higher than the battery voltage. Hence, the 14- or 28-volt rating is required for aircraft DC generators.

The power output of any generator is given as the maximum number of amperes the generator can safely supply. Generator rating and performance data are stamped on the nameplate

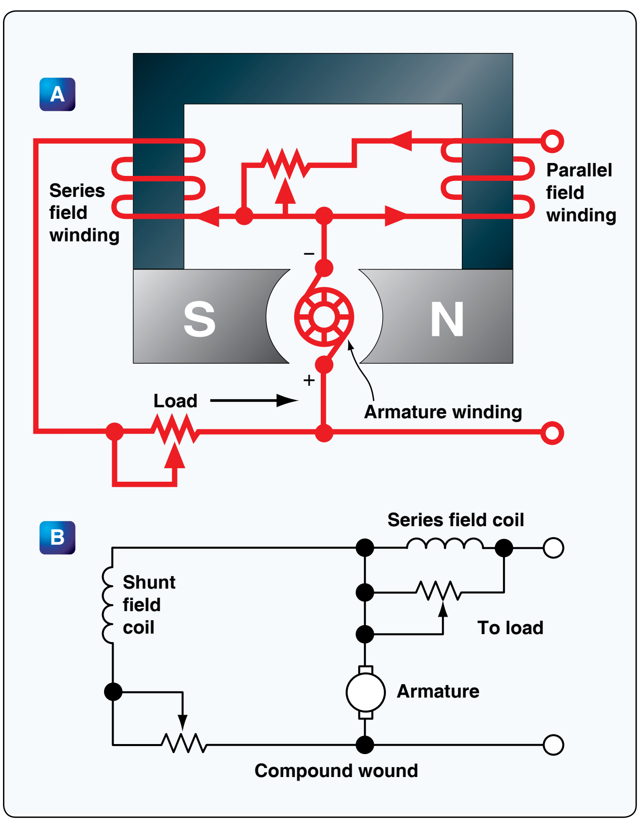


Figure 4-23. *Compound wound generator.*

attached to the generator. When replacing a generator, it is important to choose one of the proper ratings.

The rotation of generators is termed either clockwise or counterclockwise, as viewed from the driven end. The direction of rotation may also be stamped on the data plate. It is important that a generator with the correct rotation be used; otherwise, the polarity of the output voltage is reversed. The speed of an aircraft engine varies from idle rpm to takeoff rpm; however, during the major portion of a flight, it is at a constant cruising speed. The generator drive is usually geared to turn the generator between 1⅛ and 1½ times the engine crankshaft speed. Most aircraft generators have a speed at which they begin to produce their normal voltage. Called the "coming in" speed, it is usually about 1,500 rpm.

DC Generator Maintenance

The following information about the inspection and maintenance of DC generator systems is general in nature because of the large number of differing aircraft generator systems. These procedures are for familiarization only. Always follow the applicable manufacturer's instructions for a given generator system. In general, the inspection of the generator installed in the aircraft should include the following items:

1. Security of generator mounting.
2. Condition of electrical connections.
3. Dirt and oil in the generator. If oil is present, check engine oil seals. Blow out any dirt with compressed air.
4. Condition of generator brushes.
5. Generator operation.
6. Voltage regulator operation.

Sparking of brushes quickly reduces the effective brush area in contact with the commutator bars. The degree of such sparking should be determined. Excessive wear warrants a detailed inspection and possible replacement of various components. *[Figure 4-24]*

Manufacturers usually recommend the following procedures to seat brushes that do not make good contact with slip rings or commutators. Lift the brush sufficiently to permit the insertion of a strip of extra-fine 000 (triple aught) grit, or finer, sandpaper under the brush, rough side towards the carbon brush. *[Figure 4-25]*

Pull the sandpaper in the direction of armature rotation, being careful to keep the ends of the sandpaper as close to the slip ring or commutator surface as possible in order to avoid rounding the edges of the brush. When pulling the sandpaper back to the starting point, raise the brush so it does not ride

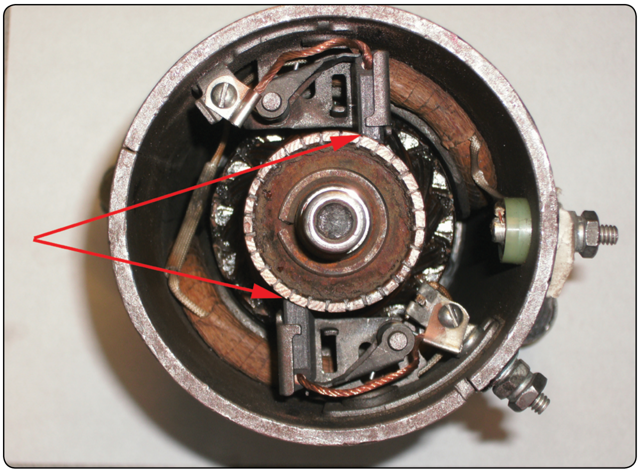


Figure 4-24. *Wear areas of commutator and brushes.*

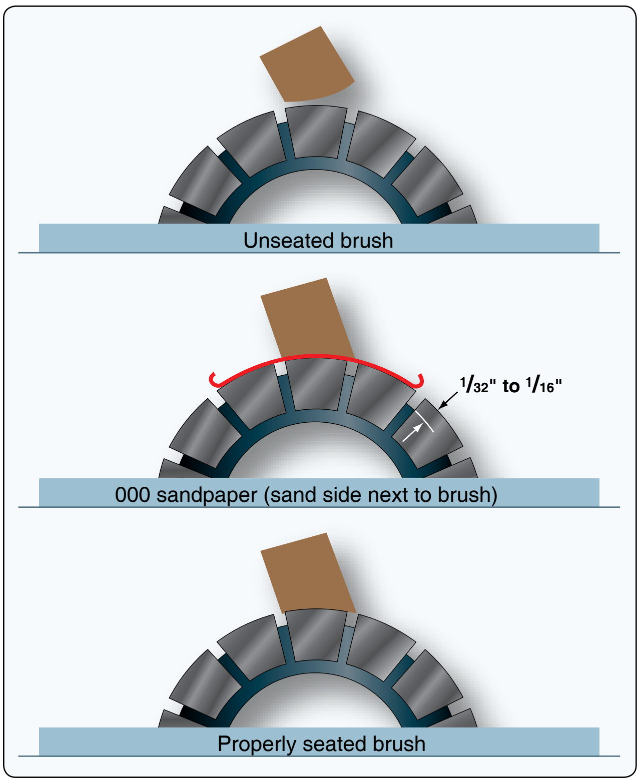


Figure 4-25. *Seating brushes with sandpaper.*

on the sandpaper. Sand the brush only in the direction of rotation. Carbon dust resulting from brush sanding should be thoroughly cleaned from all parts of the generators after a sanding operation.

After the generator has run for a short period, brushes should be inspected to make sure that pieces of sand have not become embedded in the brush. Under no circumstances should emery cloth or similar abrasives be used for seating brushes (or smoothing commutators), since they contain conductive materials that cause arcing between brushes and commutator bars. It is important that the brush spring pressure be correct. Excessive pressure causes rapid wear of brushes. Too little pressure, however, allows bouncing of the brushes, resulting in burned and pitted surfaces. The pressure recommended by the manufacturer should be checked by the use of a spring scale graduated in ounces. Brush spring tension on some generators can be adjusted. A spring scale is used to measure the pressure that a brush exerts on the commutator.

Flexible low-resistance pigtails are provided on most heavy current carrying brushes, and their connections should be securely made and checked at frequent intervals. The pigtails should never be permitted to alter or restrict the free motion of the brush. The purpose of the pigtail is to conduct the current from the armature, through the brushes, to the external circuit of the generator.

FADEC System Description

A FADEC is a solid-state digital electronic ignition and electronic sequential port fuel injection system with only one moving part that consists of the opening and closing of the fuel injector. FADEC continuously monitors and controls ignition, timing, and fuel mixture/delivery/injection, and spark ignition as an integrated control system. FADEC monitors engine operating conditions (crankshaft speed, top dead center position, the induction manifold pressure, and the induction air temperature) and then automatically adjusts the fuel-to-air ratio mixture and ignition timing accordingly for any given power setting to attain optimum engine performance. As a result, engines equipped with FADEC require neither magnetos nor manual mixture control.

This microprocessor-based system controls ignition timing for engine starting and varies timing with respect to engine speed and manifold pressure. *[Figure 4-26]*

PowerLink provides control in both specified operating conditions and fault conditions. The system is designed to prevent adverse changes in power or thrust. In the event of loss of primary aircraft-supplied power, the engine controls continue to operate using a secondary power source (SPS). As a control device, the system performs self-diagnostics to determine overall system status and conveys this information to the pilot by various indicators on the health status annunciator (HSA) panel. PowerLink is able to withstand storage temperature extremes and operate at the same capacity as a non-FADEC-equipped engine in extreme heat, cold, and high humidity environments.

Low-Voltage Harness

The low-voltage harness connects all essential components of the FADEC System. *[Figure 4-26]* This harness acts as a signal transfer bus interconnecting the electronic control

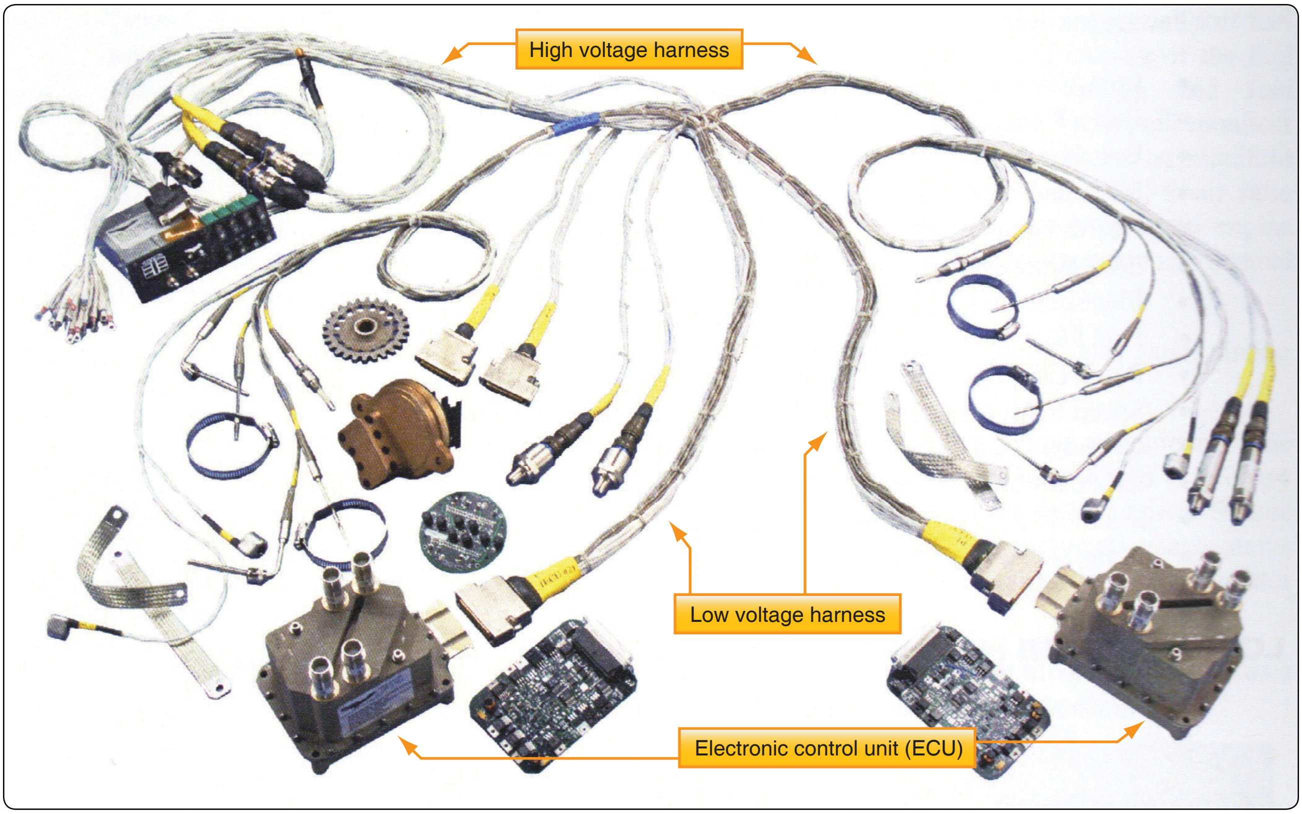


Figure 4-26. *PowerLink system components.*

units (ECUs) with aircraft power sources, the ignition switch, speed sensor assembly (SSA), temperature and pressure sensors. The fuel injector coils and all sensors, except the SSA and fuel pressure and manifold pressure sensors, are hardwired to the low-voltage harness. This harness transmits sensor inputs to the ECUs through a 50-pin connector. The harness connects to the engine-mounted pressure sensors via cannon plug connectors. The 25-jpin connectors connect the harness to the speed sensor signal conditioning unit. The low-voltage harness attaches to the cabin harness by a firewall-mounted data port through the same cabin harness/bulkhead connector assembly. The bulkhead connectors also supply the aircraft electrical power required to run the system.

The ECU is at the heart of the system, providing both ignition and fuel injection control to operate the engine with the maximum efficiency realizable. Each ECU contains two microprocessors, referred to as a computer, that control two cylinders. Each computer controls its own assigned cylinder and is capable of providing redundant control for the other computer's cylinder.

The computer constantly monitors the engine speed and timing pulses developed from the camshaft gear as they are detected by the SSA. Knowing the exact engine speed and the timing sequence of the engine, the computers monitor the manifold air pressure and manifold air temperature to calculate air density and determine the mass air flow into the cylinder during the intake stroke. The computers calculate the percentage of engine power based on engine revolutions per minute (rpm) and manifold air pressure.

From this information, the computer can then determine the fuel required for the combustion cycle for either best power or best economy mode of operation. The computer precisely times the injection event, and the duration of the injector should be on time for the correct fuel-to-air ratio. Then, the computer sets the spark ignition event and ignition timing, again based on percentage of power calculation. Exhaust gas temperature is measured after the burn to verify that the fuel-to-air ratio calculations were correct for that combustion event. This process is repeated by each computer for its own assigned cylinder on every combustion/power cycle.

The computers can also vary the amount of fuel to control the fuel-to-air ratio for each individual cylinder to control both cylinder head temperature (CHT) and exhaust gas temperature (EGT).

Electronic Control Unit (ECU)

An ECU is assigned to a pair of engine cylinders. *[Figure 4-27]* The ECUs control the fuel mixture and spark timing for their respective engine cylinders; ECU 1 controls opposing cylinders 1 and 2, ECU 2 controls cylinders 3 and 4, and ECU

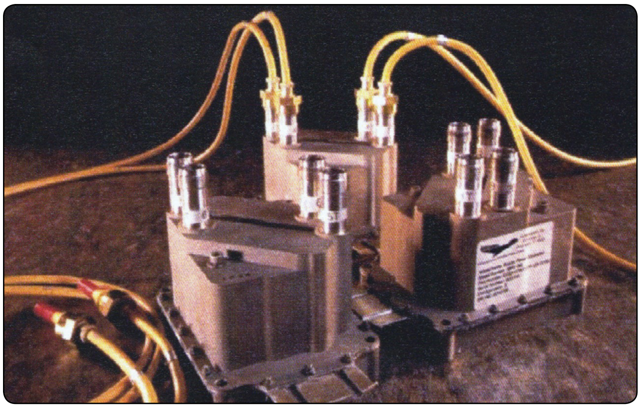


Figure 4-27. *Electronic control unit.*

3 controls cylinders 5 and 6. Each ECU is divided into upper and lower portions. The lower portion contains an electronic circuit board, while the upper portion houses the ignition coils. Each electronic control board contains two independent microprocessor controllers that serve as control channels. During engine operation, one control channel is assigned to operate a single engine cylinder. Therefore, one ECU can control two engine cylinders, one control channel per cylinder. The control channels are independent, and there are no shared electronic components within one ECU. They also operate on independent and separate power supplies. However, if one control channel fails, the other control channel in the pair within the same ECU is capable of operating both its assigned cylinder and the other opposing engine cylinder as backup control for fuel injection and ignition timing. Each control channel on the ECU monitors the current operating conditions and operates its cylinder to attain engine operation within specified parameters. The following transmit inputs to the control channels across the low-voltage harness:

1. Speed sensor that monitors engine speed and crank position,
2. Fuel pressure sensors,
3. Manifold pressure sensors,
4. Manifold air temperature (MAT) sensors,
5. CHT sensors, and
6. EGT sensors.

All critical sensors are dually redundant with one sensor from each type of pair connected to control channels in different ECUs. Synthetic software default values are also used in the unlikely event that both sensors of a redundant pair fail. The control channel continuously monitors changes in engine speed, manifold pressure, manifold temperature, and fuel pressure based on sensor input relative to operating conditions to determine how much fuel to inject into the intake port of the cylinder.

PowerLink Ignition System

The ignition system consists of the high-voltage coils atop the ECU, the high-voltage harness, and spark plugs. Since there are two spark plugs per cylinder on all engines, a six-cylinder engine has 12 leads and 12 spark plugs. One end of each lead on the high-voltage harness attaches to a spark plug, and the other end of the lead wire attaches to the spark plug towers on each ECU. The spark tower pair is connected to opposite ends of one of the ECU's coil packs. Two coil packs are located in the upper portion of the ECU. Each coil pack generates a high-voltage pulse for two spark plug towers. One tower fires a positive polarity pulse and the other of the same coil fires a negative polarity pulse. Each ECU controls the ignition spark for two engine cylinders. The control channel within each ECU commands one of the two coil packs to control the ignition spark for the engine cylinders. *[Figure 4-28]* The high-voltage harness carries energy from the ECU spark towers to the spark plugs on the engine.

For both spark plugs in a given cylinder to fire on the compression stroke, both control channels must fire their coil packs. Each coil pack has a spark plug from each of the two cylinders controlled by that ECU unit.

The ignition spark is timed to the engine's crankshaft position. The timing is variable throughout the engine's operating range and is dependent upon the engine load conditions. The spark energy is also varied with respect to the engine load.

Note: Engine ignition timing is established by the ECUs and cannot be manually adjusted.

Engine Indicating & Crew Alerting System (EICAS)

An engine indicating and crew alerting system (EICAS) performs many of the same functions as an ECAM system. The objective is still to monitor the aircraft systems for the pilot. All EICAS display engine, as well as airframe, parameters. Traditional gauges are not utilized, other than a standby combination engine gauge in case of total system failure.

EICAS is also a two-monitor, two-computer system with a display select panel. Both monitors receive information from the same computer. The second computer serves as a standby. Digital and analog inputs from the engine and airframe systems are continuously monitored. Caution and warning lights, as well as aural tones, are incorporated. *[Figure 4-29]*

EICAS provides full time primary engine parameters (EPR, N1, EGT) on the top, primary monitor. Advisories and warnings are also shown there. Secondary engine parameters

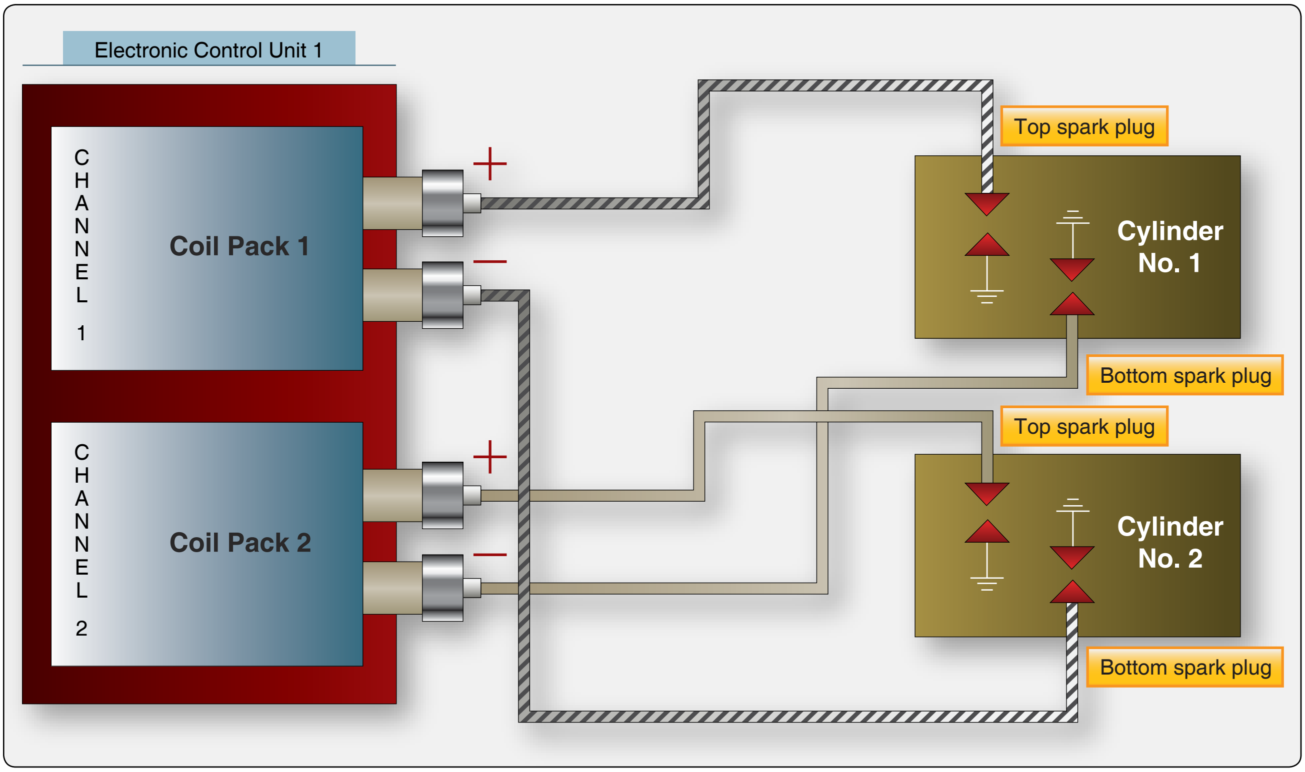


Figure 4-28. *Ignition control.*

and nonengine system status are displayed on the bottom screen. The lower screen is also used for maintenance diagnosis when the aircraft is on the ground. Color coding is used, as well as message prioritizing.

The display select panel allows the pilot to choose which computer is actively supplying information. It also controls the display of secondary engine information and system status displays on the lower monitor. EICAS has a unique feature that automatically records the parameters of a failure event to be regarded afterwards by maintenance personnel. Pilots that suspect a problem may be occurring during flight can press the event record button on the display select panel. This also records the parameters for that flight period to be studied later by maintenance. Hydraulic, electrical, environmental, performance, and APU data are examples of what may be recorded.

EICAS uses BITE for systems and components. A maintenance panel is included for technicians. From this panel, when the aircraft is on the ground, push-button switches display information pertinent to various systems for analysis. *[Figure 4-30]*

Auxiliary Ignition Units

During engine starting, the output of a magneto is low because the cranking speed of the engine is low. This is understandable when the factors that determine the amount of voltage induced in a circuit are considered.

To increase the value of an induced voltage, the strength of the magnetic field must be increased by using a stronger magnet, by increasing the number of turns in the coil, or by increasing the rate of relative motion between the magnet and the conductor.

Since the strength of the rotating magnet and the number of turns in the coil are constant factors in magneto ignition systems, the voltage produced depends upon the speed at which the rotating magnet is turned. When the engine is being cranked for starting, the magnet is rotated at about 80 rpm. Since the value of the induced voltage is so low, a spark may not jump the spark plug gap. To facilitate engine starting, an auxiliary device is connected to the magneto to provide a high ignition voltage.

Ordinarily, such auxiliary ignition units are energized by the battery and connected to the left magneto. Reciprocating engine starting systems normally include one of the following types of auxiliary starting systems: booster coil (older style), starting vibrator (sometimes called shower of sparks), impulse coupling, or electronic ignition systems.

During the starting cycle, the engine is turning very slowly compared to normal speed. The ignition must be retarded or moved back to prevent kickback of the piston trying to

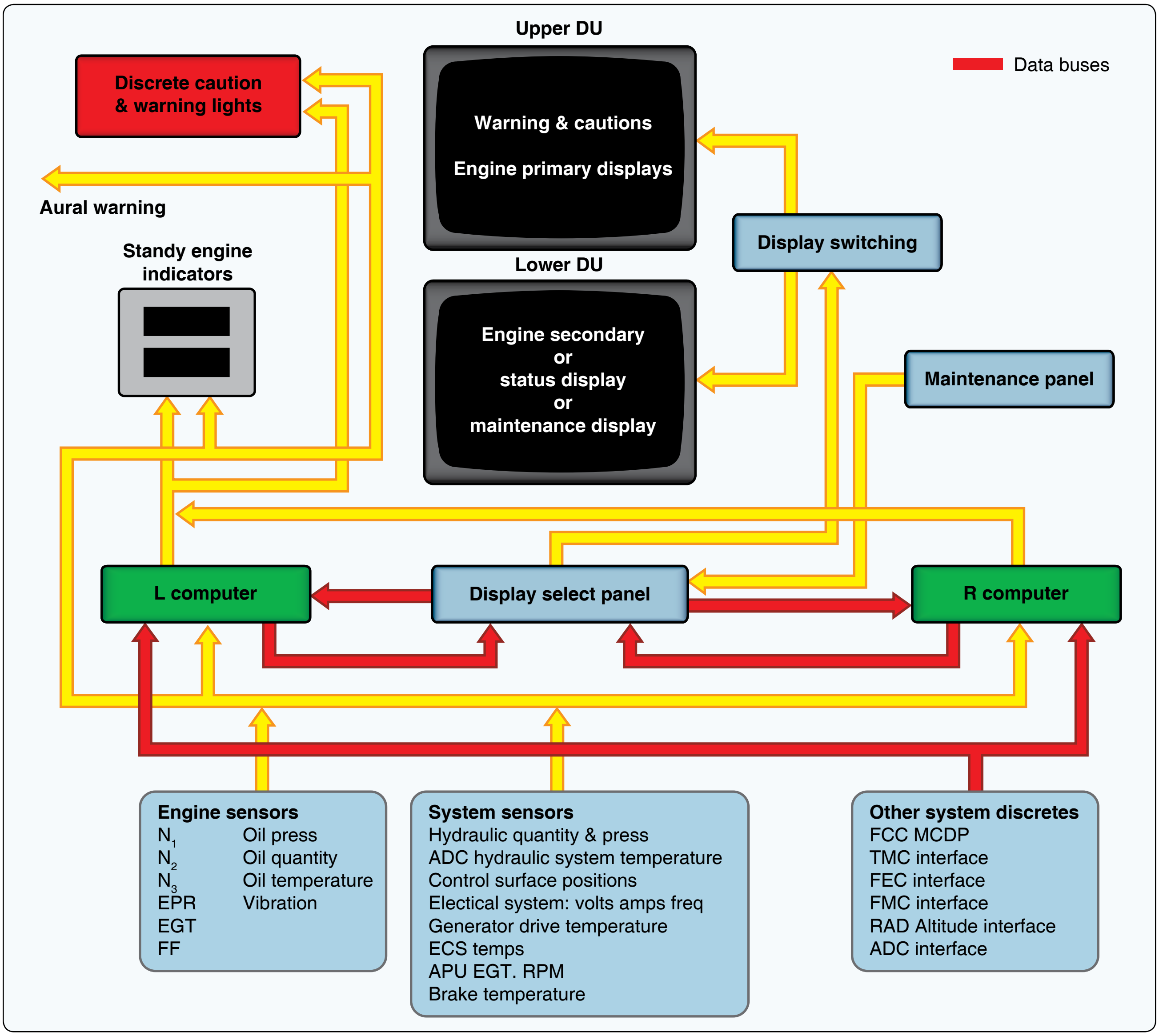


Figure 4-29. *Schematic of an engine indicating and crew alerting system (EICAS).*

rotate opposite normal rotation. Each starting system has a method of retarding the spark during starting of the engine.

Booster Coil

Used mainly with older radial engine ignition systems, the booster coil assembly consists of two coils wound on a soft iron core, a set of contact points, and a condenser. *[Figure 4-31]* The booster coil is separate from the magneto and can generate a series of sparks on its own. During the start cycle, these sparks are routed to the trailing finger on the distributor rotor and then to the appropriate cylinder ignition lead. The primary winding has one end grounded at the internal grounding strip and its other end connected to the moving contact point. The stationary contact is fitted with a terminal to which battery voltage is applied when the magneto switch is placed in the start position, or automatically applied when the starter is engaged. The secondary winding, which contains several times as many turns as the primary coil, has one end grounded at the internal grounding strip and the other terminated at a high-tension terminal. The high-tension terminal is connected to an electrode in the distributor by an ignition cable.

Since the regular distributor terminal is grounded through the primary or secondary coil of a high-tension magneto, the high-voltage furnished by the booster coil must be distributed by a separate circuit in the distributor rotor. This is accomplished by using two electrodes in one distributor rotor. The main electrode, or finger, carries the magneto output voltage; the auxiliary electrode or trailing finger, distributes only the output of the booster coil. The auxiliary electrode is always located so that it trails the main electrode, thus retarding the spark during the starting period.

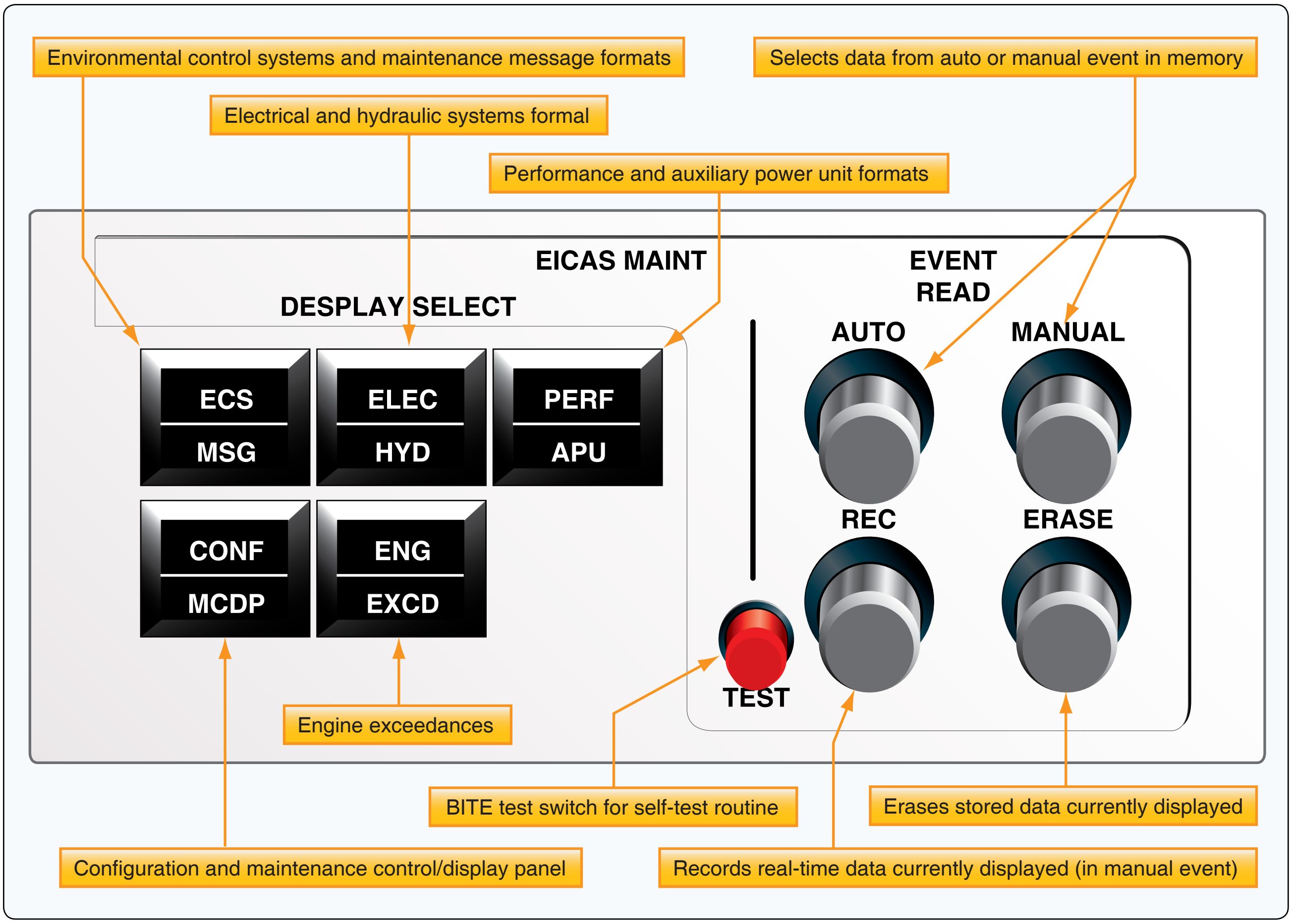


Figure 4-30. *The EICAS maintenance control panel is for the exclusive use of technicians.*

Figure 4-32 illustrates, in schematic form, the booster coil components shown in *Figure 4-31*. In operation, battery voltage is applied to the positive (+) terminal of the booster coil through the start switch. This causes current to flow through the closed contact points to the primary coil and ground. *[Figure 4-32]* Current flow through the primary coil sets up a magnetic field about the coil that magnetizes the coil core. As the core is magnetized, it attracts the movable contact point, which is normally held against the stationary contact point by a spring.

As the movable contact point is pulled toward the iron core, the primary circuit is broken, collapsing the magnetic field that extended about the coil core. Since the coil core acts as an electromagnet only when current flows in the primary coil, it loses its magnetism as soon as the primary coil circuit is broken. This permits the action of the spring to close the contact points and again complete the primary coil circuit. This remagnetizes the coil core, and again attracts the movable contact point, which again opens the primary coil circuit. This action causes the movable contact point to vibrate rapidly, as long as the start switch is held in the closed, or on, position. The result of this action is a continuously expanding and collapsing magnetic field that links the secondary coil of the booster coil. With several times as many turns in the secondary as in the primary, the induced voltage that results from lines of force linking the secondary is high enough to furnish ignition for the engine.

The condenser, which is connected across the contact points, has an important function in this circuit. *[Figure 4-32]* As current flow in the primary coil is interrupted by the opening of the contact points, the high self-induced voltage that accompanies each collapse of the primary magnetic field surges into the condenser. Without a condenser, an arc would jump across the points with each collapse of the magnetic field. This would burn and pit the contact points and greatly reduce the voltage output of the booster coil. The booster coil generates a pulsating DC in the primary winding that induces a high-voltage spark in the secondary windings of the booster coil.

Impulse Coupling

Many opposed reciprocating engines are equipped with an impulse coupling as the auxiliary starting system. An impulse coupling gives one of the magnetos attached to the

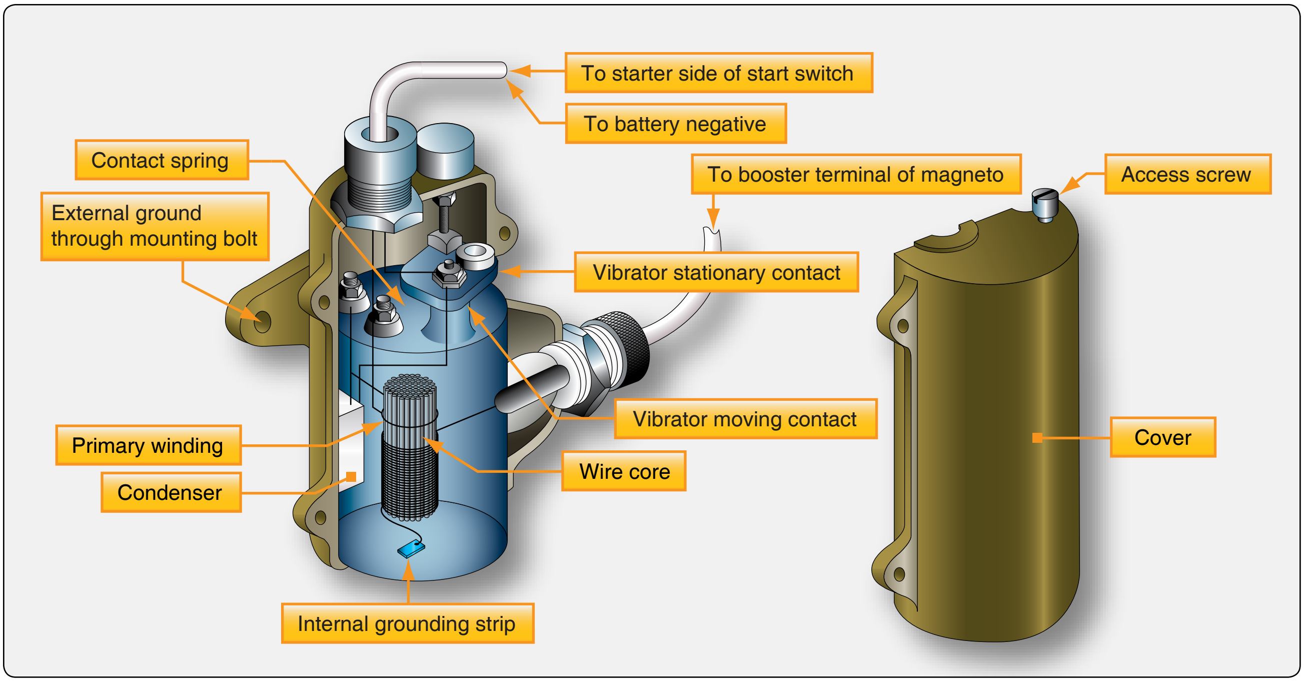


Figure 4-31. *Booster coil.*

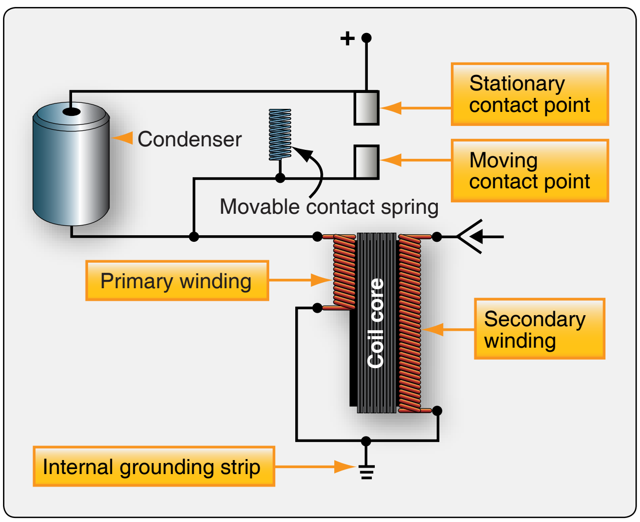


Figure 4-32. *Booster coil schematic.*

engine, generally the left, a brief acceleration, that produces an intense spark for starting. This device consists of a cam and flyweight assembly, spring, and a body assembly. *[Figure 4-33]* The assembled impulse coupling is shown installed on a typical magneto in *Figure 4-34*.

The magneto is flexibly connected through the impulse coupling by means of the spring so that at low speed the magneto is temporarily held. *[Figure 4-35]* The flyweight, because of slow rotation, catches on a stud or stop pins, and the magneto spring is wound as the engine continues to turn. The engine continues to rotate until the piston of the cylinder to be fired reaches approximately a top dead center position. At this point, the magneto flyweight contacts the body of the impulse coupling and is released. The spring kicks back to its original position, resulting in a quick twist of the rotating magnet of the magneto. *[Figure 4-36]* This, being equivalent to high-speed magneto rotation, produces a spark that jumps the gap at the spark plug electrodes. The impulse coupling has two functions: rotating the magneto fast enough to produce a good spark and retarding the timing of the spark during the start cycle. After the engine is started and the magneto reaches a speed at which it furnishes sufficient current, the flyweights in the impulse coupling fly outward due to centrifugal force or rapid rotation. This action prevents the two flyweight coupling members from contact with the stop pin. That makes it a solid unit, returning the magneto to a normal timing position relative to the engine. The presence of an impulse coupling is identified by a sharp clicking noise as the crankshaft is turned at starter cranking speed past top center on each cylinder.

A problem that can arise from impulse couplings is that the flyweights can become magnetized and not engage the stop pins. Congealed oil or sludge on the flyweights during cold weather may produce the same results. This prevents the flyweight weights from engaging the stop pins, which results in no starting spark being produced. Wear can cause problems with impulse couplings. They should be inspected and any maintenance should be performed as set forth by the manufacturer. Another disadvantage of the impulse coupling is that it can produce only one spark for each firing cycle of the cylinder. This is a disadvantage, especially during

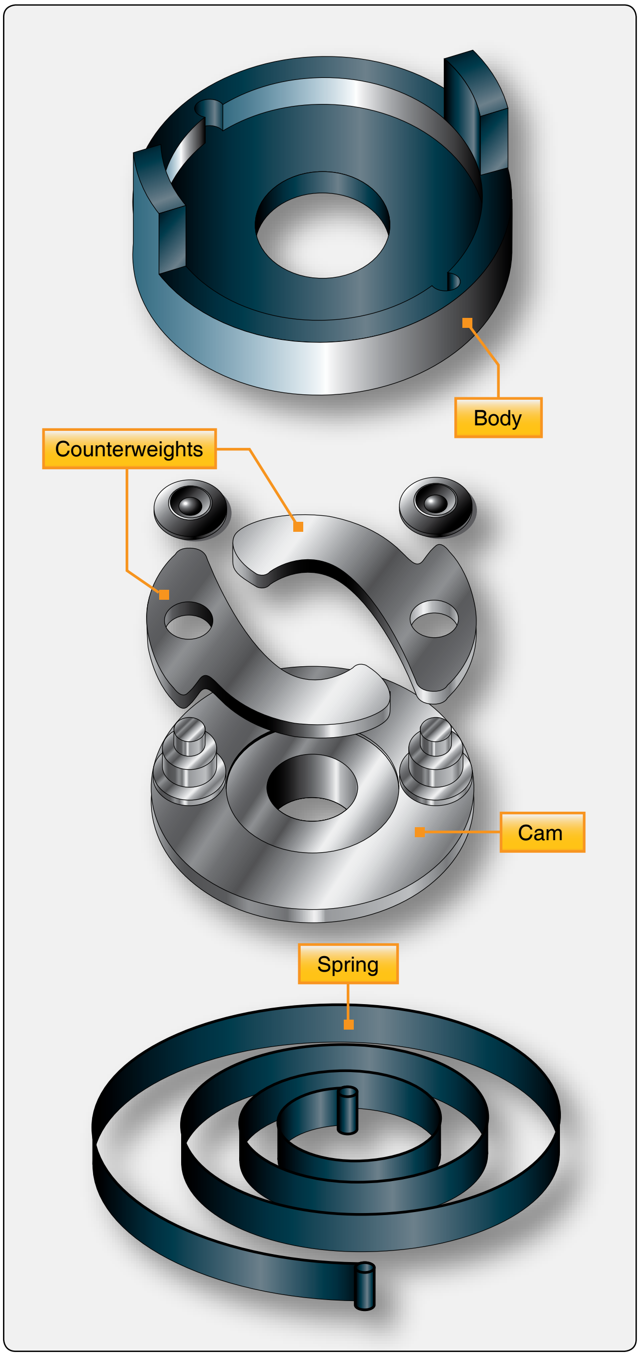


Figure 4-33. *Parts of an impulse coupling.*

adverse starting conditions. Even with these disadvantages, the impulse coupling is still in wide use.

High-Tension Retard Breaker Vibrator

To provide for more spark power during the starting cycle, the shower of sparks system was developed, which provides several sparks at the spark plug electrodes during starting. The starting vibrator, or shower of sparks, consists essentially of an electrically operated vibrator, a condenser, and a relay. *[Figure 4-37]* These units are mounted on a base plate and

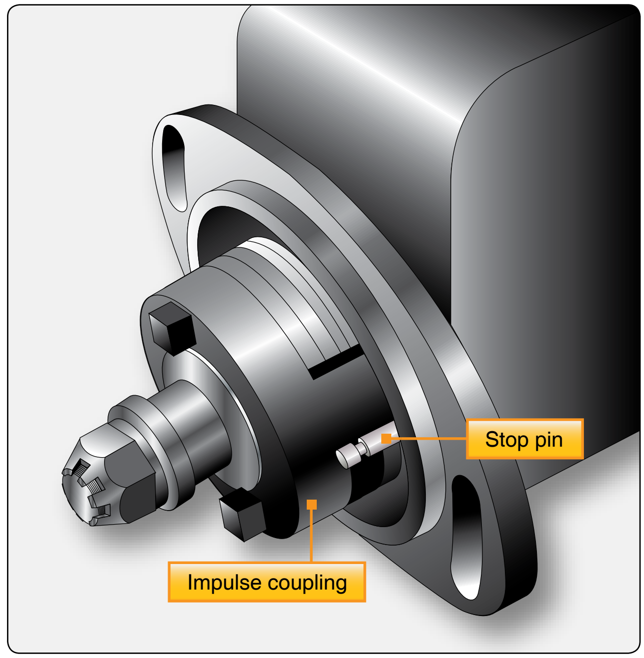


Figure 4-34. *Impulse coupling on a magneto.*

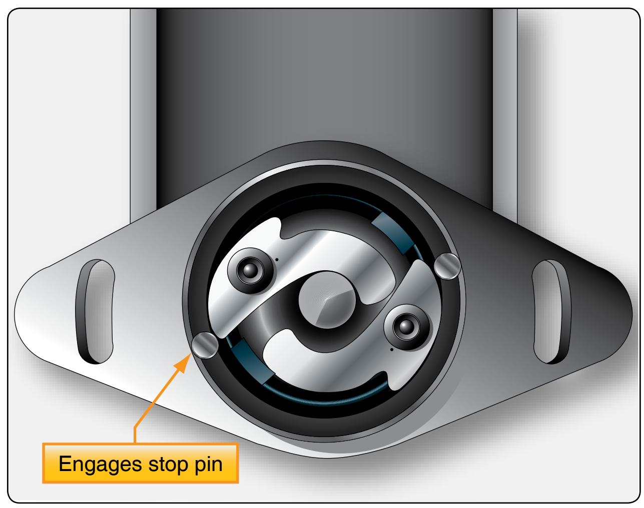


Figure 4-35. *Flyweights engage stop pins.*

enclosed in a metal case.

The starting vibrator, unlike the booster coil, does not produce the high ignition voltage within itself. The function of this starting vibrator is to change the DC of the battery into a pulsating DC and deliver it to the primary coil of the magneto. Closing the ignition switch energizes the starter solenoid and causes the engine to rotate. At the same time, current also flows through the vibrator coil and its contact points. Current flow in the vibrator coil sets up a magnetic field that attracts and opens the vibrator points. When the vibrator points open, current flow in the coil stops, and the magnetic field that attracted the movable vibrator contact point disappears. This allows the vibrator points to close and

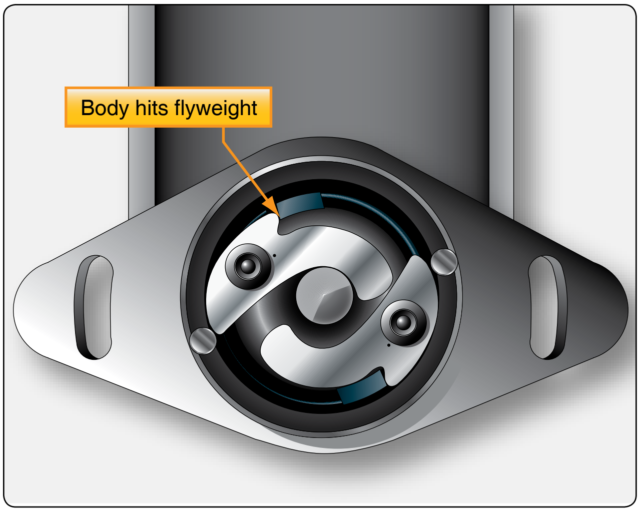


Figure 4-36. *Flyweight contacts body, releasing impulse coupling to spin.*

again permits battery current to flow in the vibrator coil. This completes a cycle of operation. The cycle, however, occurs many times per second, so rapidly that the vibrator points produce an audible buzz.

Each time the vibrator points close, current flows to the magneto as a pulsating DC. Since this current is being interrupted many times per second, the resulting magnetic field is building and collapsing across the primary and secondary coils of the magneto many times per second. The rapid successions of separate voltages induced in the secondary coil produces a shower of sparks across the selected spark plug air gap.

The retard breaker magneto and starting vibrator system is used as part of the high-tension starting system on many types of aircraft. Designed for four- and six-cylinder ignition systems, the retard breaker magneto eliminates the need for the impulse coupling in light aircraft. This system uses an additional breaker to obtain retarded sparks for starting. The starting vibrator is also adaptable to many helicopter ignition systems. A schematic diagram of an ignition system using the retard breaker magneto and starting vibrator concept is shown in *Figure 4-37*.

With the magneto switch in the both position and the starter switch S1 in the on position, starter solenoid L3 and coil L1 are energized, closing relay contacts R4, R1, R2, and R3. R3 connects the right magneto to ground, keeping it inoperative during starting operation. Electrical current flows from the battery through R1, vibrator points V1, coil L2, through both the retard breaker points, through R2, and the main breaker points of the left magneto to ground.

The energized coil L2 opens vibrator points V1, interrupting the current flow through L2. The magnetic field about L2 collapses, and vibrator points V1 close again. Once more,

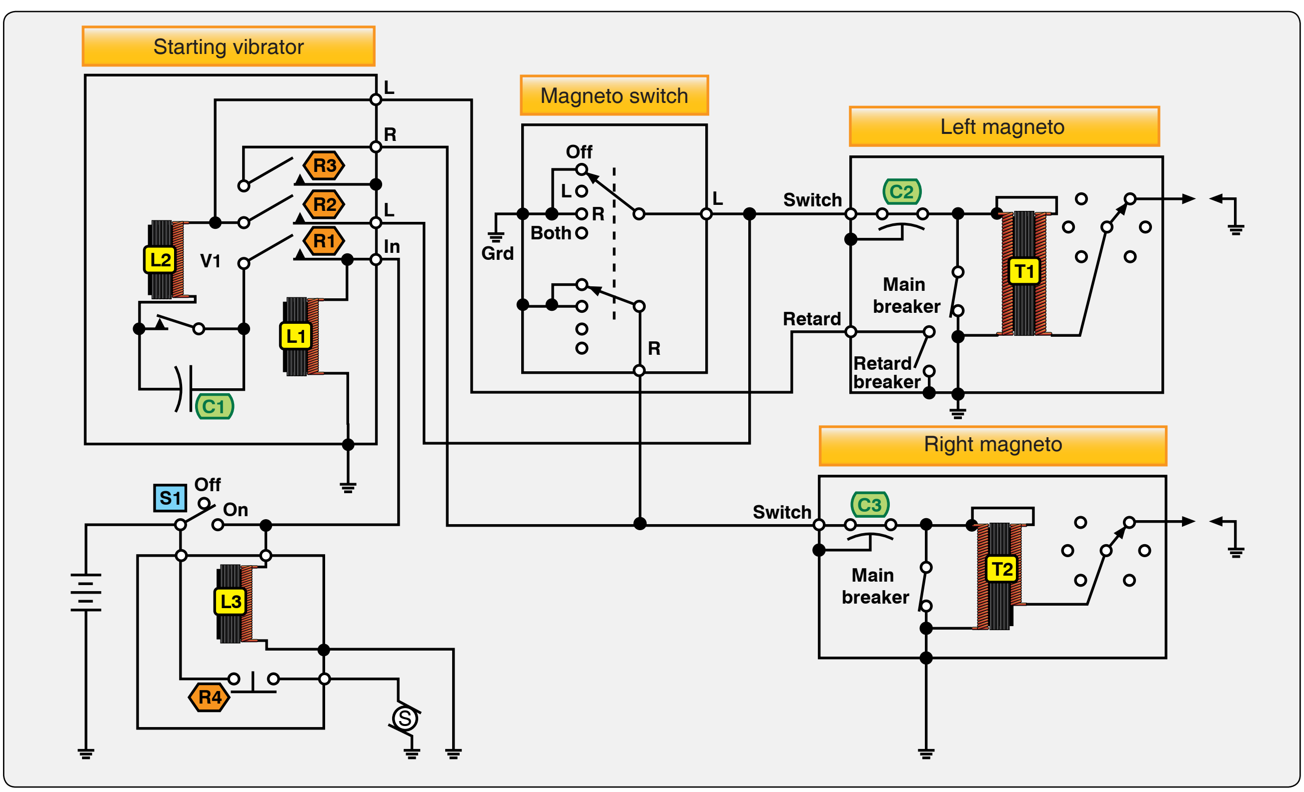


Figure 4-37. *High-tension retard breaker magneto and starting vibrator circuit.*

current flows through L2, and again V1 vibrator points open. This process is repeated continuously, and the interrupted battery current flows to ground through the main and retard breaker points of the left magneto.

Since relay R4 is closed, the starter is energized and the engine crankshaft is rotated. When the engine reaches its normal advance firing position, the main breaker points of the left magneto begin to open. The interrupted surges of current from the vibrator can still find a path to ground through the retard breaker points, which do not open until the retarded firing position of the engine is reached. At this point in crankshaft travel, the retard points open. Since the main breaker points are still open, the magneto primary coil is no longer shorted, and current produces a magnetic field around T1.

Each time the vibrator points V1 open, current flow through V1 is interrupted. The collapsing field about T1 cuts through the magneto coil secondary and induces a high-voltage surge of energy used to fire the spark plug. Since the V1 points are opening and closing rapidly and continuously, a shower of sparks is furnished to the cylinders when both the main and retard breaker points are open.

After the engine begins to accelerate, the manual starter switch is released, causing L1 and L3 to become deenergized. This action causes both the vibrator and retard breaker circuits to become inoperative. It also opens relay contact R3, which removes the ground from the right magneto. Both magnetos now fire at the normal running advanced degree position of crankshaft rotation before top dead center piston position.

Low-Tension Retard Breaker Vibrator

This system, which is in limited use, is designed for light aircraft reciprocating engines. A typical system consists of a retard breaker magneto, a single breaker magneto, a starting vibrator, transformer coils, and a starter and ignition switch. *[Figure 4-38]*

To operate the system, place the starter switch S3 in the on position. This energizes starter solenoid L3 and coil L1, closing relay contacts R1, R2, R3, and R4. With the magneto switch in the L position, current flows through R1, the vibrator points, L2, R2, and through the main breaker points to ground. Current also flows through R3 and the retard breaker points to ground. Current through L2 builds up a magnetic field that opens the vibrator points. Then, the current stops flowing through L2, reclosing the points. These surges of current flow through both the retard and main breaker points to ground.

Since the starter switch is closed, the engine crankshaft is turning. When it has turned to the normal advance or running ignition position, the main breaker points of the magneto

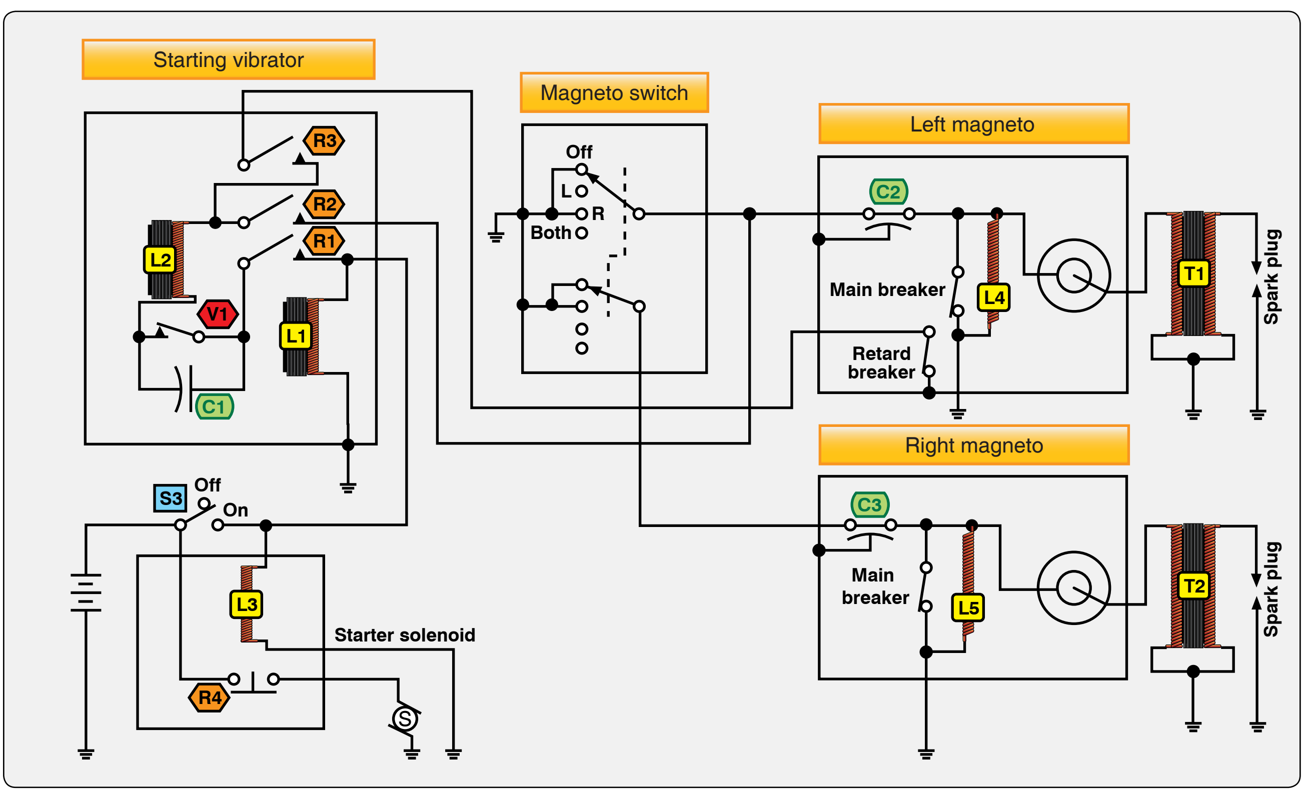


Figure 4-38. *Low-tension retard breaker magneto and starting vibrator circuit.*

open. However, current still flows to ground through the closed retard breaker points. As the engine continues to turn, the retard ignition position is reached, and the retard breaker points open. Since the main breaker points are still open, current must flow to ground through coil L4, producing a magnetic field around the coil L4.

As the engine continues to turn, the vibrator breaker points open, collapsing the L4 magnetic field through T1 primary, inducing a high-voltage in the secondary of T1 to fire the spark plug.

When the engine fires, the starter switch is released, de-energizing L1 and L3. This opens the vibrator circuit and retard breaker points circuit. The ignition switch is then turned to the both position, permitting the right magneto to operate in time with the left magneto.

Spark Plugs

The function of the spark plug in an ignition system is to conduct a short impulse of high-voltage current through the wall of the combustion chamber. Inside the combustion chamber, it provides an air gap across which the impulse can produce an electric spark to ignite the air-fuel charge. While the aircraft spark plug is simple in construction and operation, it can be the cause of malfunctions in aircraft engines. Despite this fact, spark plugs provide a great deal of trouble-free operation when properly maintained and when correct engine operating procedures are practiced.

Spark plugs operate at extreme temperatures, electrical pressures, and very high cylinder pressures. A cylinder of an engine operating at 2,100 rpm must produce approximately 17 separate and distinct high-voltage sparks that bridge the air gap of a single spark plug each second. This would appear as a continuous spark across the spark plug electrodes at temperatures of over 3,000 °F. At the same time, the spark plug is subjected to gas pressures as high as 2,000 pounds per square inch (psi) and electrical pressure as high as 20,000 volts. Given the extremes that spark plugs must operate under, and the fact that the engine loses power if one spark does not occur correctly, proper function of a spark plug in the operation of the engine is imperative.

The three main components of a spark plug are the electrode, insulator, and outer shell. *[Figure 4-39]* The outer shell, threaded to fit into the cylinder, is usually made of finely machined steel and is often plated to prevent corrosion from engine gases and possible thread seizure. Close-tolerance screw threads and a copper gasket prevent cylinder gas pressure from escaping around the plug. Pressure that might escape through the plug is retained by inner seals between the outer metal shell and the insulator, and between the insulator

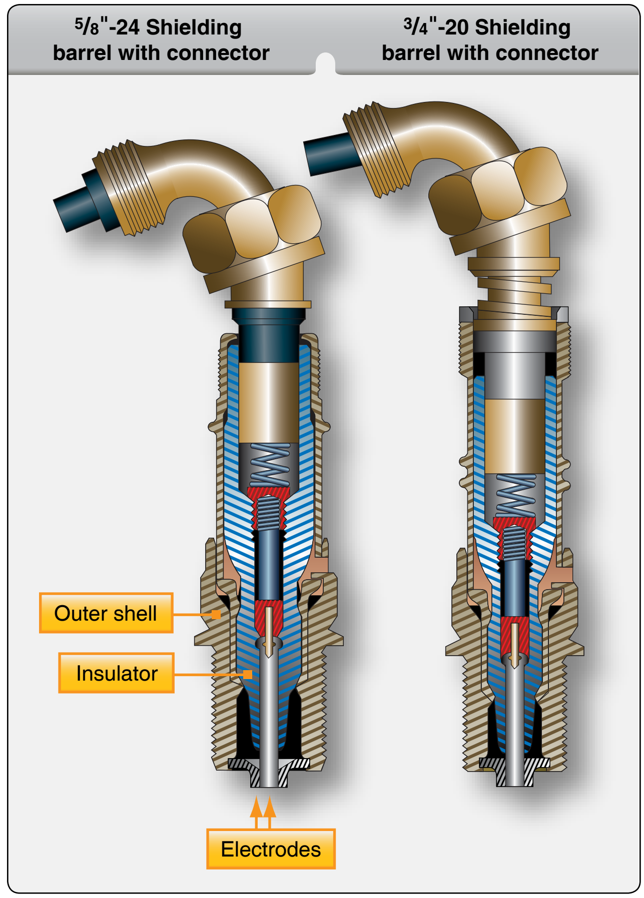


Figure 4-39. *Spark plug cutaway.*

and the center electrode assembly. The other end is threaded to receive the ignition lead from the magneto. All-weather plugs form a seal between the lead and the plug that is water proof to prevent moisture from entering this connection.

The insulator provides a protective core around the electrode. In addition to affording electrical insulation, the ceramic insulator core also transfers heat from the ceramic tip, or nose, to the cylinder. The insulator is made from aluminum oxide ceramic having excellent dielectric strength, high mechanical strength, and thermal conductivity. The types of spark plugs used in different engines vary in respect to heat range, reach, massive electrode, fine wire electrode (Iridium/platinum), or other characteristics of the installation requirements for different engines.

The electrodes can be of several designs from massive electrodes or Nickel-base alloy to fine wire electrodes. *[Figure 4-39* and *4-40]* The massive electrode material has a lower melting point and is more susceptible to corrosion. The main differences include cost and length of service. Fine wire iridium and platinum electrodes have a very high melting point and are considered precious metals. Therefore, the cost of this type of spark plug is higher, but they have

Figure 4-40. *Fine wire electrodes.*

a longer service life with increased performance. Fine wire spark plugs are more effective than massive electrode plugs because the size shields its own spark from some of the fuel air mixture. Less than efficient combustion occurs due to uneven ignition. The iridium electrode allows for a larger spark gap, which creates a more intense spark that increases performance. The spark gap of any electrode is vulnerable to erosion and the melting point of the electrode material.

The heat range of a spark plug is a measure of its ability to transfer the heat of combustion to the cylinder head. The plug must operate hot enough to burn off carbon deposits, which can cause fouling, a condition where the plug no longer produces a spark across the electrodes, yet remain cool enough to prevent a pre-ignition condition. Spark plug pre-ignition is caused by plug electrodes glowing red hot as a glow plug, setting off the air-fuel mixture before the normal firing position. The length of the nose core is the principal factor in establishing the plug's heat range. *[Figure 4-41]* Hot plugs have a long insulator nose that creates a long heat transfer path; cold plugs have a relatively short insulator to provide a rapid transfer of heat to the cylinder head. *[Figure 4-41]*

If an engine were operated at only one speed, spark plug design would be greatly simplified. Because flight demands impose different loads on the engine, spark plugs must be designed to operate as hot as possible at slow speeds and light loads, and as cool as possible at cruise and takeoff power.

The choice of spark plugs to be used in a specific aircraft engine is determined by the engine manufacturer after extensive tests. When an engine is certificated to use hot

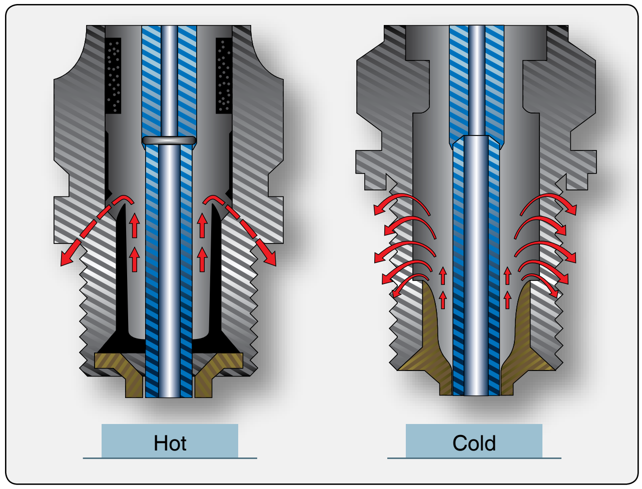


Figure 4-41. *Hot and cold spark plugs.*

or cold spark plugs, the plug used is determined by the compression ratio, the degree of supercharging, and how the engine is to be operated. High-compression engines tend to use colder range plugs while low-compression engines tend to use hot range plugs.

A spark plug with the proper reach ensures that the electrode end inside the cylinder is in the best position to achieve ignition. The spark plug reach is the length of the threaded portion that is inserted in the spark plug bushing of the cylinder. *[Figure 4-42]* Spark plug seizure and/or improper combustion within the cylinder can occur if a plug with the wrong reach is used. In extreme cases, if the reach is too long, the plug may contact a piston or valve and damage the engine. If the plug threads are too long, they extend into the combustion chamber and carbon adheres to the threads making it almost impossible to remove the plug. This can also be a source of pre-ignition. Heat of combustion can make some of the carbon a source for ignition, which can ignite the air-fuel mixture prematurely. It is very important to select the approved spark plugs for the engine.

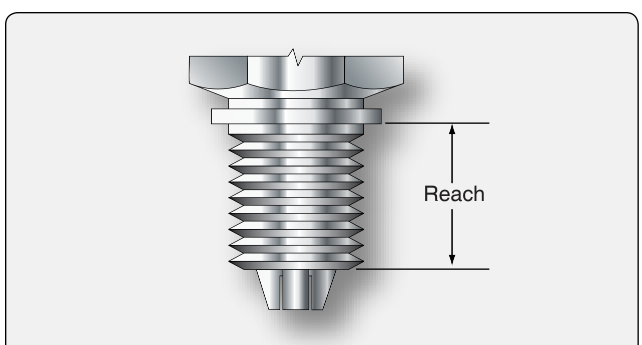


Figure 4-42. *Spark plug reach.*

Reciprocating Engine Ignition System Maintenance & Inspection

An aircraft's ignition system is the result of careful design and thorough testing. The ignition system usually provides good, dependable service, provided it is maintained and inspected properly. However, difficulties can occur with normal wear, which affects ignition system performance, especially with magneto systems. Breakdown and deterioration of insulating materials, breaker point wear, corrosion, bearing and oil seal wear, and electrical connection problems are all possible defects that can be associated with magneto-ignition systems. The ignition timing requires precise adjustment and painstaking care so that the following four conditions occur at the same instant:

1. The piston in the No. 1 cylinder must be in a position a prescribed number of degrees before top dead center on the compression stroke.
2. The rotating magnet of the magneto must be in the E-gap position.
3. The breaker points must be just opening on the No. 1 cam lobe.
4. The distributor finger must be aligned with the electrode serving the No. 1 cylinder.

If one of these conditions is out of synchronization with any of the others, the ignition system is out of time. If the spark is out of time, it is not delivered to the cylinder at the correct time and engine performance decreases.

When ignition in the cylinder occurs before the optimum crankshaft position is reached, the timing is said to be early. If ignition occurs too early, the piston rising in the cylinder is opposed by the full force of combustion. This condition results in a loss of engine power, overheating, and possible detonation and pre-ignition.

If ignition occurs at a time after the optimum crankshaft position is reached, the ignition timing is said to be late. If it occurs too late, not enough time is allowed to consume the air-fuel charge, and combustion is incomplete. As a result, the engine loses power and requires a greater throttle opening to carry a given propeller load.

Moisture forming on different parts of the ignition system causes more common irregularities. Moisture can enter ignition system units through cracks or loose covers, or it can result from condensation. Breathing, a situation that occurs during the readjustment of the system from low to high atmospheric pressure, can result in drawing in moisture-laden air. Ordinarily, the heat of the engine is sufficient to evaporate this moisture, but occasionally the moist air condenses as the engine cools. The result is an appreciable moisture accumulation which causes the insulation materials to lose electrical resistance. A slight amount of moisture contamination may cause reduction in magneto output by short-circuiting to ground a part of the high-voltage current intended for the spark plug. If the moisture accumulation is appreciable, the entire magneto output may be dissipated to ground by way of flashover and carbon tracking. Moisture accumulation during flight is extremely rare because the high operating temperature of the system is effective in preventing condensation. Difficulties from moisture accumulation are probably more evident during starting and ground operation.

Spark plugs are often diagnosed as being faulty when the real malfunction exists in a different system. Malfunctioning of the carburetor, poor fuel distribution, too much valve overlap, leaking primer system, or poor idle speed and mixture settings show symptoms that are the same as those for faulty ignition. Unfortunately, many of these conditions can be temporarily improved by a spark plug change, but the trouble recurs in a short time because the real cause of the malfunction has not been eliminated. A thorough understanding of the various engine systems, along with meticulous inspection and good maintenance methods, can substantially reduce such errors.

Magneto-Ignition Timing Devices

Built-In Engine Timing Reference Marks

Most reciprocating engines have timing reference marks built into the engine. The timing reference marks vary by manufacturer. *[Figure 4-43]* When the starter gear hub is installed correctly, the timing marks are marked on it that line up with the mark on the starter. On an engine that has no starter gear hub, the timing mark is normally on the propeller flange edge. *[Figure 4-44]* The top center (TC) mark stamped on the edge aligns with the crankcase split line below the crankshaft when the No. 1 piston is at top dead center. Other flange marks indicate degrees before top center.

Some engines have degree markings on the propeller reduction drive gear. To time these engines, the plug provided on the exterior of the reduction gear housing must be removed to view the timing marks. On other engines, the timing marks are on a crankshaft flange and can be viewed by removing a plug from the crankcase. In every case, the engine manufacturer's instructions give the location of built-in timing reference marks.

In using built-in timing marks to position the crankshaft, be sure to sight straight across the stationary pointer or mark on the nose section, the propeller shaft, crankshaft flange, or bell gear. *[Figure 4-45]* Sighting at an angle results in an error in positioning the crankshaft. Normally, the No. 1 cylinder is used to time or check the timing of the magnetos. When installing magnetos, the timing marks must be lined up and the No. 1 cylinder must be on the compression stroke.

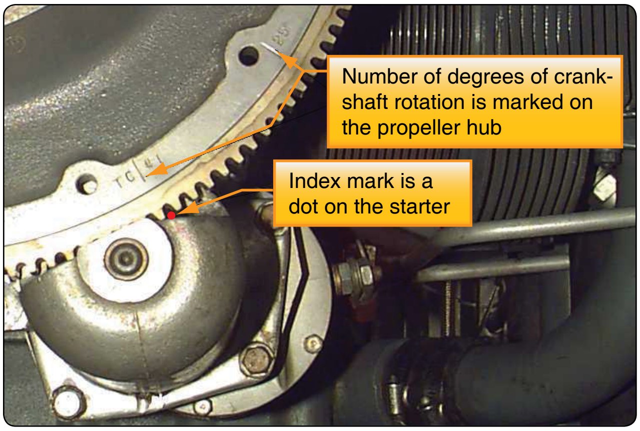


Figure 4-43. *Lycoming timing marks.*

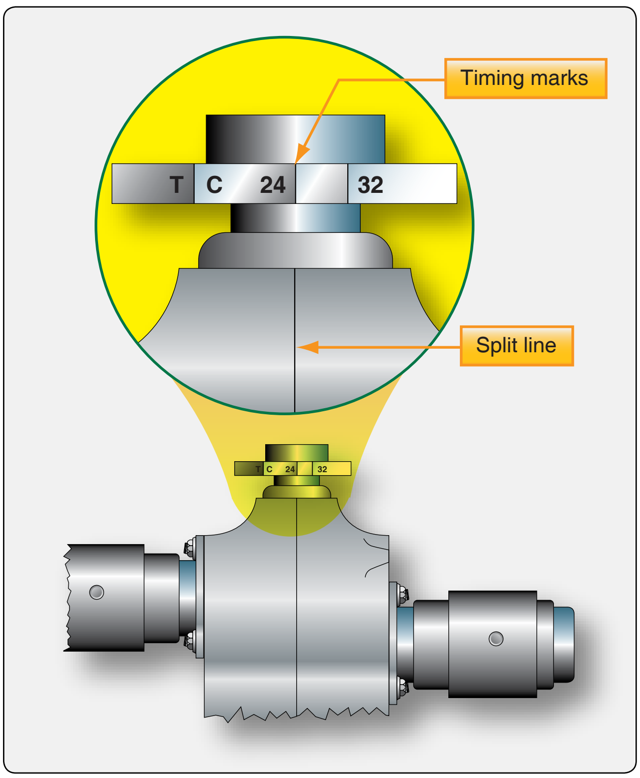


Figure 4-44. *Propeller flange timing marks.*

The amount of gear backlash in any system of gears varies between installations because there is clearance between the gear teeth. Always take timing when reading, or stop movement of the engine for timing set up, in the direction of rotation. Another unfavorable aspect in the use of timing marks on the reduction gear is the small error that exists when sighting down the reference mark to the timing mark inside the housing on the reduction gear. This can occur because there is depth between the two reference marks.

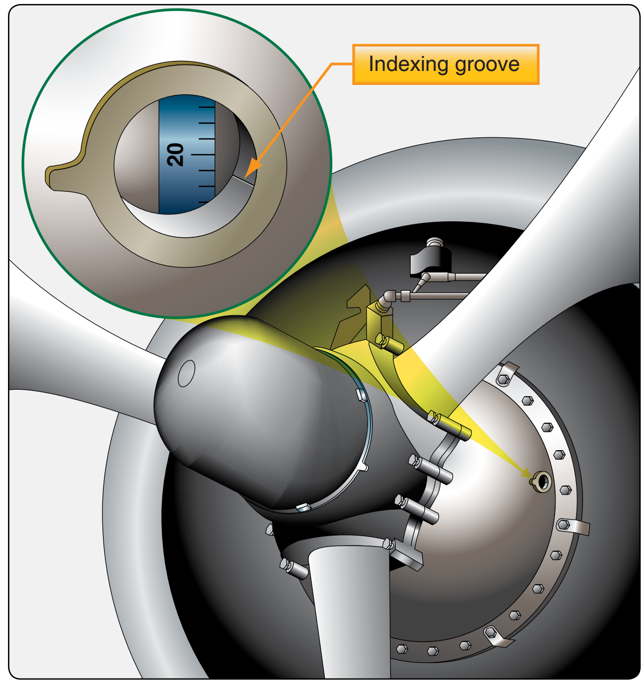


Figure 4-45. *Typical built-in timing mark on propeller reduction gear.*

Timing Discs

Most timing disc devices are mounted to the crankshaft flange and use a timing plate. *[Figure 4-46]* The markings vary according to the specifications of the engine. This plate is temporarily installed on the crankshaft flange with a scale numbered in crankshaft degrees and the pointer attached to the timing disc.

Piston Position Indicators

Any given piston position, whether it is to be used for ignition, valve, or injection pump timing, is referenced to a piston position called top dead center. This piston position is not to be confused with a piston position called top center. A piston in top center has little value from a timing standpoint because the corresponding crankshaft position may vary from 1° to 5° for this piston position. This is illustrated in *Figure 4-47,* which is exaggerated to emphasize the no-travel zone of the piston. Notice that the piston does not move while the crankshaft describes the small arc from position A to position B. This no-travel zone occurs between the time the crankshaft and connecting rod stop pushing the piston upward, and continues until the crankshaft has swung the lower end of the connecting rod into a position where the crankshaft can start pulling the piston downward. Top dead center is a piston and crankshaft position from which all other piston and crankshaft locations are referenced. When a piston is in the top dead center position of the crankshaft, it is also in the center of the no-travel zone. The piston is in a position where a straight line can be drawn through the center of the crankshaft journal, the crankpin, and the piston pin. This is

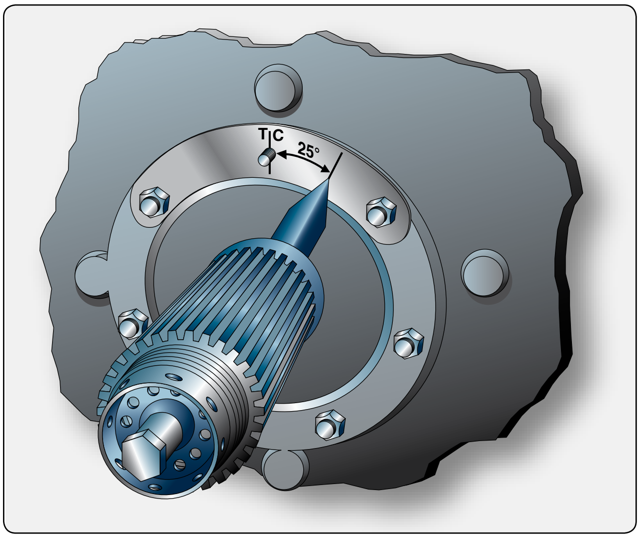


Figure 4-46. *A timing plate and pointer.*

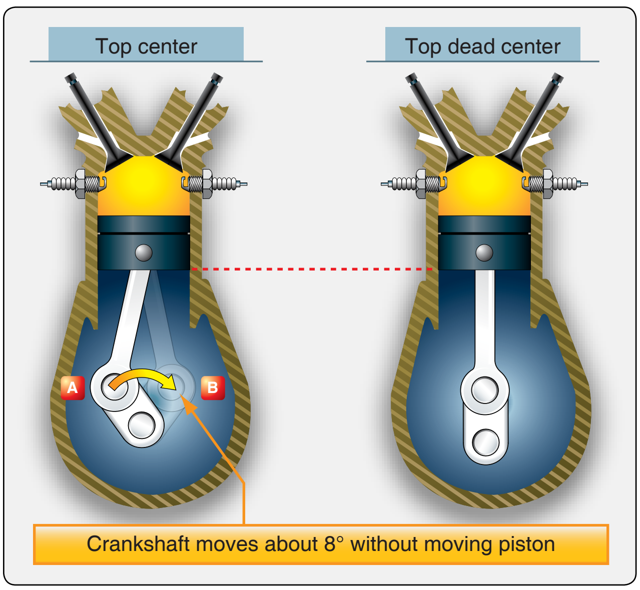


Figure 4-47. *Difference between top center and top dead center.*

shown on the right of *Figure 4-47*. With such an alignment, a force applied to the piston could not move the crankshaft.

Timing Lights

Timing lights are used to help determine the exact instant that the magneto points open. There are two general types of timing lights in common use. Both have two lights and three external wire connections. Although both have internal circuits that are somewhat different, their function is very much the same. *[Figures 4-48* and *4-49]*

Three wires plug into the light box. *[Figure 4-49]* There are two lights on the front face of the unit, one green and one red, and a switch to turn the unit on and off. To use the timing light, the center lead, which is black, marked "ground lead" is connected to the case of the magneto being tested. The other leads are connected to the primary leads of the breaker point assembly of the magnetos being timed. The color of the lead corresponds to the color of the light on the timing light.

With the leads connected in this manner, it can be easily determined whether the points are open or closed by turning on the switch and observing the two lights. If the points are closed, most of the current flows through the breaker points and not through the transformers, and the lights do not come on. If the points are open, the current flows through the transformer and the lights glow. Some models of timing lights operate in the reverse manner (i.e., the light goes out when the points open). Each of the two lights is operated separately by the set of breaker points to which it is connected. This makes it possible to observe the time, or point in reference to magneto rotor rotation, that each set of points opens.

Most timing lights use batteries that must be replaced after long use. Attempts to use a timing light with weak batteries may result in erroneous readings because of low current flow in the circuits.

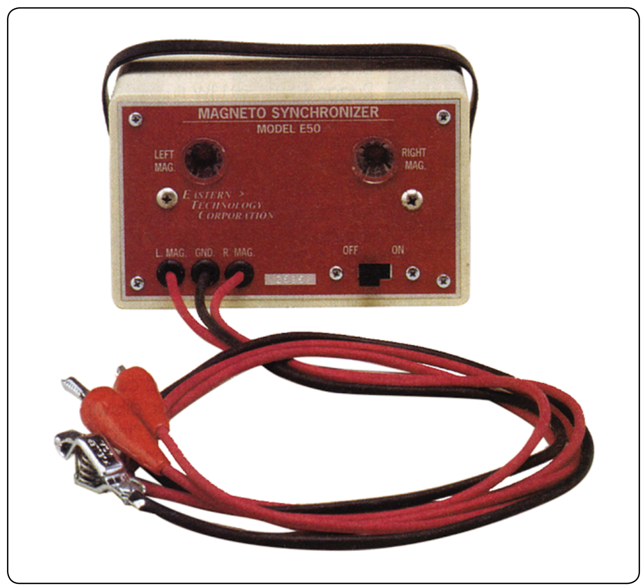


Figure 4-48. *E50 Magneto Synchronizer.*

Figure 4-49. *Timing light.*

Checking the Internal Timing of a Magneto

When replacing or preparing a magneto for installation, the first concern is with the internal timing of the magneto. For each magneto model, the manufacturer determines how many degrees beyond the neutral position a pole of the rotor magnet should be to obtain the strongest spark at the instant of breaker point separation. This angular displacement from the neutral position, known as the E-gap angle, varies with different magneto models. On one model, a step is cut on the end of the breaker cam to check internal timing of the magneto. When a straightedge is laid along this step and it coincides with the timing marks on the rim of the breaker housing, the magneto rotor is then in the E-gap position, and the breaker contact points should just begin to open.

Another method for checking E-gap is to align a timing mark with a pointed chamfered tooth. *[Figure 4-50]* The breaker points should be just starting to open when these marks line up.

In a third method, the E-gap is correct when a timing pin is in place and red marks visible through a vent hole in the side of the magneto case are aligned. *[Figure 4-51]* The contact points should be just opening when the rotor is in the position just described.

Bench timing the magneto, or setting the E-gap, involves positioning the magneto rotor at the E-gap position and setting the breaker points to open when the timing lines or marks provided for that purpose are perfectly aligned.

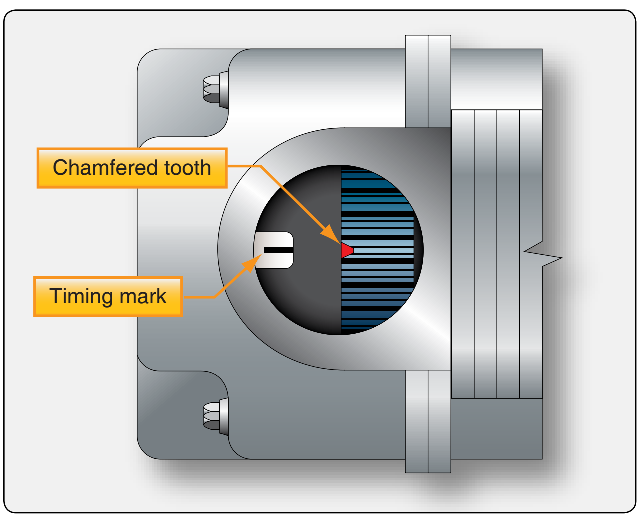


Figure 4-50. *Timing marks indicate the number one firing position of a magneto.*

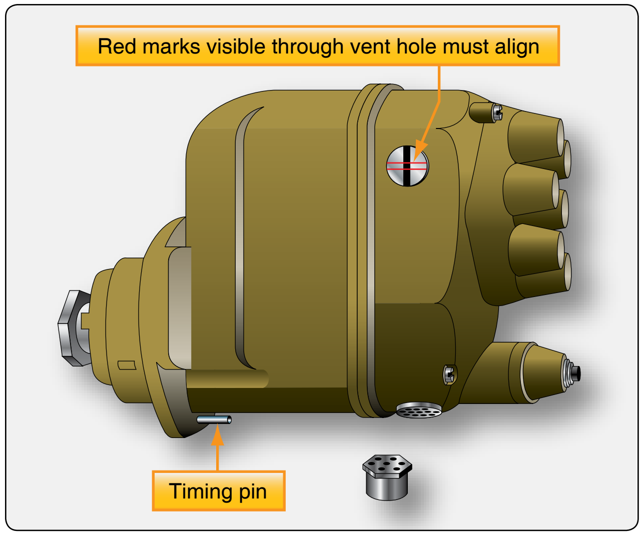


Figure 4-51. *Checking magneto E-gap.*

High-Tension Magneto E-Gap Setting (Bench Timing)

The following steps are taken to check and adjust the timing of the breaker points for the S-200 magneto, which does not have timing marks in the breaker compartment:

1. Remove the timing inspection plug from the top of the magneto. Turn the rotating magnet in its normal direction of rotation until the painted, chamfered tooth on the distributor gear is approximately in the center of the inspection window. Then, turn the magnet back a few degrees until it is in its neutral position. Because of its magnetism, the rotating magnet holds itself in the neutral position.
2. Install the timing kit and place the pointer in the zero position. *[Figure 4-52]*
3. Connect a suitable timing light across the main breaker points and turn the magnet in its normal direction of rotation 10° as indicated by the pointer. This is the E-gap position. The main breaker points should be adjusted to open at this point.
4. Turn the rotating magnet until the cam follower is at the highpoint on the cam lobe, and measure the clearance between the breaker points. This clearance must be 0.018 inch ± 0.006 inch [0.46 millimeter (mm) ± 0.15 mm]. If the breaker point clearance is not within these limits, the points must be adjusted for correct setting. It is then necessary to recheck and readjust the timing for breaker opening. If the breaker points cannot be adjusted to open at the correct time, they should be replaced.

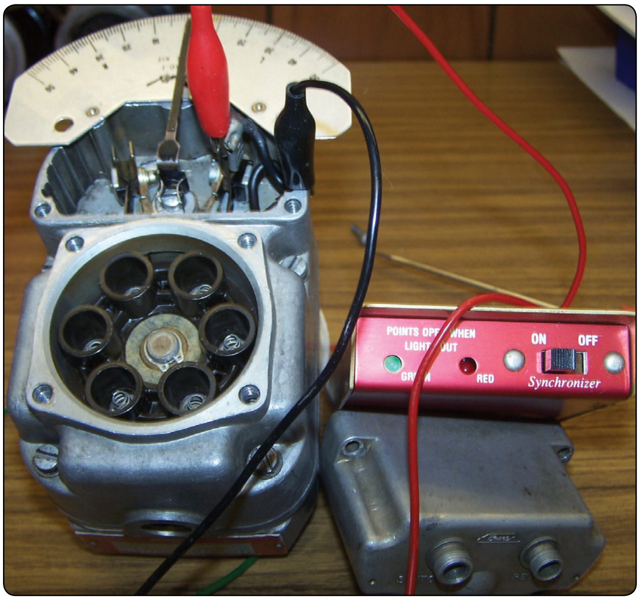


Figure 4-52. *Installing timing kit.*

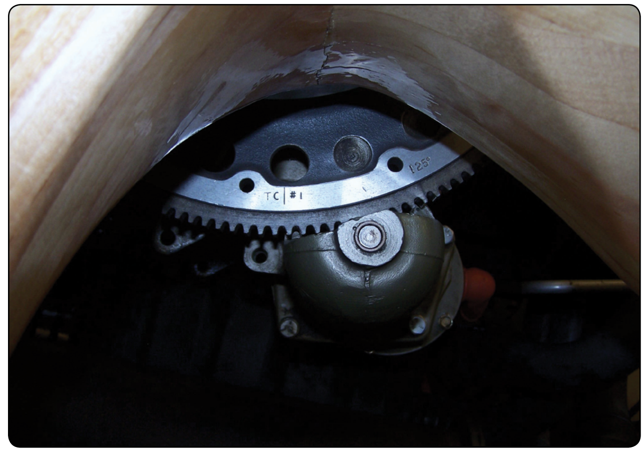


Figure 4-53. *Timing marks aligned.*

Timing the High-tension Magneto to the Engine

When replacing magnetos on aircraft engines, two factors must be considered:

1. The internal timing of the magneto, including breaker point adjustment, which must be correct to obtain maximum potential voltage from the magneto.
2. The engine crankshaft position where the spark occurs. The engine is usually timed by using the No. 1 cylinder on the compression stroke.

The magneto must be timed by first adjusting or checking the internal timing with the magneto off the engine. This is done by checking and adjusting the ignition points to open at the E-gap position. The chamfered tooth should line up (reference timing mark for the magneto) in the middle of the timing window. The magneto is set to fire the No. 1 cylinder. Remove the most accessible spark plug from the No. 1 cylinder. Pull the propeller through in the direction of rotation until the No. 1 piston is coming up on the compression stroke. This can be determined by holding a thumb over the spark plug hole until the compression air is felt. Set the engine crankshaft at the prescribed number of degrees ahead of true top dead center as specified in the applicable manufacturer's instruction, usually using the timing marks on the engine. With the engine set at a prescribed number of degrees ahead of true top dead center on the compression stroke and with final movement of the engine stopped in the direction of normal rotation, the magneto can be installed on the engine. *[Figure 4-53]*

While holding the magneto drive in the firing position for the No. 1 cylinder as indicated by the alignment of the reference marks for the magneto, install the magneto drive into the engine drive. It should be installed in the middle of its slotted flange to allow for fine timing of the magneto to the engine. Attach a timing light to both magnetos. With the engine still in the firing position, the magnetos should be timed by moving them in the flange slots until the breaker points in the magneto just open. If the slots in the mounting flange of the magneto do not permit sufficient movement to effect breaker point opening for the No. 1 cylinder, move the magneto out of position far enough to permit turning the magneto drive shaft. Then, install the magneto in position again and repeat the previous check for point opening.

Install the magneto attaching nuts on the studs and tighten slightly. The nuts must not be tight enough to prevent the movement of the magneto assembly when the magneto mounting flange is tapped with a mallet. Reconnect the timing light to the magneto and breaker points. With the light and ignition switch turned on, rotate the magneto assembly first in the direction of rotation and then in the opposite direction. This is done to determine that the points just opened. After completing this adjustment, tighten the mounting nuts. Move the propeller one blade opposite the direction of rotation and then, while observing the timing light, move the propeller in the direction of rotation until the prescribed number of degrees ahead of top dead center is reached. Be sure that the lights for both sets of points come on points open, within the prescribed timing position.

Both right and left sets of breaker points should open at the same instant, proper magneto-to-engine timing exists, and all phases of magneto operation are synchronized. Some early engines had what was referred to as staggered timing where one magneto would fire at a different number of degrees before top dead center on the compression stroke. In this case, each magneto had to be timed separately. If staggered ignition timing is used, the spark plug nearest the exhaust valve will fire first.

In the following example, a timing light is used for timing the magneto to the engine. The timing light is designed in such a way that one of two lights come on when the points open. The timing light incorporates two lights. When connecting the timing light to the magneto, the leads should be connected so that the light on the right side of the box represents the breaker points on the right magneto, and the light on the left side represents the left magneto breaker points. The black lead or ground lead must be attached to the engine or an effective ground. When using the timing light to check a magneto in a complete ignition system installed on the aircraft, the ignition switch for the engine must be turned to both. Otherwise, the lights do not indicate breaker point opening.

Performing Ignition System Checks

The ignition system has checks performed on it during the aircraft engine run-up, which is the engine check before each flight. The magneto check, as it is usually referred to, is performed during the engine run-up check list.

One other check is accomplished prior to engine shutdown. The ignition system check is used to check the individual magnetos, harnesses, and spark plugs. After reaching the engine rpm specified for the ignition system check, allow the rpm to stabilize. Place the ignition switch in the right position and note the rpm drop on the tachometer. Return the switch to the both position. Allow the switch to remain in the both position for a few seconds so that the rpm stabilizes again. Place the ignition switch in the left position and again note the rpm drop. Return the ignition switch to the both position. Note the amount of total rpm drop that occurs for each magneto position. The magneto drop should be even for both magnetos and is generally in the area of a 25–75 rpm drop for each magneto. Always refer to the aircraft operating manual for specific information. This rpm drop is because operating on one magneto combustion is not as efficient as it is with two magnetos providing sparks in the cylinder.

Remember, this tests not only the magnetos but also the ignition leads and spark plugs. If either magneto has excessive rpm drop while operating by itself, the ignition system needs to be checked for problems. If only one magneto has a high magneto drop, the problem can be isolated and corrected by operating on that magneto. This ignition system check is usually performed at the beginning of the engine run-up because rpm drops not within the prescribed limits affect later checks.

Ignition Switch Check

The ignition switch check is performed to see that all magneto ground leads are electrically grounded. The ignition switch check is usually made at 700 rpm. On those aircraft engine installations that do not idle at this low rpm, set the engine speed to the lowest possible to perform this check. When the speed to perform this check is obtained, momentarily turn the ignition switch to the off position. The engine should completely quit firing. After a drop of 200–300 rpm is observed, return the switch to the both position as rapidly as possible. Do this quickly to eliminate the possibility of afterfire and backfire when the ignition switch is returned to both.

If the ignition switch is not returned quickly enough, the engine rpm drops off completely and the engine stops. In this case, leave the ignition switch in the off position and place the mixture control in the idle-cutoff position to avoid overloading the cylinders and exhaust system with raw fuel. When the engine has completely stopped, allow it to remain inoperative for a short time before restarting.

If the engine does not cease firing in the off position, the magneto ground lead, more commonly referred to as the P lead, is open, and the trouble must be corrected. This means that one or more of the magnetos are not being shut off even when the ignition switch is in the off position. Turning the propeller of this engine can result in personnel injury or death. If the propeller is turned in this condition, the engine can start with personnel in the propeller arch.

Maintenance & Inspection of Ignition Leads

Inspection of ignition leads should include both a visual and an electrical test. During the visual test, the lead cover should be inspected for cracks or other damage, abrasions, mutilated braid, or other physical damage. Inspect leads for overheating if routed close to exhaust stacks. Disconnect the harness coupling nuts from the top of the spark plugs and remove the leads from the spark plug lead well. Inspect the contact springs and compression springs for any damage or distortion and the sleeves for cracks or carbon tracking. The coupling nut that connects to the spark plug should be inspected for damaged threads or other defects.

Each lead should be checked for continuity using a high-tension lead tester by connecting the black lead to the contact spring and the red lead to the eyelet of the same lead in the cover. The continuity lamp on the tester should illuminate when tested. The insulation resistance test of each lead is accomplished using the high-tension lead tester by attaching the red, or high-voltage, lead to the spring of the harness lead. Then, attach the black lead to the ferrule of the same lead. Depress the press-to-test push button switch on the lead tester. Observe that the indictor lamp flashes and gap fires simultaneously as long as the press-to-test switch is held in the depressed position.

If the indicator lamp flashes and the gap fails to fire, the lead under test is defective and must be replaced. The indicator lamp flashes to show that a high-voltage impulse was sent out. If it fails to pass through the tester, then the electrical pulse leaked through the wire showing it to be defective.

When defective leads are revealed by an ignition harness test, continue the test to determine whether the leads or distributor block are defective. If the difficulty is in an individual ignition lead, determine whether the electrical leak is at the spark plug elbow or elsewhere. Remove the elbow, pull the ignition lead out of the manifold a slight amount, and repeat the harness test on the defective lead. If this stops the leakage, cut away the defective portion of the lead and reinstall the elbow assembly, integral seal, and terminal (sometimes referred to as cigarette). *[Figure 4-54]* When installing the leads, you should avoid bends because weak points may develop in the insulation through which high-tension current can leak.

If the lead is too short to repair in the manner described, or the electrical leak is inside the harness, replace the defective lead. Single ignition lead replacement procedures are as follows:

1. Disassemble the magneto or distributor so that the distributor block is accessible.
2. Loosen the piercing screw in the distributor block for the lead to be replaced, and remove the lead from the distributor block.
3. Remove approximately 1 inch of insulation from the distributor block end of the defective lead and approximately 1 inch of insulation from the end of the replacement cable. Splice this end to the end of the lead to be replaced and solder the splice.
4. Remove the elbow adapter from the spark plug end of the defective lead, then pull the old lead out and put the new lead into the harness. While pulling the leads through the harness, have someone push the replacement lead into the ignition manifold at the distributor end to reduce the force required to pull the lead through the ignition manifold.
5. When the replacement lead has been pulled completely through the manifold, force the ignition lead up into the manifold from the distributor block end to provide extra length for future repairs, which may be necessary because of chafing at the spark plug elbow.
6. Remove approximately ⅜ inch of insulation from the distributor block end. Bend the ends of the wire back and prepare the ends of the cable for installation into the distributor block well. Insert the lead in the distributor and tighten the piercing screw.
7. Remove approximately ¼ inch of insulation from the spark plug end of the lead and install the elbow, integral seal, and cigarette. *[Figure 4-54]*
8. Install a marker on the distributor end of the cable to identify its cylinder number. If a new marker is not available, use the marker removed from the defective cable.

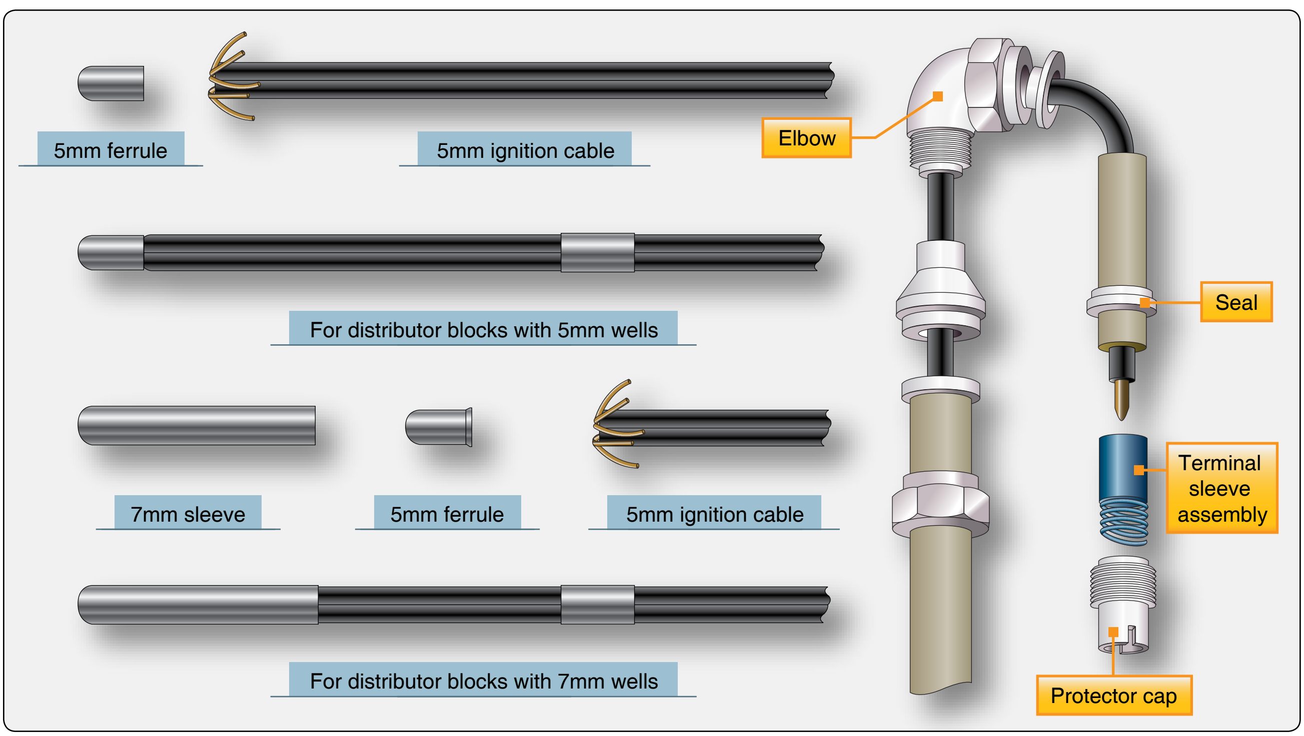


Figure 4-54. *Replacement procedure for ignition lead terminals.*

Replacement of Ignition Harness

Replace a complete ignition harness only when the shielding of the manifold is damaged or when the number of defective leads makes it more practical to replace the harness than to replace the individual leads. Replace a cast-filled harness only when leakage in the cast-filled portion is indicated. Before replacing any harness to correct engine malfunctioning, make extensive ignition harness tests. Typical procedures for installing an ignition harness are detailed in the following paragraphs.

Install the ignition harness on the engine. Tighten and safety the hold down nuts and bolts and install and tighten the individual lead brackets according to instructions. The ignition harness is then ready for connection of the individual leads to the distributor block. A band is attached to each lead at the distributor end of the harness to identify the cylinder for the lead. However, each lead should be checked individually with a continuity or timing light prior to connecting it.

Check for continuity by grounding the lead at the cylinder and then checking at the distributor block end to establish that the lead grounded is as designated on the band for the lead. After checking all leads for proper identification, cut them to the proper length for installation into the distributor block. Before cutting the leads, however, force them back into the manifold as far as possible to provide surplus wire in the ignition manifold. This extra wire may be needed at a later date in the event that chafing of a lead at the spark plug elbow necessitates cutting a short section of wire from the spark plug end of the harness. After cutting each lead to length, remove approximately ⅜ inch of insulation from the end and prepare the lead for insertion into the distributor block. Before installing the lead, back out the set screw in the distributor block far enough to permit slipping the end of the wire into the hole without force. Insert the lead into the block and tighten the set screw. Connect the wires in firing order (the first cylinder to fire No. 1 location on the block, the second in the firing order to No. 2 location, etc).

After connecting each lead, check continuity between the lead and its distributor block electrode with continuity light or timing light. To perform one test lead, touch the other test lead to the proper distributor block electrode. If the light does not indicate a complete circuit, the set screw is not making contact with the ignition wire or the lead is connected to the wrong block location. Correct any faulty connections before installing the distributor block.

Checking Ignition Induction Vibrator Systems

To check the induction vibrator, ensure that the manual mixture control is in idle cutoff, the fuel shutoff valve and booster pump for that engine are in the off position, and the battery switch is on. Since the induction vibrator buzzes whether the ignition switch is on or off, leave the switch off during the check. If the engine is equipped with an inertia or combination starter, make the check by closing the engage mesh switch; if the engine is equipped with a direct-cranking starter, see that the propeller is clear and close the start switch. An assistant stationed close to the induction vibrator should listen for an audible buzzing sound. If the unit buzzes when the starter is engaged or cranked, the induction vibrator is operating properly.

Spark Plug Inspection & Maintenance

Spark plug operation can often be a major source of engine malfunctions because of lead, oil, graphite, carbon fouling, and spark plug gap erosion. Most of these failures, which usually accompany normal spark plug operation, can be minimized by good operational and maintenance practices. A spark plug is considered fouled if it has stopped allowing the spark to bridge the gap either completely or intermittently.

Carbon Fouling of Spark Plugs

Carbon fouling from fuel is associated with mixtures that are too rich to burn or mixtures that are so lean they cause intermittent firing. *[Figure 4-55]* Each time a spark plug does not fire, raw fuel and oil collect on the nonfiring electrodes and nose insulator. These difficulties are almost invariably associated with an improper idle mixture adjustment, a leaking primer, or carburetor malfunctions that cause too rich a mixture in the idle range. A rich air-fuel mixture is detected by soot or black smoke coming from the exhaust and by an increase in rpm when the idling air-fuel mixture is leaned to best power. The soot that forms as a result of overly rich idle air-fuel mixtures settles on the inside of the combustion chamber because the heat of the engine and the turbulence

Figure 4-55. *Carbon fouled spark plug.*

in the combustion chamber are slight. At higher engine speeds and powers, however, the soot is swept out and does not condense out of the charge in the combustion chamber.

Oil Fouling of Spark Plugs

Even though the idling air-fuel mixture is correct, there is a tendency for oil to be drawn into the cylinder past the piston rings, valve guides, and impeller shaft oil seal rings. At low engine speeds, the oil combines with the soot in the cylinder to form a solid that is capable of shorting out the spark plug. Spark plugs that are wet or covered with lubricating oil are usually grounded out during the engine start. In some cases, these plugs may clear up and operate properly after a short period of engine operation.

Engine oil that has been in service for any length of time holds in suspension minute carbon particles that are capable of conducting an electric current. Thus, a spark plug will not arc the gap between the electrodes when the plug is full of oil. Instead, the high-voltage impulse flows through the oil from one electrode to the other without a spark as though a wire conductor were placed between the two electrodes. Combustion in the affected cylinder does not occur until, at a higher rpm, increased airflow has carried away the excess oil. Then, when intermittent firing starts, combustion assists in emitting the remaining oil. In a few seconds, the engine is running clean with white fumes of evaporating and burning oil coming from the exhaust.

Lead Fouling of Spark Plugs

Lead fouling of aviation spark plugs is a condition likely to occur in any engine using leaded fuels. Lead is added to aviation fuel to improve its anti-knock qualities. The lead, however, has the undesirable effect of forming lead oxide during combustion. This lead oxide forms as a solid with varying degrees of hardness and consistency. Lead deposits on combustion chamber surfaces are good electrical conductors at high temperatures and cause misfiring. At low temperatures, the same deposits may be good insulators. In either case, lead formations on aircraft spark plugs prevent their normal operation. *[Figure 4-56]* To minimize the formation of lead deposits, ethylene dibromide is added to the fuel as a scavenging agent that combines with the lead during combustion.

Lead fouling may occur at any power setting, but perhaps the power setting most conducive to lead fouling is cruising with lean mixtures. At this power, the cylinder head temperature is relatively low and there is more oxygen than needed to consume all the fuel in the air-fuel mixture. Oxygen, when hot, is very active and aggressive. When all the fuel has been consumed, some of the excess oxygen unites with some of the lead and some of the scavenger agent to form oxygen compounds of lead or bromine or both. Some of these undesirable lead compounds solidify and build up in layers as they contact the relatively cool cylinder walls and spark plugs. Although lead fouling may occur at any power setting, experience indicates that the lead buildup is generally confined to a specific combustion temperature range. Combustion temperatures outside this specific range minimize the lead fouling tendency.

Figure 4-56. *Lead fouled spark plug.*

If lead fouling is detected before the spark plugs become completely fouled, the lead can usually be eliminated or reduced by either a sharp rise or a sharp decrease in combustion temperature. This imposes a thermal shock on cylinder parts, causing them to expand or contract. Since there is a different rate of expansion between deposits and metal parts on which they form, the deposits chip off or are loosened and then scavenged from the combustion chamber by the exhaust or are burned in the combustion process.

Several methods of producing thermal shock to cylinder parts are used. The method used depends on the accessory equipment installed on the engine. A sharp rise in combustion temperatures can be obtained on all engines by operating them at full takeoff power for approximately 1 minute. When using this method to eliminate fouling, the propeller control must be placed in low pitch, or high rpm, and the throttle advanced slowly to produce takeoff rpm and manifold pressure. Slow movement of the throttle control provides reasonable freedom from backfiring in the affected cylinders during the application of power.

Another method of producing thermal shock is the use of excessively rich air-fuel mixtures. This method suddenly cools the combustion chamber because the excess fuel does not contribute to combustion; instead, it absorbs heat from the combustion area. Some carburetor installations use two-position manual mixture controls that provide a lean mixture setting for cruising economy and a richer mixture setting for all powers above cruising. Neither manual mixture control setting in this type of configuration is capable of producing an excessively rich air-fuel mixture. Even when the engine is operated in auto-rich at powers where an auto-lean setting would be entirely satisfactory, the mixture is not rich enough.

Graphite Fouling of Spark Plugs

As a result of careless and excessive application of thread lubricant, called antiseize compound, to the spark plug, the lubricant flows over the electrodes and causes shorting. Shorting occurs because graphite is a good electrical conductor. The elimination of service difficulties caused by graphite is up to the aircraft technician. Use care when applying the lubricant to make certain that smeared fingers, shop towels, or brushes do not contact the electrodes or any part of the ignition system except the spark plug threads. Never apply to the first set of threads.

Gap Erosion of Spark Plugs

Erosion of the electrodes takes place in all aircraft spark plugs as the spark jumps the air gap between the electrodes. *[Figure 4-57]*

The spark carries with it a portion of the electrode, part of which is deposited on the other electrode. The remainder is blown off in the combustion chamber. As the airgap is enlarged by erosion, the resistance that the spark must overcome in jumping the air gap also increases. This means that the magneto must produce a higher voltage to overcome the higher resistance. With higher voltages in the ignition system, a greater tendency exists for the spark to discharge at some weak insulation point in the ignition system. Since the resistance of an air gap also increases as the pressure in the engine cylinder increases, a double danger exists at takeoff and during sudden acceleration with enlarged airgaps. Insulation breakdown, premature flashover, and carbon tracking result in misfiring of the spark plug and go hand in hand with excessive spark plug gap. Wide gap settings also raise the coming in speed of a magneto and therefore cause hard starting.

Figure 4-57. *Spark plug gap erosion.*

Spark plug manufacturers have partially overcome the problem of gap erosion by using a hermetically sealed resistor in the center electrode of spark plugs. This added resistance in the high-tension circuit reduces the peak current at the instant of firing. This reduced current flow helps prevent metal disintegration in the electrodes. Also, due to the high erosion rate of steel or any of its known alloys, spark plug manufacturers are using tungsten or an alloy of nickel for their massive electrode plugs and iridium/platinum plating for their fine wire electrode plugs.

Spark Plug Removal

Spark plugs should be removed for inspection and servicing at the intervals recommended by the manufacturer. Since the rate of gap erosion varies with different operating conditions, engine models, and type of spark plug, engine malfunction traceable to faulty spark plugs may occur before the regular servicing interval is reached. Normally, in such cases, only the faulty plugs are replaced.

Since spark plugs can be easily damaged, careful handling of the used and replacement plugs during installation and removal of spark plugs from an engine cannot be overemphasized. To prevent damage, spark plugs should always be handled individually and new and reconditioned plugs should be stored in separate cartons. A common method of storage is illustrated in *Figure 4-58*. This is a drilled tray, which prevents the plugs from bumping against one another and damaging the fragile insulators and threads. Additionally, the tray helps identify where the spark plug came from and its proper rotation. If a plug is dropped on the floor or other hard surface, it should not be installed in an engine, since the shock of impact usually causes small, invisible cracks in the insulators. A dropped spark plug should be discarded.

Before a spark plug can be removed, the ignition harness lead must be disconnected. Using the special spark plug coupling elbow wrench, loosen and remove the spark plug to elbow coupling nut from the spark plug. Take care to pull the lead

Figure 4-58. *Spark plug tray.*

straight out and in line with the centerline of the plug barrel. If a side load is applied, damage to the barrel insulator and the ceramic lead terminal may result. *[Figure 4-59]* If the lead cannot be removed easily in this manner, the neoprene collar may be stuck to the shielding barrel. Break loose the neoprene collar by twisting the collar as though it were a nut being unscrewed from a bolt.

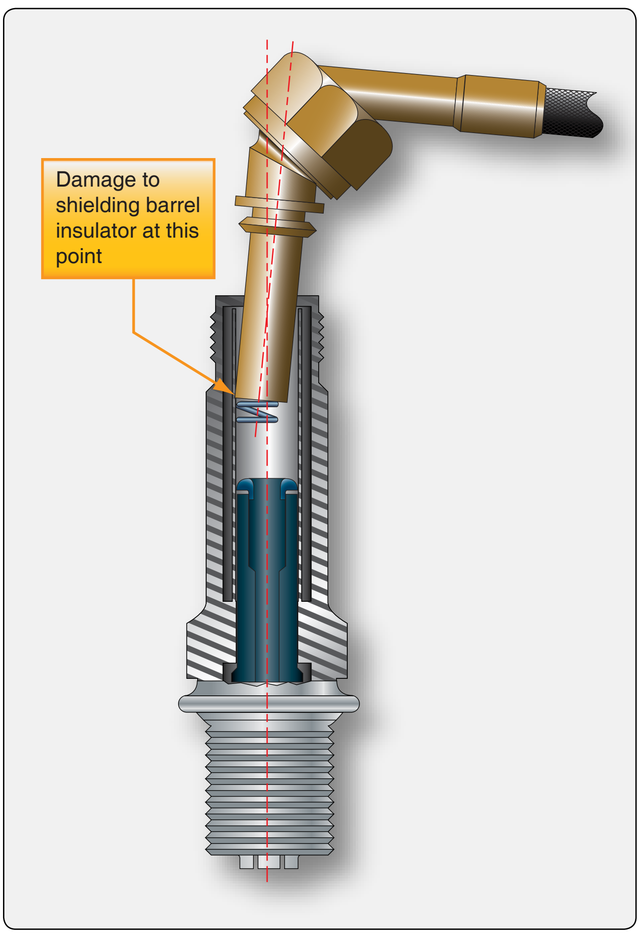


Figure 4-59. *Improper lead removal technique.*

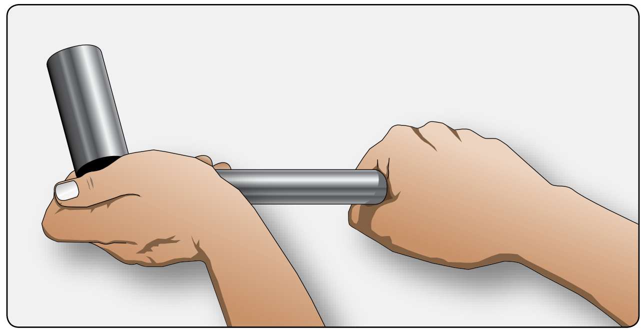


Figure 4-60. *Proper spark plug removal technique.*

After the lead has been disconnected, select the proper size deep socket for spark plug removal. Apply steady pressure with one hand on the hinge handle, holding the socket in alignment with the other hand. Failure to hold the socket in correct alignment causes the socket to tilt to one side and damage the spark plug. *[Figure 4-60]*

In the course of engine operation, carbon and other products of combustion are deposited across the spark plug and cylinder, and some carbon may even penetrate the lower threads of the shell. As a result, a high torque is generally required to break the spark plug loose. This factor imposes a shearing load on the shell section of the plug. After removing the plugs, they should be placed in a spark plug tray. *[Figure 4-58]*

Spark Plug Reconditioning Service

A visual inspection should be the first step in servicing spark plugs. The threads on the shielding barrel and on the shell that screws into the cylinder should be inspected for damaged or nicked threads. Inspect the lead shielding barrel for corrosion, nicks, and cracks. The firing end should be checked for insulator cracks, chips, and excessive electrode wear. The shell hex or wrench hex should be checked to see if it is rounded off or mutilated. If the spark plug passes the visual check, then it should be degreased using petroleum solvent. Take care to keep solvent out of the shielding barrel.

Never soak the plugs in solvent. After drying the firing end of the plugs, remove the lead compound deposits using a vibrator cleaner. *[Figure 4-61]* The firing end can now be cleaned by using an abrasive blaster. This is usually done using a spark plug cleaner tester. *[Figure 4-62]* As the firing end is subjected to the abrasive blast, the plug should be rotated so all the area of the firing end is cleaned. After the abrasive blast, the firing end gets a thorough air blast to remove the abrasive material. The shielding barrel insulators may be cleaned with a cotton cloth or felt swab saturated with solvent, wood alcohol, or other approved cleaner. The firing end should be inspected using a light and a magnifying glass. If the plug passes the firing end visual and cleaning checks, then the spark gap should be set using a round thickness

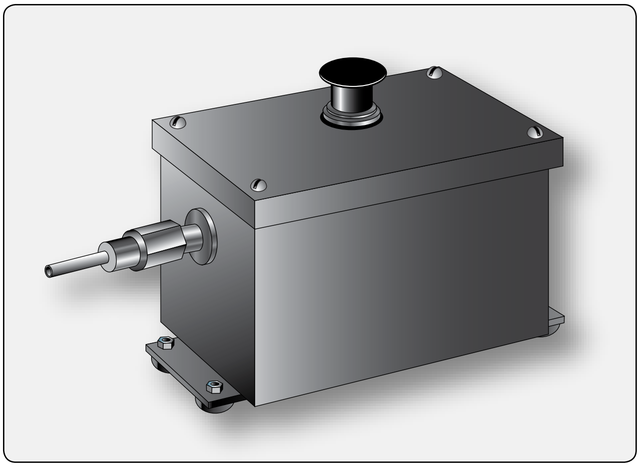


Figure 4-61. *Spark plug vibrator cleaner.*

Figure 4-62. *Spark plug cleaner tester.*

gauge. The spark plug should be tested by using a tester as shown in *Figure 4-62*, which passes a high-voltage through the spark plug and fire the gap. As this test takes place, the firing end of the plug is subjected to air pressure to simulate the pressure in the engine's cylinder. If the firing pattern is good, the plug should be returned to its holder ready for installation in the engine.

Inspection Prior to Installation

Before installing new or reconditioned spark plugs in the engine cylinders, clean the spark plug bushings or Heli-Coil inserts.

Brass or stainless steel spark plug bushings are usually cleaned with a spark plug bushing cleanout tap. Before inserting the cleanout tap in the spark plug hole, fill the flutes of the tap, or channels between threads, with clean grease to prevent hard carbon or other material removed by the tap from dropping into the inside of the cylinder. Align the tap with the bushing threads by sight where possible, and start the tap by hand until there is no possibility of it being cross-threaded in the bushing. To start the tap on installations where the spark plug hole is located deeper than can be reached by a clenched hand, it may be necessary to use a short length of hose slipped over the square end of the tap to act as an extension. When screwing the tap into the bushing, be sure that the full tap cutting thread reaches the bottom thread of the bushing. This removes carbon deposits from the bushing threads without removing bushing metal, unless the pitch diameter of the threads has contracted as the result of shrinkage or some other unusual condition. Replace the cylinder if, during the thread-cleaning process, the bushing is found to be loose, loosened in the cylinder, or the threads are cross-threaded or otherwise seriously damaged.

Spark plug Heli-Coil inserts are cleaned with a round wire brush, preferably one having a diameter slightly larger than the diameter of the spark plug hole. A brush considerably larger than the hole may cause removal of material from the Heli-Coil proper or from the cylinder head surrounding the insert. Also, the brush should not disintegrate with use, allowing wire bristles to fall into the cylinder. Clean the insert by carefully rotating the wire brush with a power tool. When using the power brush, be careful that no material is removed from the spark plug gasket seating surface, since this may cause a change in the spark plug's heat range, combustion leakage, and eventual cylinder damage. Never clean the Heli-Coil inserts with a cleaning tap, since permanent damage to the insert results. If a Heli-Coil insert is damaged as a result of normal operation or while cleaning it, replace it according to the applicable manufacturer's instructions.

Using a lint-free rag and cleaning solvent, wipe the spark plug gasket seating surface of the cylinder to eliminate the possibility of dirt or grease being accidentally deposited on the spark plug electrodes at the time of installation.

Before the new or reconditioned plugs are installed, they must be inspected for each of the following conditions:

1. Ensure that the plug is of the approved type, as indicated by the applicable manufacturer's instructions.
2. Check for evidence of rust-preventive compound on the spark plug exterior and core insulator and on the inside of the shielding barrel. Rust-preventive compound accumulations are removed by washing the plug with a brush and cleaning solvent. It must then be dried with a dry air blast.
3. Check both ends of the plug for nicked or cracked threads and any indication of cracks in the nose insulator.

4. Inspect the inside of the shielding barrel for cracks in the barrel insulator, and the center electrode contact for rust and foreign material that might cause poor electrical contact.
5. Install a new spark plug gasket. When the thermocouple gasket is used, do not use an additional gasket.

The gap setting should be checked with a round wire-thickness gauge. *[Figure 4-63]* A flat-type gauge gives an incorrect clearance indication because the massive ground electrodes are contoured to the shape of the round center electrode. When using the wire thickness gauge, insert the gauge in each gap parallel to the centerline of the center electrode. If the gauge is tilted slightly, the indication is incorrect. Do not install a plug that does not have an air gap within the specified clearance range.

Spark Plug Installation

Prior to spark plug installation, carefully coat the first two or three threads from the electrode end of the shell with a graphite base antiseize compound. Prior to application, stir the antiseize compound to ensure thorough mixing. When applying the antiseize compound to the threads, be extremely careful that none of the compound gets on the ground, center electrodes, or on the nose of the plug, where it can spread to the ground or center electrode during installation. This precaution is mentioned because the graphite in the compound is an excellent electrical conductor and could cause permanent fouling.

To install a spark plug, start it into the cylinder without using a wrench of any kind, and turn it until the spark plug is seated on the gasket. If you can screw the plug into the cylinder with comparative ease using your fingers, this indicates good, clean threads. In this case, only a small amount of additional tightening torque is needed to compress the gasket to form a gastight seal. If a high torque is needed to install the plug, dirty or damaged threads on either the plug or plug bushing are indicated. The use of excessive torque might compress the gasket out of shape and distort and stretch the plug shell to a point where breakage would result during the next removal or installation. Shell stretching occurs as excessive torque continues to screw the lower end of the shell into the cylinder after the upper end has been stopped by the gasket shoulder. As the shell stretches, the seal between the shell and core insulator is opened, creating a loss of gas tightness or damage to the core insulator. After a spark plug has been seated with the fingers, use a torque wrench and tighten to the specified torque. *[Figure 4-64]*

Figure 4-63. *Wire gap gauge.*

Spark Plug Lead Installation

Before installing the spark plug lead, carefully wipe the terminal sleeve and the integral seal with a cloth moistened with acetone or an approved solvent. After the plug lead is cleaned, inspect it for cracks and scratches. If the terminal sleeve is damaged or heavily stained, replace it.

Application of a light coating of an insulating material to the outer surface of the terminal sleeve, as well as filling the space occupied by the contact spring, is sometimes recommended. By occupying the space in the electrical contact area of the shielding barrel, the insulating material prevents moisture from entering the contact area and shorting the spark plug.

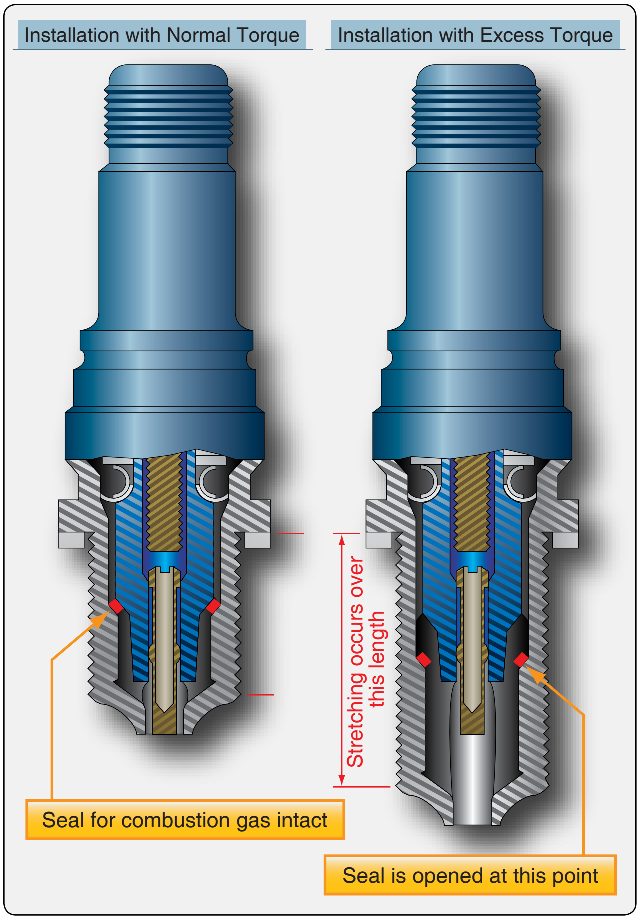


Figure 4-64. *Effect of excessive torque in installing a spark plug.*

Some manufacturers recommend the use of such insulating compounds only when moisture in the ignition system becomes a problem, and others have discontinued the use of such materials.

After inspection of the spark plug lead, slip the lead into the shielding barrel of the plug with care. Then, tighten the spark plug coupling elbow nut with the proper tool. Most manufacturers' instructions specify the use of a tool designed to help prevent an overtorque condition. After the coupling nut is tightened, avoid checking for tightness by twisting the body of the elbow.

After all plugs have been installed, torqued, and the leads properly installed, start the engine and perform a complete ignition system operational check.

Breaker Point Inspection

Inspection of the magneto consists essentially of a periodic breaker point and dielectric inspection. After the magneto has been inspected for security of mounting, remove the magneto cover, or breaker cover, and check the cam for proper lubrication. Under normal conditions, there is usually ample oil in the felt oiler pad of the cam follower to keep the cam lubricated between overhaul periods. However, during the regular routine inspection, examine the felt pad on the cam follower to be sure it contains sufficient oil for cam lubrication. Make this check by pressing the thumbnail against the oiler pad. If oil appears on the thumbnail, the pad contains sufficient oil for cam lubrication. If there is no evidence of oil on the fingernail, apply one drop of a light aircraft engine oil to the bottom felt pad and one drop to the upper felt pad of the follower assembly. *[Figure 4-65]*

After application, allow at least 15 minutes for the felt to absorb the oil. At the end of 15 minutes, blot off any excess oil with a clean, lint-free cloth. During this operation, or any time the magneto cover is off, use extreme care to keep the breaker compartment free of oil, grease, or engine cleaning solvents, since each of these have an adhesiveness that collects dirt and grime that could foul an otherwise good set of breaker contact points.

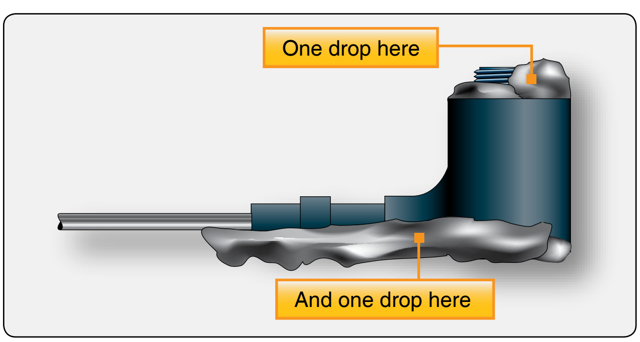


Figure 4-65. *Felt lubricator.*

After the felt oiler pad has been inspected, serviced, and found to be satisfactory, visually inspect the breaker contacts for any condition that may interfere with proper operation of the magneto. If the inspection reveals an oily or gummy substance on the sides of the contacts, swab the contacts with a flexible wiper, such as a pipe cleaner dipped in acetone or other approved solvent. By forming a hook on the end of the wiper, ready access can be gained to the back side of the contacts.

To clean the contact mating surfaces, force open the breaker points enough to admit a small swab. Whether spreading the points for purposes of cleaning or checking the surfaces for condition, always apply the opening force at the outer end of the mainspring and never spread the contacts more than $\frac{1}{16}$ inch. If the contacts are spread wider than recommended, the mainspring, the spring carrying the movable contact point, is likely to take a permanent set. If the mainspring takes a permanent set, the movable contact point loses some of its closing tension and the points then either bounce or float, preventing the normal induction buildup of the magneto.

A swab can be made by wrapping a piece of linen tape or a small piece of lint-free cloth over one of the leaves of a clearance gauge and dipping the swab in an approved solvent. Pass the swab between the carefully separated contact surfaces until the surfaces are clean. During this entire operation, take care that drops of solvent do not fall on lubricated parts, such as the cam, follower block, or felt oiler pad.

To inspect the breaker contact surfaces, it is necessary to know what a normal operating set of contacts looks like, what surface condition is considered as permissible wear, and what surface condition is cause for dressing or replacement. The probable cause of an abnormal surface condition can be determined from the contact appearance. The normal contact surface has a dull gray, sandblasted, almost rough appearance over the area where electrical contact is made. *[Figure 4-66]* This gray, sandblasted appearance indicates that the points have worn in and have mated to each other and are providing the best possible electrical contact. This does not imply that this is the only acceptable contact surface condition. Slight, smooth-surfaced irregularities, without deep pits or high peaks, such as shown in *Figure 4-67*, are considered normal wear and are not cause for replacement.

However, when wear advances to a point where the slight, smooth irregularities develop into well-defined peaks extending noticeably above the surrounding surface, the breaker contacts must be replaced. *[Figure 4-68]*

Unfortunately, when a peak forms on one contact, the mating

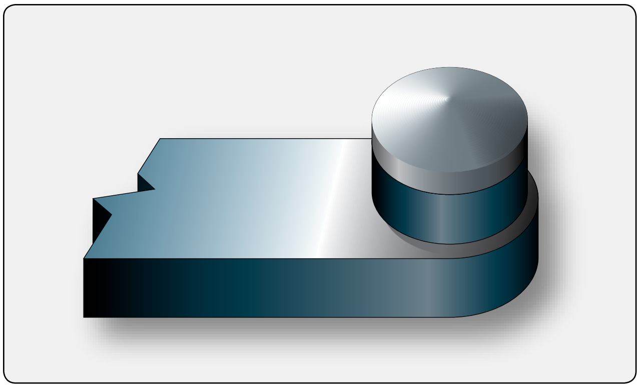


Figure 4-66. *Normal contact surface.*

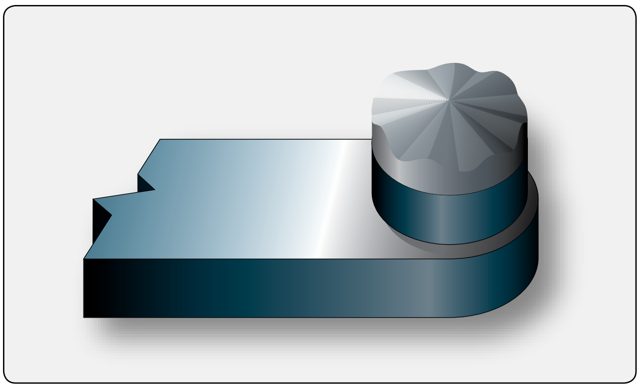


Figure 4-67. *Points with normal irregularities.*

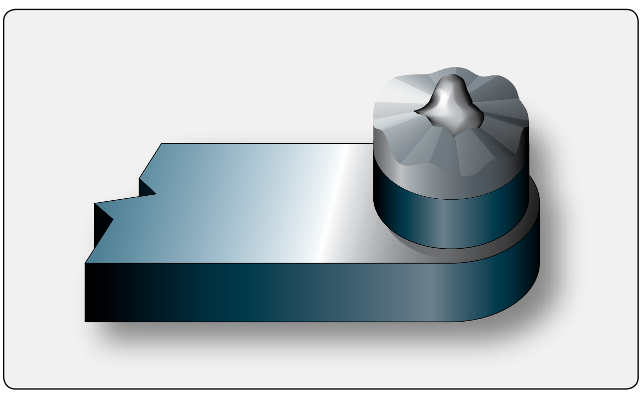


Figure 4-68. *Points with well-defined peaks.*

contact has a corresponding pit or hole. This pit is more troublesome than the peak because it penetrates the platinum pad of the contact surface. It is sometimes difficult to judge whether a contact surface is pitted deeply enough to require replacement because this depends on how much of the original platinum is left on the contact surface. The danger arises from the possibility that the platinum pad may already be thin as a result of long service life and previous dressings. At overhaul facilities, a gauge is used to measure the remaining thickness of the pad, and no difficulty in determining the condition of the pad exists. But at line maintenance activities, this gauge is generally unavailable. Therefore, if the peak is quite high or the pit quite deep, remove and replace them with a new assembly. A comparison between *Figures 4-67* and *4-68* will help to draw the line between minor irregularities and well-defined peaks.

Some examples of possible breaker contact surface conditions are illustrated in *Figure 4-69*. Item A illustrates an example of erosion or wear called frosting. This condition results from an open-circuited condenser and is easily recognized by the coarse, crystalline surface and the black "sooty" appearance of the sides of the points. The lack of effective condenser action results in an arc of intense heat being formed each time the points open. This, together with the oxygen in the air, rapidly oxidizes and erodes the platinum surface of the points, producing the coarse, crystalline, or frosted appearance. Properly operating points have a fine-grained, frosted, or silvery appearance and should not be confused with the coarse-grained and sooty point caused by faulty condenser action.

Figure 4-69B and *C* illustrate badly pitted points. In the early stage, these points are identified by a fairly even contact edge and minute pits or pocks in or near the center of the contact surface with an overall smoky appearance. In more advanced stages, the pit may develop into a large, jagged crater, and eventually the entire contact surface takes on a burned, black, and crumpled appearance. Pitted points, as a general rule, are caused by dirt and impurities on the contact surfaces. If points are excessively pitted, a new breaker assembly must be installed.

Figure 4-69E illustrates a built-up point that can be recognized by the mound of metal that has been transferred from one point to another. Buildup, like the other conditions mentioned, results primarily from the transfer of contact material by means of the arc as the points separate. But, unlike the others, there is no burning or oxidation in the process because of the closeness of the pit of one point and the buildup of the other. This condition may result from excessive breaker point spring tension that retards the opening of the points or causes a slow, lazy break. It can also be caused by a poor primary condenser or a loose connection at the primary coil. If excessive buildup has occurred, a new breaker assembly must be installed.

Figure 4-69F illustrates oily points that can be recognized by their smoked and smudged appearance and by the lack of any of the previously mentioned irregularities. This condition may be the result of excessive cam lubrication or of oil vapors that may come from within or outside the magneto. A smoking or fuming engine, for example, could produce the oil vapors. These vapors then enter the magneto through the magneto ventilator and pass between and around the points. These conductive vapors produce arcing and burning on the

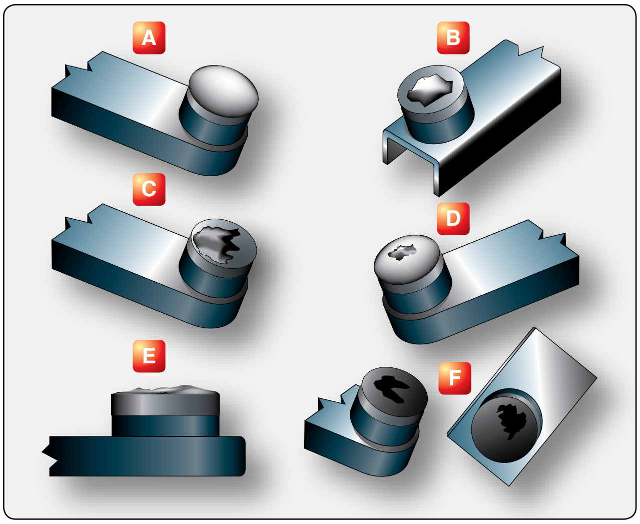


Figure 4-69. *Examples of contact surface conditions.*

contact surfaces. The vapors also adhere to the other surfaces of the breaker assembly and form the sooty deposit. If so, install new breaker assembly.

Dielectric Inspection

Another phase of magneto inspection is the dielectric inspection. This inspection is a visual check for cleanliness and cracks. If inspection reveals that the coil cases, condensers, distributor rotor, or blocks are oily or dirty or have any trace of carbon tracking, they require cleaning and possibly waxing to restore their dielectric qualities.

Clean all accessible condensers and coil cases that contain condensers by wiping them with a lint-free cloth moistened with acetone. Many parts of this type have a protective coating. This protective coating is not affected by acetone, but it may be damaged by scraping or by the use of other cleaning fluids. Never use unapproved cleaning solvents or improper cleaning methods. Also, when cleaning condensers or parts that contain condensers, do not dip, submerge, or saturate the parts in any solution because the solution used may seep inside the condenser and short out the plates.

Coil cases, distributor blocks, distributor rotors, and other dielectric parts of the ignition system are treated with a wax coating when they are new and again at overhaul. The waxing of dielectrics aids their resistance to moisture absorption, carbon tracking, and acid deposits. When these parts become dirty or oily, some of the original protection is lost, and carbon tracking may result.

If any hairline carbon tracks or acid deposits are present on the surface of the dielectric, immerse the part in approved cleaning solvent and scrub it vigorously with a stiff bristle brush. When the carbon track or acid deposits have been removed, wipe the part with a clean, dry cloth to remove all traces of the solvent used for cleaning. Then, coat the part with a special ignition-treating wax. After wax treating the part, remove excess wax deposits and reinstall the part in the magneto.

Ignition Harness Maintenance

Although the ignition harness is simple, it is a vital link between the magneto and spark plug. Because the harness is mounted on the engine and exposed to the atmosphere, it is vulnerable to heat, moisture, and the effects of changing altitude. These factors, plus aging insulation and normal gap erosion, work against efficient engine operation. The insulation may break down on a wire inside the harness and allow the high-voltage to leak through the insulation to the harness shielding instead of going to the spark plug. Open circuits may result from broken wires or poor connections. A bare wire may be in physical contact with the shielding, or two wires may be shorted together.

Any serious defect in an individual lead prevents the high-tension impulse from reaching the spark plug to which the lead is connected. As a result, this plug will not fire. When only one spark plug is firing in a cylinder, the charge is not consumed as quickly as it would be if both plugs were firing. This factor causes the peak pressure of combustion to occur later on in the power stroke. If the peak pressure in the cylinder occurs later, a loss of power in that cylinder results. However, the power loss from a single cylinder becomes a minor factor when the effects of a longer burning time is considered. A longer burning time overheats the affected cylinder, causing detonation, possible pre-ignition, and perhaps permanent damage to the cylinder.

High-Tension Ignition Harness Faults

Perhaps the most common and most difficult high-tension ignition system faults to detect are high-voltage leaks. This is leakage from the core conductor through insulation to the ground of the shielded manifold. A certain small amount of leakage exists even in brand new ignition cable during normal operation. Various factors combine to produce first a high rate of leakage and then complete breakdown. Of these factors, moisture in any form is probably the worst.

Under high-voltage stress, an arc forms and burns a path across the insulator where the moisture exists. If there is gasoline, oil, or grease present, it breaks down and forms carbon. The burned path is called a carbon track, since it is actually a path of carbon particles. With some types of insulation, it may be possible to remove the carbon track and restore the insulator to its former useful condition. This is generally true of porcelain, ceramics, and some of the plastics because these materials are not hydrocarbons and any carbon track forming on them is the result of a dirt film that can be wiped away.

Differences in location and amount of leakage produce different indications of malfunction during engine operation. Indications are generally misfiring or crossfiring. The indication may be intermittent, changing with manifold pressure or with climate conditions. An increase in manifold pressure increases the compression pressure and the resistance of the air across the air gap of the spark plugs. An increase in the resistance at the air gap opposes the spark discharge and produces a tendency for the spark to discharge at some weak point in the insulation. A weak spot in the harness may be aggravated by moisture collecting in the harness manifold. With moisture present, continued engine operation causes the intermittent faults to become permanent carbon tracks. Thus, the first indication of ignition harness unserviceability may be engine misfiring or roughness caused by partial leakage of the ignition voltage.

Figure 4-70 demonstrates four faults that may occur. Fault A shows a short from one cable conductor to another. This fault usually causes misfiring, since the spark is short circuited to a plug in a cylinder where the cylinder pressure is low. Fault B illustrates a cable with a portion of its insulation scuffed away. Although the insulation is not completely broken down, more than normal leakage exists, and the spark plug to which this cable is connected may be lost during takeoff when the manifold pressure is quite high. Fault C is the result of condensation collecting in the lowest portion of the ignition manifold. This condensation may completely evaporate during engine operation, but the carbon track that is formed by the initial flashover remains to allow continued flashover whenever high manifold pressure exists. Fault D may be caused by a flaw in the insulation or the result of a weak spot in the insulation that is aggravated by the presence of moisture. However, since the carbon track is in direct contact with the metal shielding, it probably results in flashover under all operating conditions.

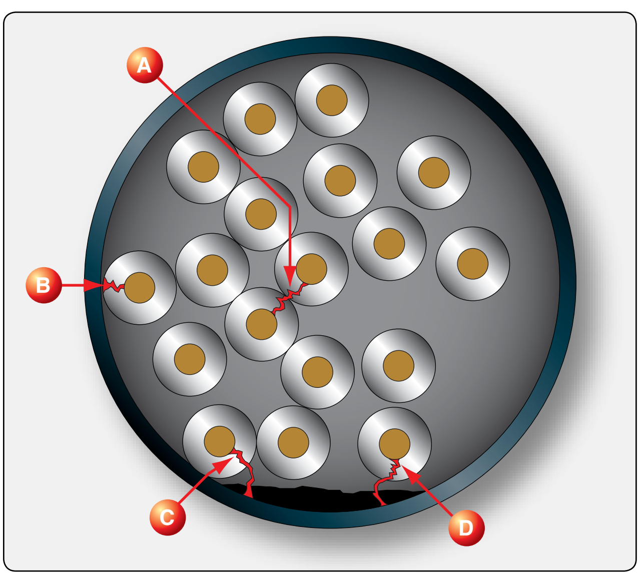


Figure 4-70. *Cross section of an ignition harness.*

Harness Testing

The electrical test of the ignition harness checks the condition or effectiveness of the insulation around each cable in the harness. *[Figure 4-71]* This test involves application of a definite voltage to each lead, and then measurement with a very sensitive meter of the amount of current leakage between the lead and the grounded harness manifold. This reading, when compared with known specifications, becomes a guide to the condition or serviceability of the cable. As mentioned earlier, there is a gradual deterioration of flexible insulating material. When new, the insulation has a low rate of conductivity; so low that, under several thousand volts of electrical pressure, the current leakage is only a very few millionths of an ampere. Natural aging causes an extremely slow, but certain, change in the resistance of insulating material, allowing an ever-increasing rate of current leakage. The procedures for testing ignition harness and leads were discussed earlier in this chapter.

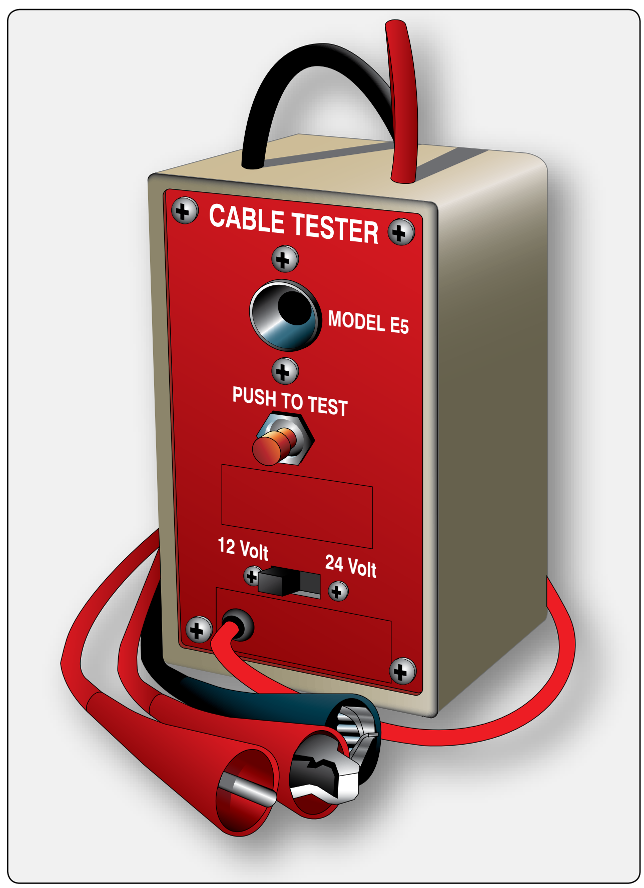


Figure 4-71. *Harness tester.*

Turbine Engine Ignition Systems

Since turbine ignition systems are operated mostly for a brief period during the engine-starting cycle, they are, as a rule, more trouble-free than the typical reciprocating engine ignition system. The turbine engine ignition system does not need to be timed to spark during an exact point in the operational cycle. It is used to ignite the fuel in the combustor and then it is switched off. Other modes of turbine ignition system operation, such as continuous ignition that is used at a lower voltage and energy level, are used for certain flight conditions.

Continuous ignition is used in case the engine were to flame out. This ignition could relight the fuel and keep the engine from stopping. Examples of critical flight modes that use continuous ignition are takeoff, landing, and some abnormal and emergency situations.

Most gas turbine engines are equipped with a high-energy, capacitor-type ignition system and are air cooled by fan airflow. Fan air is ducted to the exciter box, and then flows around the igniter lead and surrounds the igniter before flowing back into the nacelle area. Cooling is important when continuous ignition is used for some extended period of time. Gas turbine engines may be equipped with an electronic-type ignition system, which is a variation of the simpler capacitor-type system.

The typical turbine engine is equipped with a capacitor-type, or capacitor discharge, ignition system consisting of two identical independent ignition units operating from a common low-voltage (DC) electrical power source: the aircraft battery, 115AC, or its permanent magnet generator. The generator is turned directly by the engine through the accessory gear box and produces power any time the engine is turning. The fuel in turbine engines can be ignited readily in ideal atmospheric conditions, but since they often operate in the low temperatures of high altitudes, it is imperative that the system be capable of supplying a high heat intensity spark. Thus, a high-voltage is supplied to arc across a wide igniter spark gap, providing the ignition system with a high degree of reliability under widely varying conditions of altitude, atmospheric pressure, temperature, fuel vaporization, and input voltage.

A typical ignition system includes two exciter units, two transformers, two intermediate ignition leads, and two high-tension leads. Thus, as a safety factor, the ignition system is actually a dual system designed to fire two igniter plugs. *[Figure 4-72]*

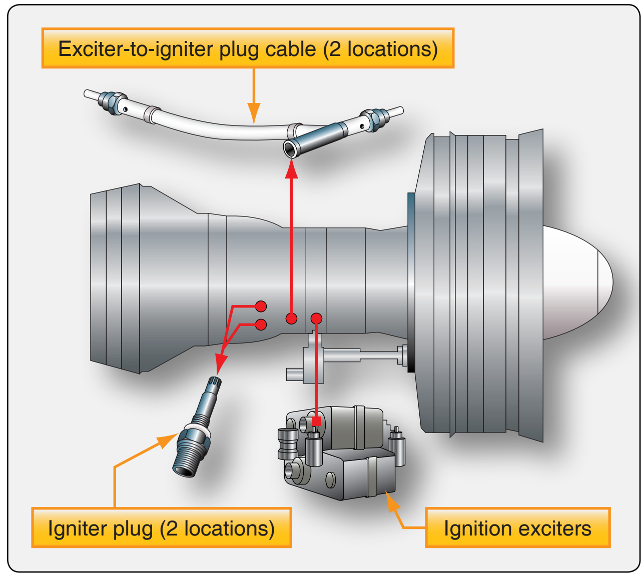


Figure 4-72. *Turbine ignition system components.*

Figure 4-73 is a functional schematic diagram of a typical older style capacitor-type turbine ignition system. A 24-volt DC input voltage is supplied to the input receptacle of the exciter unit. Before the electrical energy reaches the exciter unit, it passes through a filter that prevents noise voltage from being induced into the aircraft electrical system. The low-voltage input power operates a DC motor that drives one multilobe cam and one single-lobe cam. At the same time, input power is supplied to a set of breaker points that are actuated by the multilobe cam.

From the breaker points, a rapidly interrupted current is delivered to an auto transformer. When the breaker closes, the flow of current through the primary winding of the transformer establishes a magnetic field. When the breaker opens, the flow of current stops, and the collapse of the field induces a voltage in the secondary of the transformer. This voltage causes a pulse of current to flow into the storage capacitor through the rectifier, which limits the flow to a single direction. With repeated pulses, the storage capacitor assumes a charge, up to a maximum of approximately 4 joules. (Note: 1 joule per second equals 1 watt.) The storage capacitor is connected to the spark igniter through the triggering transformer and a contactor, normally open.

When the charge on the capacitor has built up, the contactor is closed by the mechanical action of the single-lobe cam. A portion of the charge flows through the primary of the triggering transformer and the capacitor connected with it. This current induces a high-voltage in the secondary, which ionizes the gap at the spark igniter.

When the spark igniter is made conductive, the storage capacitor discharges the remainder of its accumulated energy along with the charge from the capacitor in series with the primary of the triggering transformer. The spark rate at the

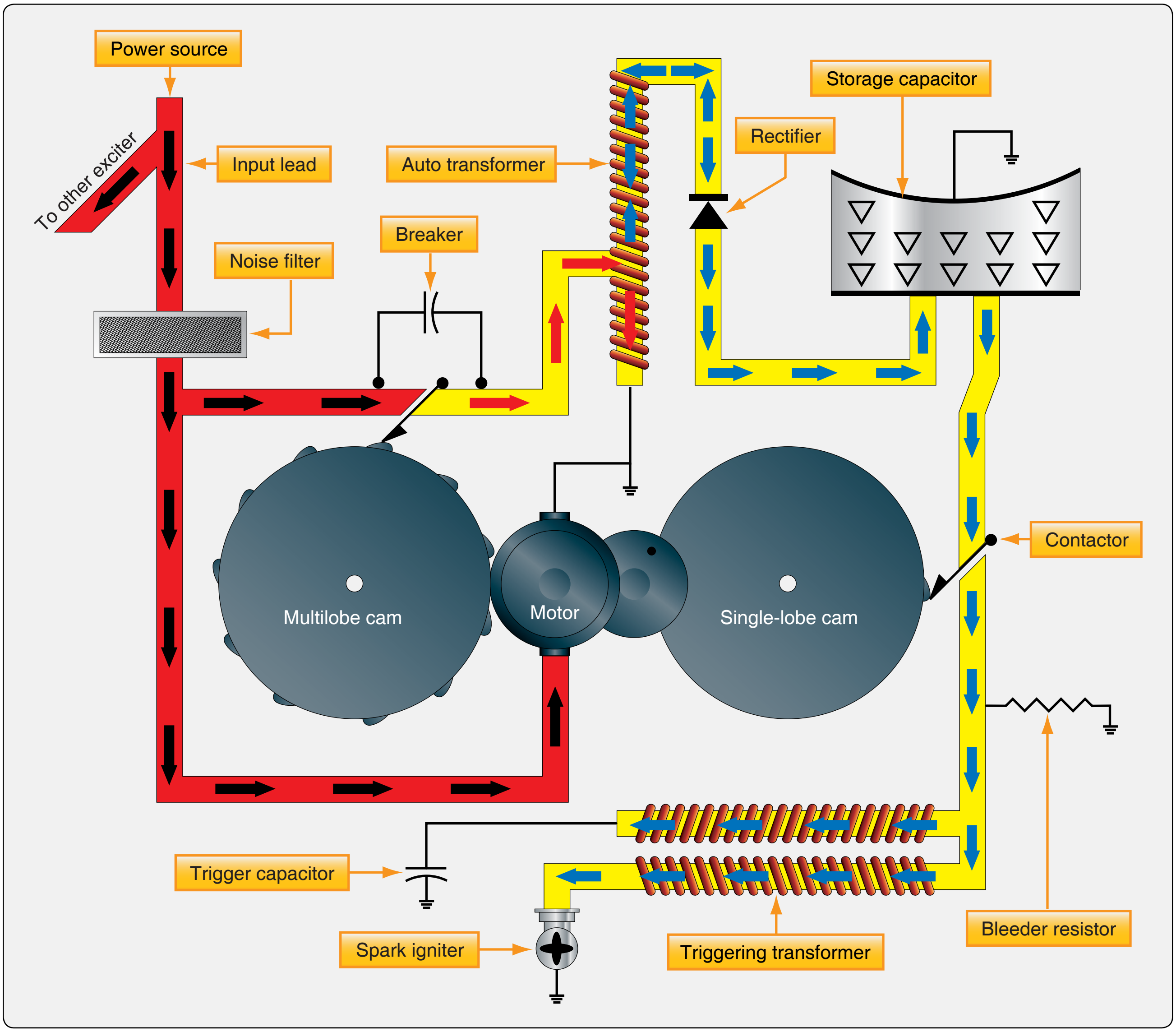


Figure 4-73. *Capacitor-type ignition system schematic.*

spark igniter varies in proportion to the voltage of the DC power supply that affects the rpm of the motor. However, since both cams are geared to the same shaft, the storage capacitor always accumulates its store of energy from the same number of pulses before discharge. The employment of the high-frequency triggering transformer, with a low-reactance secondary winding, holds the time duration of the discharge to a minimum. This concentration of maximum energy in minimum time achieves an optimum spark for ignition purposes, capable of blasting carbon deposits and vaporizing globules of fuel.

All high-voltage in the triggering circuits is completely isolated from the primary circuits. The complete exciter is hermetically sealed, protecting all components from adverse operating conditions, eliminating the possibility of flashover at altitude due to pressure change. This also ensures shielding against leakage of high-frequency voltage interfering with the radio reception of the aircraft.

Capacitor Discharge Exciter Unit

This capacity-type system provides ignition for turbine engines. Like other turbine ignition systems, it is required only for starting the engine; once combustion has begun, the flame is continuous. *[Figure 4-74]*

The energy is stored in capacitors. Each discharge circuit incorporates two storage capacitors; both are located in the exciter unit. The voltage across these capacitors is stepped up by transformer units. At the instant of igniter plug firing, the resistance of the gap is lowered sufficiently to permit the larger capacitor to discharge across the gap. The discharge of the second capacitor is of low-voltage, but of very high

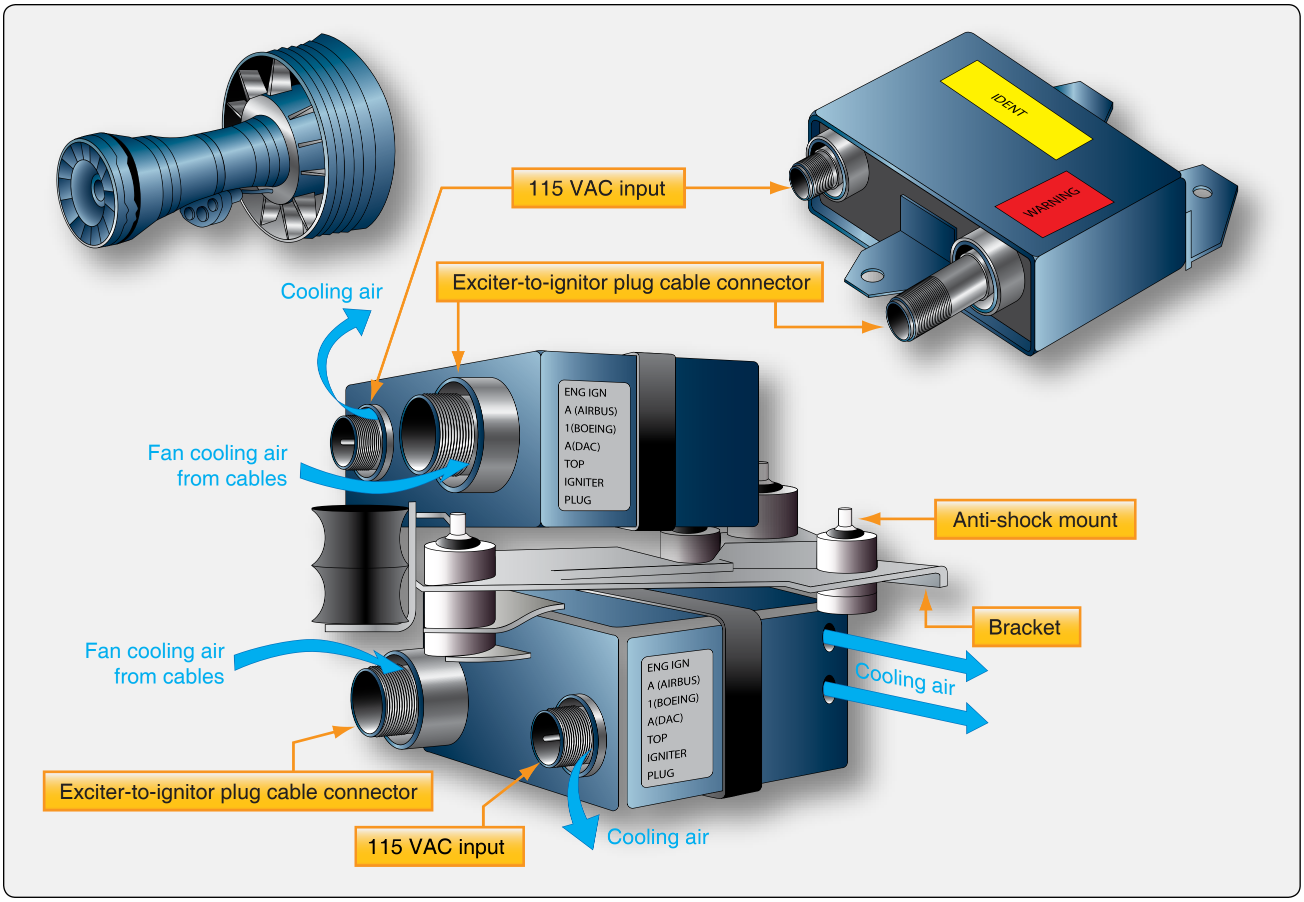


Figure 4-74. *Fan air-cooled exciter.*

energy. The result is a spark of great heat intensity, capable of not only igniting abnormal fuel mixtures but also burning away any foreign deposits on the plug electrodes.

The exciter is a dual unit that produces sparks at each of the two igniter plugs. A continuous series of sparks is produced until the engine starts. The power is then cut off, and the plugs do not fire while the engine is operating other than on continuous ignition for certain flight conditions. This is why the exciters are air cooled to prevent overheating during long use of continuous ignition.

Igniter Plugs

The igniter plug of a turbine engine ignition system differs considerably from the spark plug of a reciprocating engine ignition system. *[Figure 4-75]* Its electrode must be capable of withstanding a current of much higher energy than the electrode of a conventional spark plug. This high energy current can quickly cause electrode erosion, but the short periods of operation minimize this aspect of igniter maintenance. The electrode gap of the typical igniter plug is designed much larger than that of a spark plug since the operating pressures are much lower and the spark can arc more easily than in a spark plug. Finally, electrode fouling, common to the spark plug, is minimized by the heat of the high-intensity spark.

Figure 4-76 is a cutaway illustration of a typical annular-gap igniter plug, sometimes referred to as a long reach igniter because it projects slightly into the combustion chamber liner to produce a more effective spark.

Another type of igniter plug, the constrained-gap plug, is used in some types of turbine engines. *[Figure 4-77]* It operates at a much cooler temperature because it does not project into the combustion-chamber liner. This is possible because the spark does not remain close to the plug, but arcs beyond the face of the combustion chamber liner.

Turbine Ignition System Inspection & Maintenance

Maintenance of the typical turbine engine ignition system consists primarily of inspection, test, troubleshooting, removal, and installation.

Inspection

Inspection of the ignition system normally includes the following:

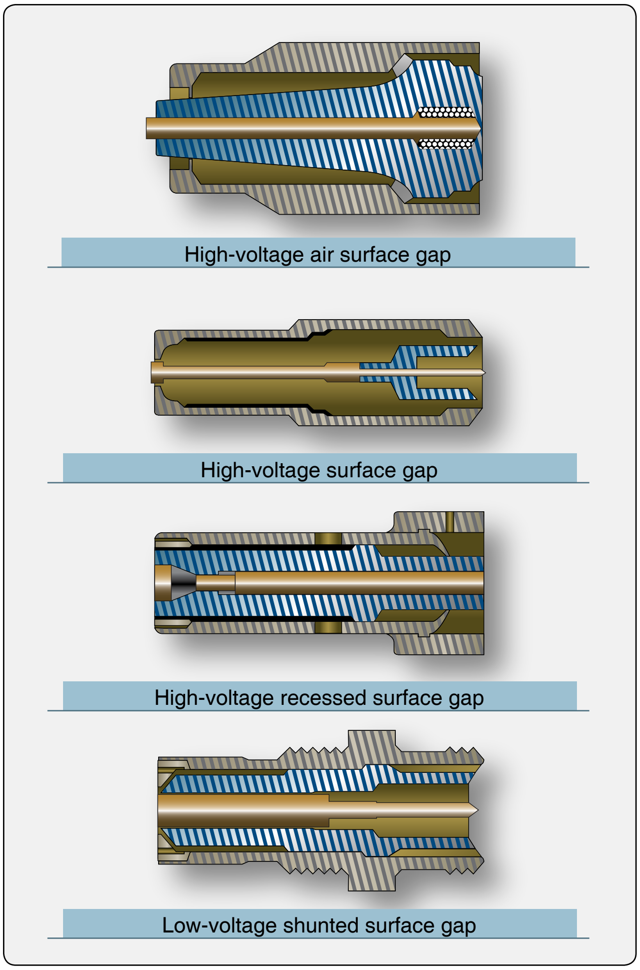


Figure 4-75. *Igniter plugs.*

- Ignition lead terminal inspection; ceramic terminal should be free of arcing, carbon tracking and cracks.
- The grommet seal should be free of flashover and carbon tracking. *[Figure 4-78]*
- The wire insulation should remain flexible with no evidence of arcing through the insulation.
- Inspect the complete system for security of component mounting, shorts or high-voltage arcing, and loose connections.

Check System Operation

The igniter can be checked by listening for a snapping noise as the engine begins to turn, driven by the starter. Though the following procedure is not common practice and should only be used when the maintenance manual suggests it as an alternative method, the igniter can also be checked by removing it and activating the start cycle, noting the spark across the igniter.

Caution: The high energy level and voltage associated with turbine ignition systems can cause injury or death to personnel coming into contact with the activated system.

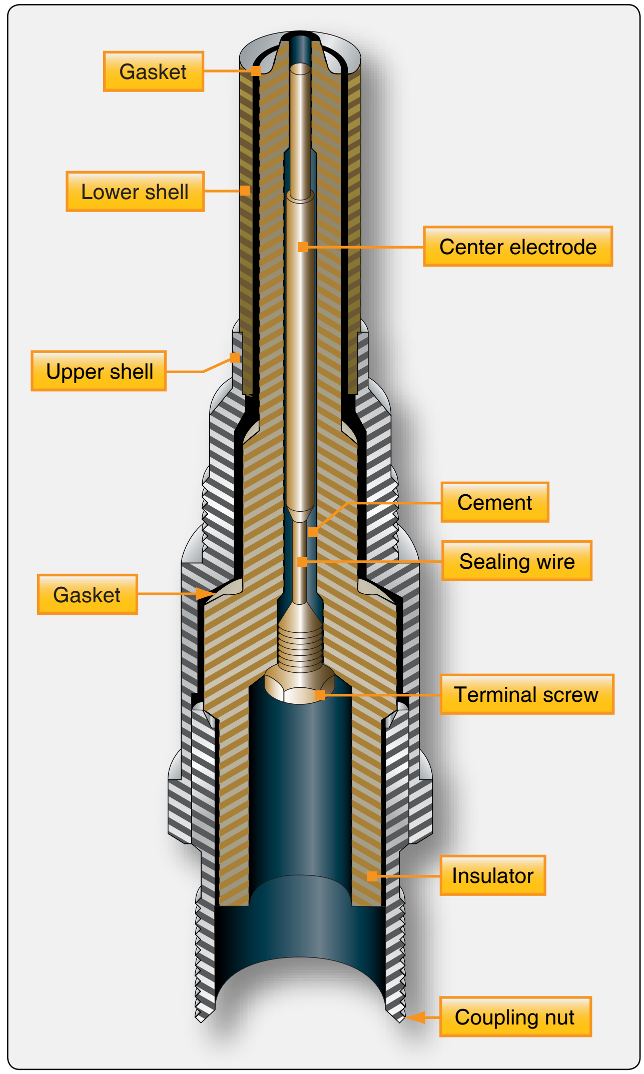


Figure 4-76. *Typical annular gap igniter plug.*

Repair

Tighten and secure as required and replace faulty components and wiring. Secure, tighten, and safety as required.

Removal, Maintenance, & Installation of Ignition System Components

The following instructions are typical procedures suggested by many gas turbine manufacturers. These instructions are applicable to the engine ignition components. Always consult the applicable manufacturer's instructions before performing any ignition system maintenance.

Ignition System Leads

1. Remove clamps securing ignition leads to engine.
2. Remove safety wire and disconnect electrical connectors from exciter units.

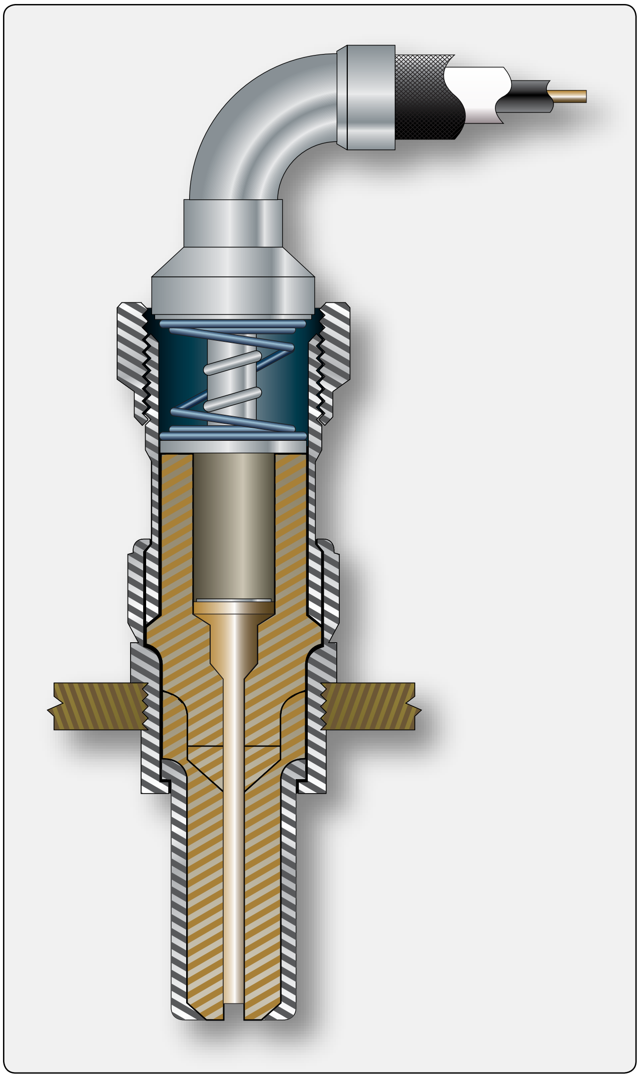


Figure 4-77. *Constrained gap igniter plug.*

3. Remove safety wire and disconnect lead from igniter plug.
4. Discharge any electrical charge stored in the system by grounding and remove ignition leads from engine.
5. Clean leads with approved dry cleaning solvent.
6. Inspect connectors for damaged threads, corrosion, cracked insulators, and bent or broken connector pins.
7. Inspect leads for worn or burned areas, deep cuts, fraying, and general deterioration.
8. Perform continuity check of ignition leads.
9. Reinstall leads, reversing the removal procedure.

Igniter Plugs

1. Disconnect ignition leads from igniter plugs. A good procedure to perform before disconnecting the ignition lead is to disconnect the low-voltage primary lead from the ignition exciter unit and wait at least one minute to permit the stored energy to dissipate before disconnecting the high-voltage cable from the igniter.

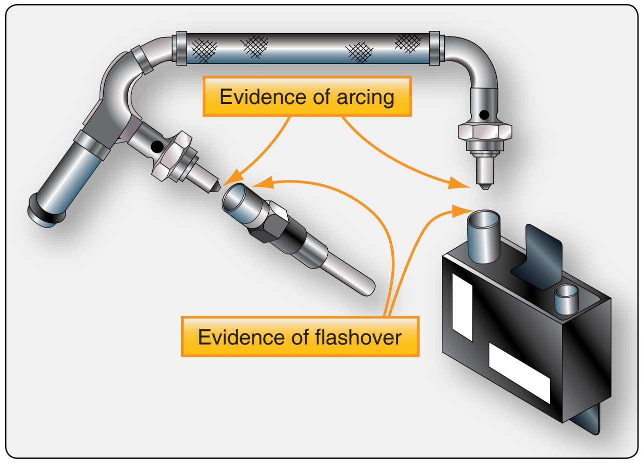


Figure 4-78. *Flashover inspection.*

2. Remove igniter plugs from mounts.
3. Inspect igniter plug gap surface material. Before inspection, remove residue from the shell exterior using a dry cloth. Do not remove any deposits or residue from the firing end of the low-voltage igniters. High-voltage igniters can have the firing end cleaned to aid in inspection. *[Figure 4-79]*
4. Inspect for fretting of igniter plug shank.
5. Replace an igniter plug whose surface is granular, chipped, or otherwise damaged.
6. Replace dirty or carbonized igniter plugs.
7. Install igniter plugs in mounting pads.
8. Check for proper clearance between chamber liner and igniter plug.
9. Tighten igniter plugs to manufacturer's specified torque.
10. Safety wire igniter plugs.

Powerplant Electrical Systems

The satisfactory performance of any modern aircraft depends to a great degree on the continuing reliability of electrical systems and subsystems. Improperly or carelessly installed or maintained wiring can be a source of both immediate and potential danger. The continued proper performance of electrical systems depends upon the knowledge and technique of the mechanic who installs, inspects, and maintains the electrical wire and cable of the electrical systems.

The procedures and practices outlined in this section are general recommendations and are not intended to replace the manufacturer's instructions in approved practices.

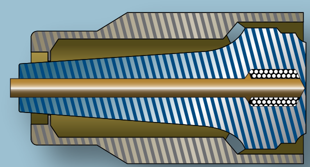
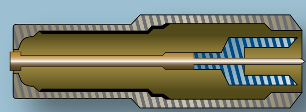
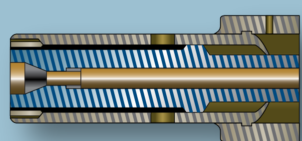
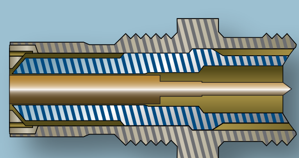
Gap Description	Typical Firing End Configuration	Clean Firing End
High-voltage air surface gap		Yes
High-voltage surface gap		Yes
High-voltage recessed surface gap		Yes
Low-voltage shunted surface gap		No

Figure 4-79. *Firing end cleaning.*

For the purpose of this discussion, a wire is described as a single solid conductor, or a stranded conductor, covered with an insulating material. *[Figure 4-80]* The term "cable," as used in aircraft electrical installations, includes the following:

1. Multiconductor cable—two or more separately insulated conductors in the same jacket.
2. Twisted pair—two or more separately insulated conductors twisted together.
3. Shielded cable—one or more insulated conductors, covered with a metallic braided shield.
4. Radio frequency cable—a single, insulated center conductor with a metallic braided outer conductor. The concentricity of the center conductor and the outer conductor is carefully controlled during manufacture to ensure that they are coaxial.

Wire Size

Wire is manufactured in sizes according to a standard known as the American wire gauge (AWG). The wire diameters become smaller as the gauge numbers become larger. The largest wire size shown in *Figure 4-81* is number 0000, and the smallest is number 40. Larger and smaller sizes are manufactured but are not commonly used.

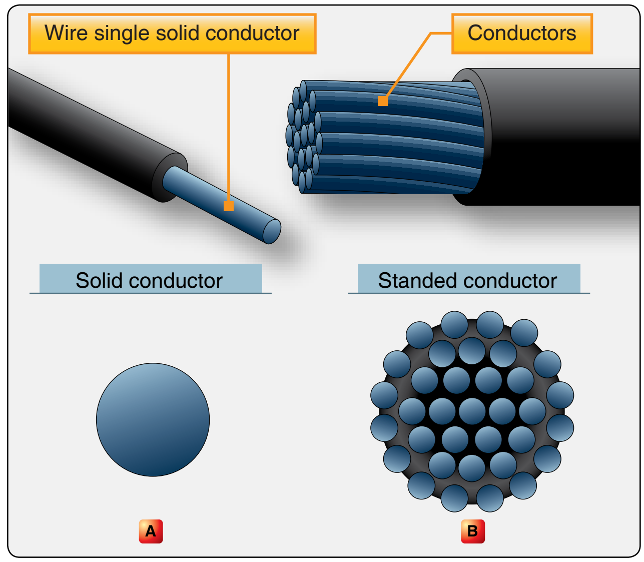


Figure 4-80. *Two types of aircraft wire.*

Wire size may be determined by using a wire gauge. *[Figure 4-82]* This type of gauge measures wires ranging in size from number 0 (zero) to number 36. The wire to be measured is inserted in the smallest slot that just accommodates the bare wire. The gauge number corresponding to that slot indicates the wire size. The slot has parallel sides and should not be confused with the semicircular opening at the end of the slot. The opening simply permits the free movement of the wire all the way through the slot.

Gauge numbers are useful in comparing the diameter of wires, but not all types of wire or cable can be accurately measured with a gauge. Large wires are usually stranded to increase their flexibility. In such cases, the total area can be determined by multiplying the area of one strand, usually computed in circular mils (commonly used as a reference to wire size) when diameter or gauge number is known by the number of strands in the wire or cable.

Factors Affecting the Selection of Wire Size

Several factors must be considered in selecting the size of wire for transmitting and distributing electric power. One factor is the allowable power loss (PR loss) in the line. This loss represents electrical energy converted into heat. The use of large conductors reduces the resistance and therefore the PR loss. However, large conductors are more expensive initially than small ones; they are heavier and require more substantial supports.

A second factor is the permissible voltage drop (IR drop) in the line. If the source maintains a constant voltage at

Cross Section				Ohms per 1,000 ft	
Gauge Number	**Diameter (mils)**	**Circular (mils)**	**Square inches**	**25 °C (77 °F)**	**65 °C (149 °F)**
0000	460.0	212,000.0	0.166	0.0500	0.0577
000	410.0	168,000.0	0.132	0.0630	0.0727
00	365.0	133,000.0	0.105	0.0795	0.0917
0	325.0	106,000.0	0.0829	0.100	0.166
1	289.0	83,700.0	0.0657	0.126	0.146
2	258.0	66,400.0	0.0521	0.159	0.184
3	229.0	52,600.0	0.0413	0.201	0.232
4	204.0	41,700.0	0.0328	0.253	0.292
5	182.0	33,100.0	0.0260	0.319	0.369
6	162.0	26,300.0	0.0206	0.403	0.465
7	144.0	20,800.0	0.0164	0.508	0.586
8	128.0	16,500.0	0.0130	0.641	0.739
9	114.0	13,100.0	0.0103	0.808	0.932
10	102.0	10,400.0	0.00815	1.02	1.18
11	91.0	8,230.0	0.00647	1.28	1.48
12	81.0	6,530.0	0.00513	1.62	1.87
13	72.0	5,180.0	0.00407	2.04	2.36
14	64.0	4,110.0	0.00323	2.58	2.97
15	57.0	3,260.0	0.00256	3.25	3.75
16	51.0	2,580.0	0.00203	4.09	4.73
17	45.0	2,050.0	0.00161	5.16	5.96
18	40.0	1,620.0	0.00128	6.51	7.51
19	36.0	1,290.0	0.00101	8.21	9.48
20	32.0	1,020.0	0.000802	10.40	11.90
21	28.5	810.0	0.000636	13.10	15.10
22	25.3	642.0	0.000505	16.50	19.00
23	22.6	509.0	0.000400	20.80	24.00
24	20.1	404.0	0.000317	26.20	30.20
25	17.9	320.0	0.000252	33.00	38.10
26	15.9	254.0	0.000200	41.60	48.00
27	14.2	202.0	0.000158	52.50	60.60
28	12.6	160.0	0.000126	66.20	76.40
29	11.3	127.0	0.0000995	83.40	96.30
30	10.0	101.0	0.0000789	105.00	121.00
31	8.9	79.7	0.0000626	133.00	153.00
32	8.0	63.2	0.0000496	167.00	193.00
33	7.1	50.1	0.0000394	211.00	243.00
34	6.3	39.8	0.0000312	266.00	307.00
35	5.6	31.5	0.0000248	335.00	387.00
36	5.0	25.0	0.0000196	423.00	488.00
37	4.5	19.8	0.0000156	533.00	616.00
38	4.0	15.7	0.0000123	673.00	776.00
39	3.5	12.5	0.0000098	848.00	979.00
40	3.1	9.9	0.0000078	1.070.00	1,230.00

Figure 4-81. *American wire gauge for standard annealed solid copper wire.*

Figure 4-82. *Wire gauge.*

the input to the line, any variation in the load on the line causes a variation in line current and a consequent variation in the IR drop in the line. A wide variation in the IR drop in the line causes poor voltage regulation at the load. The obvious remedy is to reduce either current or resistance. A reduction in load current lowers the amount of power being transmitted, whereas a reduction in line resistance increases the size and weight of conductors required. A compromise is generally reached whereby the voltage variation at the load is within tolerable limits and the weight of line conductors is not excessive.

A third factor is the current carrying ability of the conductor. When current is drawn through the conductor, heat is generated. The temperature of the wire rises until the heat radiated, or otherwise dissipated, is equal to the heat generated by the passage of current through the line. If the conductor is insulated, the heat generated in the conductor is not so readily removed as it would be if the conductor were not insulated. Thus, to protect the insulation from too much heat, the current through the conductor must be maintained below a certain value.

When electrical conductors are installed in locations where the ambient temperature is relatively high, the heat generated by external sources constitutes an appreciable part of the total conductor heating. Allowance must be made for the influence of external heating on the allowable conductor current, and each case has its own specific limitations. The maximum allowable operating temperature of insulated conductors varies with the type of conductor insulation being used.

Tables are available that list the safe current ratings for various sizes and types of conductors covered with various types of insulation. The chart in *Figure 4-83* shows the current carrying capacity and resistance of copper wire continuous duty wire in bundles at various temperature ratings.

Factors Affecting Selection of Conductor Material

Although silver is the best conductor, its cost limits its use to special circuits where a substance with high conductivity is needed. The two most generally used conductors are copper and aluminum. Each has characteristics that make its use advantageous under certain circumstances; also, each has certain disadvantages.

Copper has a higher conductivity; it is more ductile, can be drawn out, has relatively high tensile strength, and can be easily soldered. It is more expensive and heavier than aluminum.

Although aluminum has only about 60 percent of the conductivity of copper, it is used extensively. Its light weight makes possible long spans, and its relatively large diameter for a given conductivity reduces corona, the discharge of electricity from the wire when it has a high potential. The discharge is greater when smaller diameter wire is used than when larger diameter wire is used. Some bus bars are made of aluminum which has a greater radiating surface than copper for the same conductance. The characteristics of copper and aluminum are compared in *Figure 4-84*.

Voltage Drop in Aircraft Wire & Cable

The voltage drop in the main power cables from the aircraft generation source or the battery to the bus should not exceed 2 percent of the regulated voltage when the generator is carrying rated current or the battery is being discharged at a 5-minute rate. The 5-minute rate in this case means that the battery should last a minimum of 5 minutes in an emergency, with all battery operated equipment running. *Figure 4-85* shows the recommended maximum voltage drop in the load circuits between the bus and the utilization equipment.

The resistance of the current return path through the aircraft structure is always considered negligible. However, this is based on the assumption that adequate bonding of the structure or a special electric current return path has been provided that is capable of carrying the required electric current with a negligible voltage drop. A resistance measurement of 0.005 ohms from ground point of the generator or battery to ground terminal of any electrical device is considered satisfactory.

Another satisfactory method of determining circuit resistance is to check the voltage drop across the circuit. If the voltage drop does not exceed the limit established by the aircraft or product manufacturer, the resistance value for the circuit is considered satisfactory. When using the voltage drop method of checking a circuit, the input voltage must be maintained at a constant value.

Wire Size	Continuous Duty Current (Amps)-Wires in Bundles, Groups, Harnesses, or Conduits (See Note #1)			Max. Resistance ohms/1,000 ft@20 °C Tin Plated Conductor (See Note #2)	Nominal Conductor Area (circ.mils)
	Wire Conductor Temperature Rating				
	105 °C	150 °C	200 °C		
24	2.5	4	5	28.40	475
22	3	5	6	16.20	755
20	4	7	9	9.88	1,216
18	6	9	12	6.23	1,900
16	7	11	14	4.81	2,426
14	10	14	18	3.06	3,831
12	13	19	25	2.02	5,874
10	17	26	32	1.26	9,354
8	38	57	71	0.70	16,983
6	50	76	97	0.44	26,818
4	68	103	133	0.28	42,615
2	95	141	179	0.18	66,500
1	113	166	210	0.15	81,700
0	128	192	243	0.12	104,500
00	147	222	285	0.09	133,000
000	172	262	335	0.07	166,500
0000	204	310	395	0.06	210,900

Note 1: Rating is for 70 °C ambient, 33 or more wires in the bundle for sizes 24 through 10, and 9 wires for size 8 and larger, with no more than 20 percent of harness current carrying capacity being used, at an operating altitude of 60,000 feet.

Note 2: For resistance of silver or nickel-plated conductors, see wire specifications.

Figure 4-83. *Current-carrying capacity and resistance of copper wire.*

Characteristic	Copper	Aluminum
Tensile strength (lb/in^2)	55,000	25,000
Tensile strength for same conductivity (lb)	55,000	40,000
Weight for same conductivity (lb)	100	48
Cross section for same conductivity (CM)	100	160
Specific resistance (Ω/mil ft)	10.6	17

Figure 4-84. *Characteristics of copper and aluminum.*

Nominal System Voltage	Allowable Voltage Drop	
	Continuous Operation	Intermittent Operation
14	0.5	1
28	1	2
115	4	8
200	7	14

Figure 4-85. *Recommended voltage drop in load circuits.*

The graph in *Figure 4-86* applies to copper conductors carrying direct current. To select the correct size of conductor, two major requirements must be met. First, the size must be sufficient to prevent an excessive voltage drop while carrying the required current over the required distance. Second, the size must be sufficient to prevent overheating of the cable while carrying the required current. The graphs in *Figures 4-86* and *4-87* can simplify these determinations. To use this graph to select the proper size of conductor, the following must be known:

1. The conductor length in feet;
2. The number of amperes of current to be carried;
3. The amount of voltage drop permitted;
4. Whether the current to be carried is intermittent or continuous;
5. The estimated or measured temperature of the conductor;
6. Whether the wire to be installed is in a conduit or in a bundle; and
7. Whether it is a single conductor in free air.

Suppose that you want to install a 50-foot conductor from the aircraft bus to the equipment in a 28-volt system. For this length, a 1-volt drop is permissible for continuous operation with a conductor temperature of 20 ºC or less. By referring to the chart in *Figure 4-86*, the maximum number of feet a conductor may be run carrying a specified current with a 1-volt drop can be determined. In this example, the number 50 is selected.

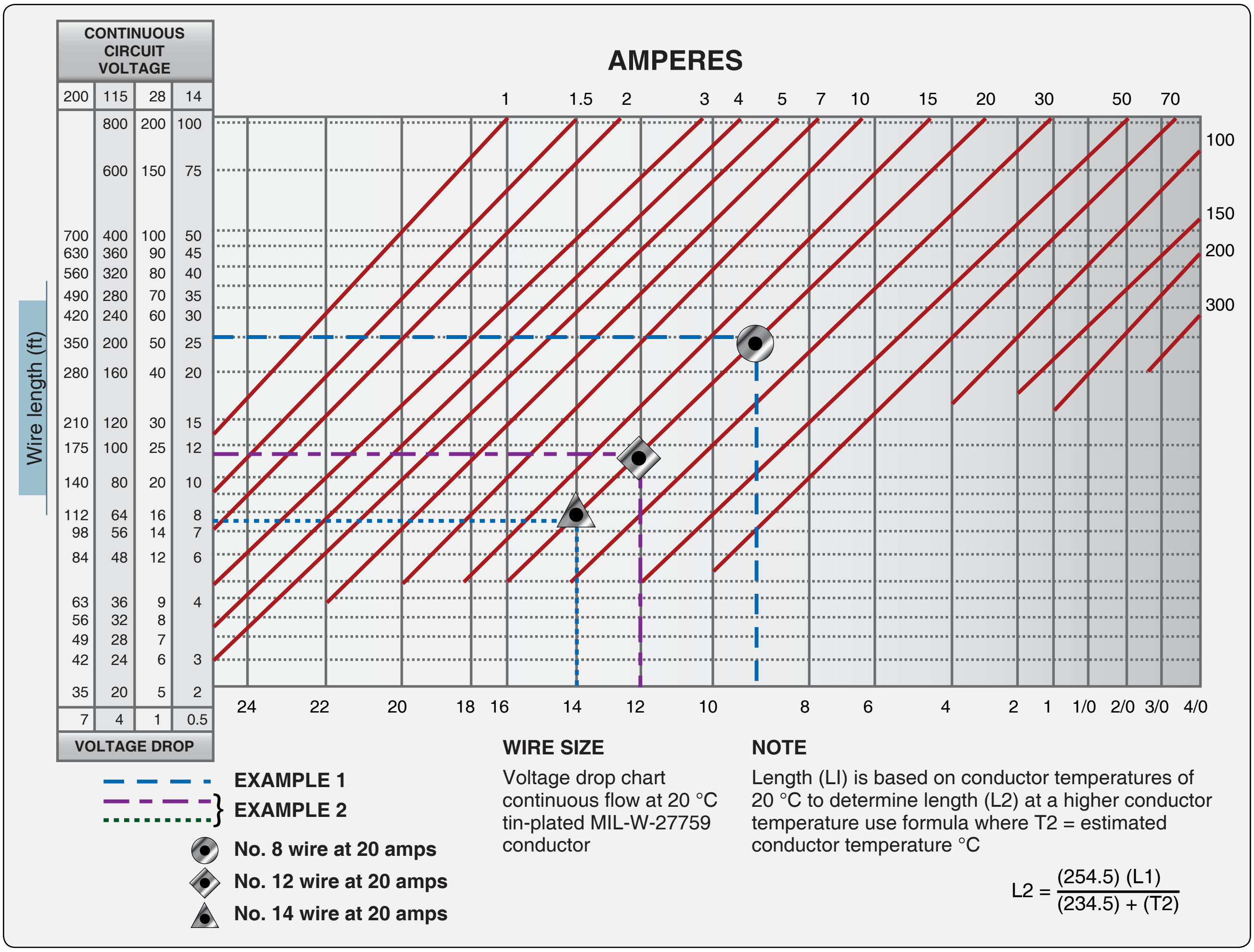


Figure 4-86. *Conductor graph—continuous flow.*

Assuming the current required by the equipment is 20 amperes, the line indicating the value of 20 amperes should be selected from the diagonal lines. Follow this diagonal line downward until it intersects the horizontal line number 50. From this point, drop straight down to the bottom of the graph to find that a conductor between size No. 8 and No. 10 is required to prevent a greater drop than 1 volt. Since the indicated value is between two numbers, the larger size, No. 8, should be selected. This is the smallest size that should be used to avoid an excessive voltage drop.

If the installation is for equipment having only an intermittent (maximum 2 minutes) requirement for power, the graph in *Figure 4-87* is used in the same manner.

Conductor Insulation

Two fundamental properties of insulation materials (e.g., rubber, glass, asbestos, and plastic) are insulation resistance and dielectric strength. These are entirely different and distinct properties.

Insulation resistance is the resistance to current leakage through and over the surface of insulation materials. Insulation resistance can be measured with a megger without damaging the insulation. This serves as a useful guide in determining the general condition of insulation. However, the data obtained in this manner may not give a true picture of the condition of the insulation. Clean, dry insulation having cracks or other faults may show a high value of insulation resistance but would not be suitable for use.

Dielectric strength is the ability of the insulator to withstand potential difference and is usually expressed in terms of the voltage at which the insulation fails due to electrostatic stress. Maximum dielectric strength values can be measured by raising the voltage of a test sample until the insulation breaks down.

Because of the expense of insulation, its stiffening effect, and the great variety of physical and electrical conditions under which the conductors are operated, only the necessary minimum insulation is applied for any particular type of cable

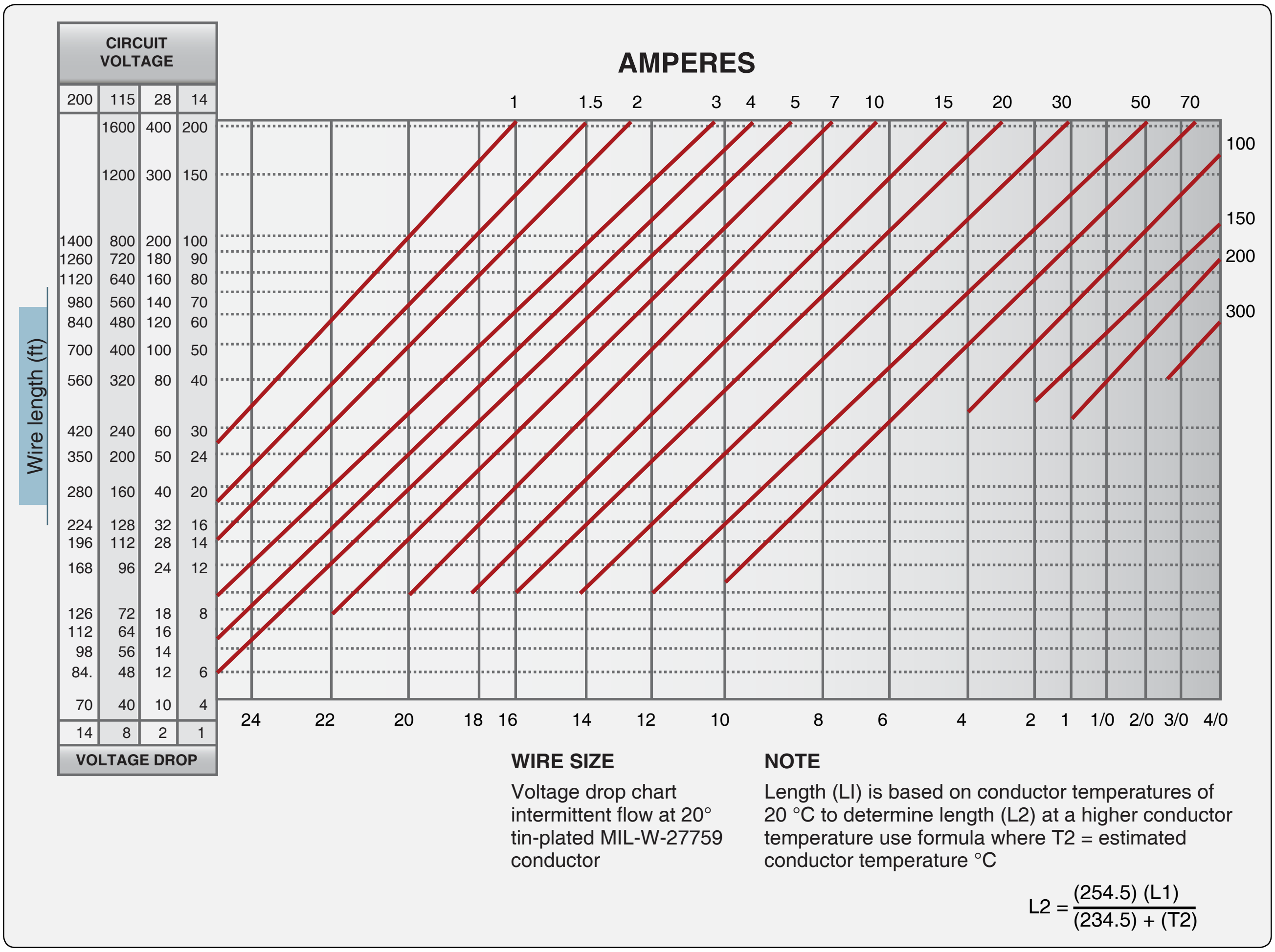


Figure 4-87. *Conductor graph—intermittent flow.*

designed to do a specific job.

The type of conductor insulation material varies with the type of installation. Rubber, silk, and paper insulation are no longer used extensively in aircraft systems. More common today are such materials as vinyl, cotton, nylon, Teflon, and Rockbestos.

Identifying Wire & Cable

To aid in testing and repair operations, many maintenance activities mark wire or cable with a combination of letters and numbers that identify the wire, the circuit it belongs to, the gauge number, and other information necessary to relate the wire or cable to a wiring diagram. Such markings are the identification code.

There is no standard procedure for marking and identifying wiring; each manufacturer normally develops its own identification code. *Figure 4-88* illustrates one identification system and shows the usual spacing in marking a wire. Some system components, especially plugs and jacks, are identified by a letter or group of letters and numbers added to the basic identification number. These letters and numbers may indicate the location of the component in the system. Interconnected cables are also marked in some systems to indicate location, proper termination, and use. In any system, the marking should be legible, and the stamping color should contrast with the color of the wire insulation. For example, use black stamping with light-colored backgrounds, or white stamping on dark-colored backgrounds.

Most manufacturers mark the wires at intervals of not more than 15 inches lengthwise and within 3 inches of each junction or terminating point. *[Figure 4-89]*
Coaxial cable and wires at terminal blocks and junction boxes are often identified by marking or stamping a wiring sleeve rather than the wire itself. For general purpose wiring, flexible vinyl sleeving, either clear or white opaque, is

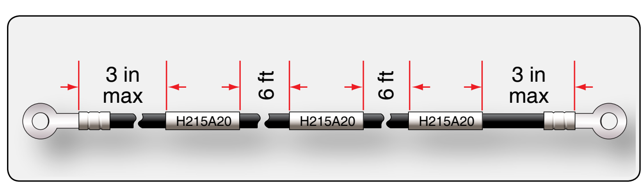


Figure 4-88. *Spacing of printed identification marks.*

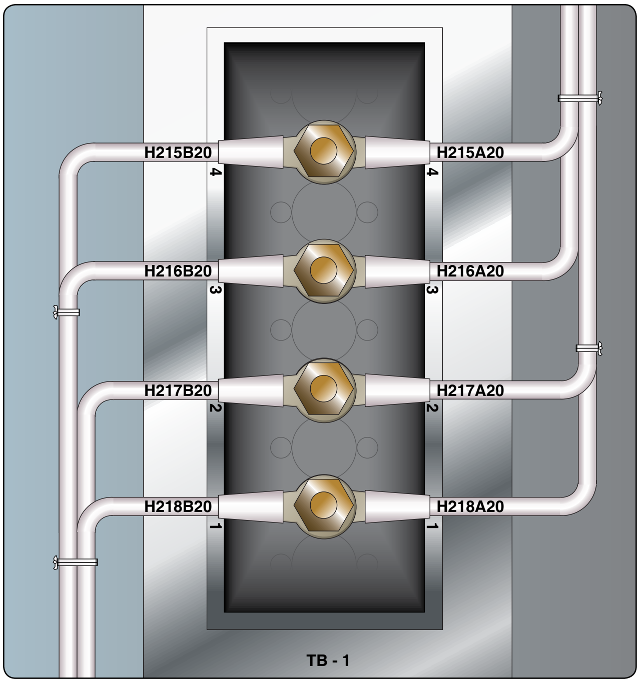


Figure 4-89. *Wire identification at a terminal block.*

commonly used. For high-temperature applications, silicone rubber or silicone fiberglass sleeving is recommended. Where resistance to synthetic hydraulic fluids or other solvents is necessary, either clear or white opaque nylon sleeving can be used.

While the preferred method is to stamp the identification marking directly on the wire or on sleeving, other methods are often employed. One method uses a marked sleeve tied in place. The other uses a pressure-sensitive tape. *[Figure 4-90]*

Electrical Wiring Installation

The following recommended procedures for installing aircraft electrical wiring are typical of those used on most types of aircraft. For purposes of this discussion, the following definitions are applicable:

1. Open wiring—any wire, wire group, or wire bundle not enclosed in conduit.
2. Wire group—two or more wires in the same location, tied together to identity the group.
3. Wire bundle—two or more wire groups tied together because they are going in the same direction at the point where the tie is located. The bundle facilitates maintenance.
4. Electrically protected wiring—wires that include in the circuit protections against overloading, such as fuses, circuit breakers, or other limiting devices.
5. Electrically unprotected wiring—wires, generally from generators to main bus distribution points, that do not have protection, such as fuses, circuit breakers, or other current-limiting devices.

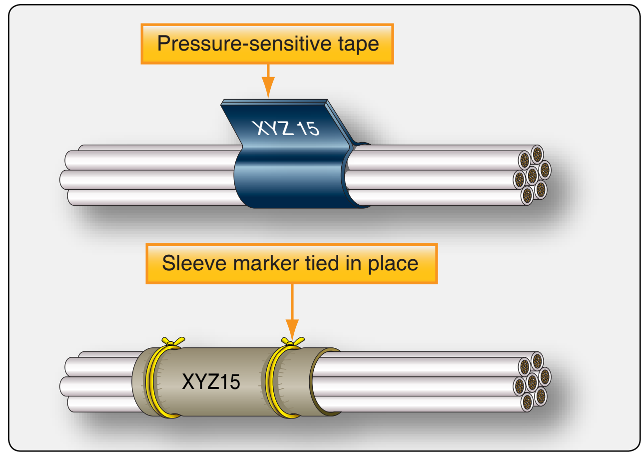


Figure 4-90. *Alternate methods of identifying wire bundles.*

Wire Groups & Bundles

Grouping or bundling certain wires, such as electrically unprotected power wiring and wiring to duplicate vital equipment, should be avoided. Wire bundles should generally be limited in size to a bundle of 75 wires, or 2 inches in diameter where practicable. When several wires are grouped at junction boxes, terminal blocks, panels, etc., the identity of the group within a bundle can be retained. *[Figure 4-91]*

Twisting Wires

When specified on the engineering drawing, parallel wires must be twisted. The most common examples are:

1. Wiring in the vicinity of magnetic compass or flux valve,
2. Three-phase distribution wiring, and
3. Certain other wires (usually radio wiring).

Twist the wires so that they lie snugly against each other, making approximately the number of twists per foot as listed in *Figure 4-92.* Always check wire insulation for damage after twisting. If the insulation is torn or frayed, replace the wire.

Spliced Connections in Wire Bundles

Spliced connections in wire groups or bundles should be located so that they can be easily inspected. Splices should also be staggered so that the bundle does not become excessively enlarged. *[Figure 4-93]* All noninsulated splices should be covered with plastic, securely tied at both ends.

Slack in Wiring Bundles

Single wires or wire bundles should not be installed with excessive slack. Slack between supports should normally not exceed ½ inch. This is the maximum it should be possible

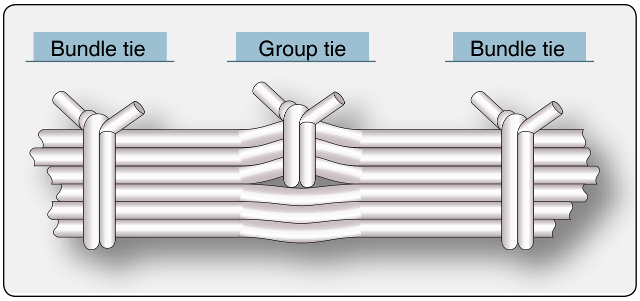


Figure 4-91. *Group and bundle ties.*

	#22	#20	#18	#16	#14	#12	#10	#8	#6	#4
2 Wires	10	10	9	8	7 1/2	7	6 1/2	6	5	4
3 Wires	10	10	8 1/2	7	6 1/2	6	5 1/2	5	4	3

Figure 4-92. *Recommended number of twists per foot.*

to deflect the wire with normal hand force. However, this may be exceeded if the wire bundle is thin and the clamps are far apart. But the slack should never be so great that the wire bundle can abrade against any surface it touches. *[Figure 4-94]* A sufficient amount of slack should be allowed near each end of a bundle to:

1. Permit easy maintenance;
2. Allow replacement of terminals;
3. Relieve mechanical strain on the wires, wire junctions, or supports;
4. Permit free movement of shock and vibration-mounted equipment; and
5. Permit shifting of equipment for purposes of maintenance.

Bend Radii

Bends in wire groups or bundles should not be less than ten times the outside diameter of the wire group or bundle. However, at terminal strips, where wire is suitably supported at each end of the bend, a minimum radius of three times the outside diameter of the wire, or wire bundle, is usually acceptable. There are exceptions to these guidelines in the case of certain types of cable; for example, coaxial cable should never be bent to a smaller radius than six times the outside diameter.

Routing & Installation

All wiring should be installed so that it is mechanically and electrically sound and neat in appearance. Whenever practicable, wires and bundles should be routed parallel with, or at right angles to, the stringers or ribs of the area involved. An exception to this general rule is the coaxial cables, which are routed as directly as possible.

The wiring must be adequately supported throughout its length. A sufficient number of supports must be provided to prevent undue vibration of the unsupported lengths. All wires and wire groups should be routed and installed to protect them from:

1. Chafing or abrasion;
2. High temperature;
3. Being used as handholds, or as support for personal belongings and equipment;
4. Damage by personnel moving within the aircraft;
5. Damage from cargo stowage or shifting;
6. Damage from battery acid fumes, spray, or spillage;

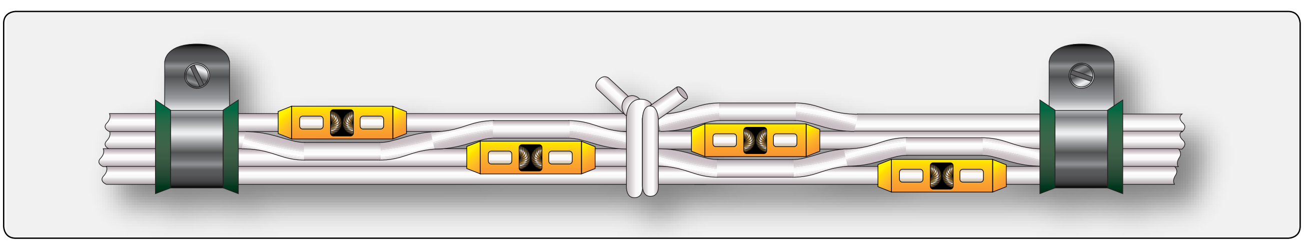


Figure 4-93. *Staggered splices in wire bundle.*

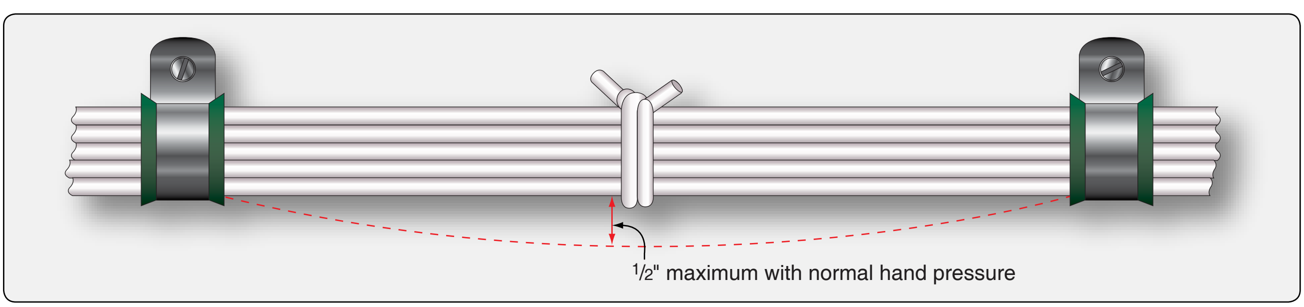


Figure 4-94. *Slack in wire bundle between supports.*

and

7. Damage from solvents and fluids.

Protection Against Chafing

Wires and wire groups should be installed so that they are protected against chafing or abrasion in those locations where contact with sharp surfaces or other wires would damage the insulation. Damage to the insulation can cause short circuits, malfunctions, or inadvertent operation of equipment. Cable clamps should be used to support wire bundles at each hole through a bulkhead. *[Figure 4-95]* If wires come closer than ¼ inch to the edge of the hole, a suitable grommet is used in the hole. *[Figure 4-96]*

Sometimes, it is necessary to cut nylon or rubber grommets to facilitate installation. In these instances, after insertion, the grommet can be secured in place with general purpose cement. The slot should be at the top of the hole, and the cut should be made at an angle of 45° to the axis of the wire bundle hole.

Protection Against High Temperature

To prevent insulation deterioration, wires should be kept separate from high-temperature equipment, such as resistors, exhaust stacks, heating ducts. The amount of separation is usually specified by engineering drawings. Some wires must be run through hot areas. These wires must be insulated with high-temperature rated material, such as asbestos, fiberglass, or Teflon. Additional protection is also often required in the form of conduits. A low-temperature insulated wire should never be used to replace a high-temperature insulated wire.

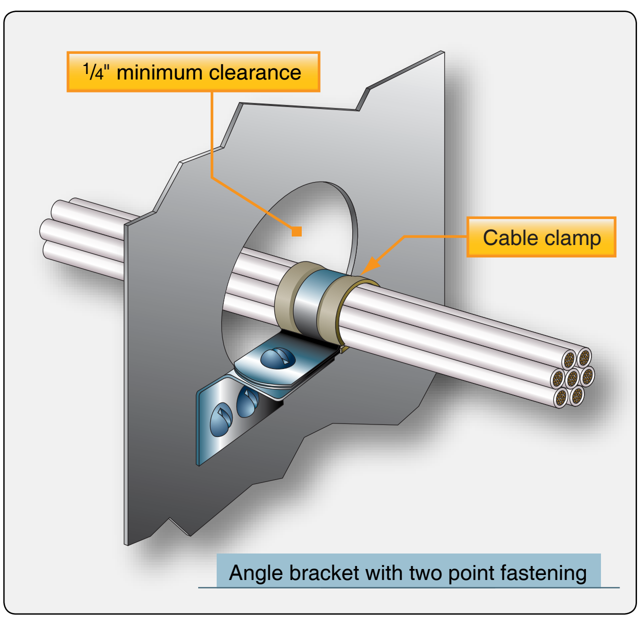


Figure 4-95. *Cable clamp at bulkhead hole.*

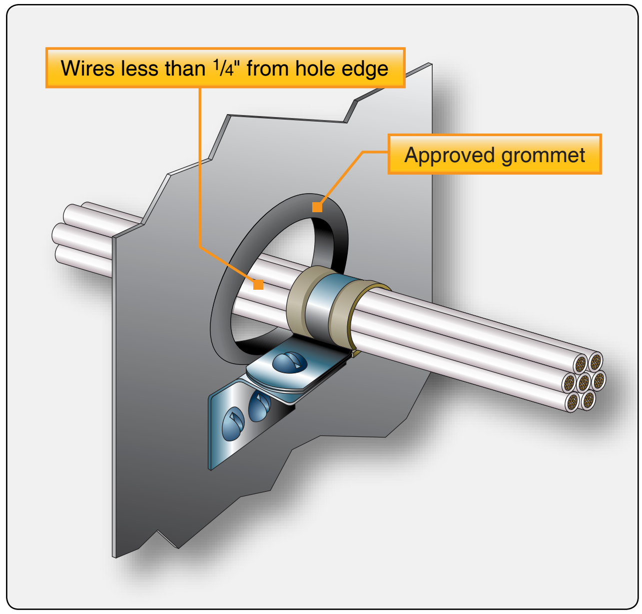


Figure 4-96. *Cable clamp and grommet at bulkhead hole.*

Many coaxial cables have soft plastic insulation, such as polyethylene, that is especially subject to deformation and deterioration at elevated temperatures. All high-temperature areas should be avoided when installing these cables.

Additional abrasion protection should be given to asbestos wires enclosed in conduit. Either conduit with a high temperature rubber liner should be used or asbestos wires can be enclosed individually in high-temperature plastic tubes before being installed in the conduit.

Protection Against Solvents & Fluids

Avoid installing wires in areas where they are subjected to damage from fluids. Wires should not be placed in the lowest four inches of the aircraft fuselage, except those that must terminate in that area. If there is a possibility that wiring without a protective nylon outer jacket may be soaked with fluids, plastic tubing should be used to protect it. This tubing should extend past the exposure area in both directions and should be tied at each end. If the wire has a low point between the tubing ends, provide a ⅛-inch drainage hole. *[Figure 4-97]* This hole should be punched into the tubing after the installation is complete and the low point definitely established by using a hole punch to cut a half circle. Care should be taken not to damage any wires inside the tubing when using the punch.

Wire should never be routed below a battery. All wires in the vicinity of a battery should be inspected frequently. Wires discolored by battery fumes should be replaced.

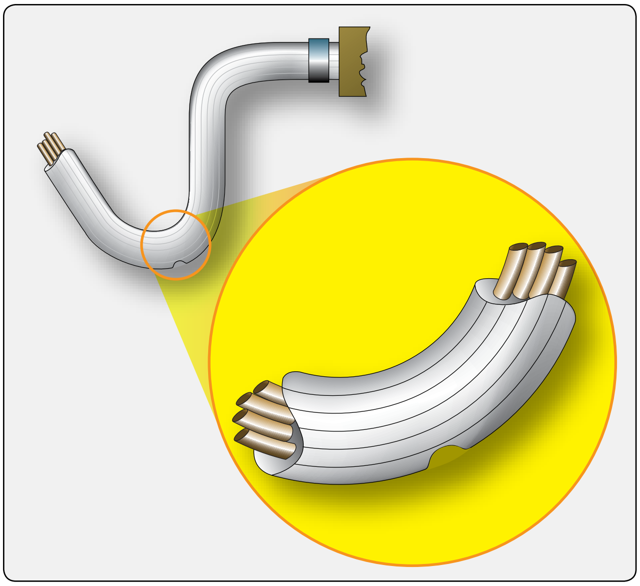


Figure 4-97. *Drainage hole in low point of tubing.*

Protection of Wires in Wheel Well Area

Wires located in wheel wells are subject to many additional hazards, such as exposure to fluids, pinching, and severe flexing in service. All wire bundles should be protected by sleeves of flexible tubing securely held at each end. There should be no relative movement at points where flexible tubing is secured. These wires and the insulating tubing should be inspected carefully at very frequent intervals, and wires or tubing should be replaced at the first sign of wear. There should be no strain on attachments when parts are fully extended, but slack should not be excessive.

Routing Precautions

When wiring must be routed parallel to combustible fluid or oxygen lines for short distances, as much separation as possible should be maintained. The wires should be on a level with, or above, the plumbing lines. Clamps should be spaced so that if a wire is broken at a clamp, it will not contact the line. Where a 6-inch separation is not possible, both the wire bundle and the plumbing line can be clamped to the same structure to prevent any relative motion. If the separation is less than 2 inches but more than ½ inch, two cable clamps back to back can be used to maintain a rigid separation only and not for support of the bundle. *[Figure 4-98]* No wire should be routed so that it is located nearer than ½ inch to a plumbing line, nor should a wire or wire bundle be supported from a plumbing line that carries flammable fluids or oxygen. Wiring should be routed to maintain a minimum clearance of at least 3 inches from control cables. If this cannot be accomplished, mechanical guards should be installed to prevent contact between wiring and control cables.

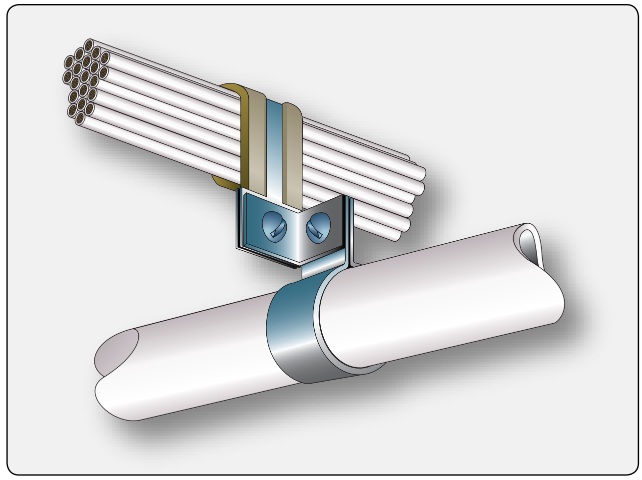


Figure 4-98. *Separation of wires from plumbing lines.*

Installation of Cable Clamps

Cable clamps should be installed with regard to the proper mounting angle. *[Figure 4-99]* The mounting screw should be above the wire bundle. It is also desirable that the back of the cable clamp rest against a structural member where practicable. *Figure 4-100* shows some typical mounting hardware used in installing cable clamps. Be sure that wires are not pinched in cable clamps. Where possible, mount them directly to structural members. *[Figure 4-101]*

Clamps can be used with rubber cushions to secure wire bundles to tubular structures. *[Figure 4-102]* Such clamps must fit tightly but should not be deformed when locked in place.

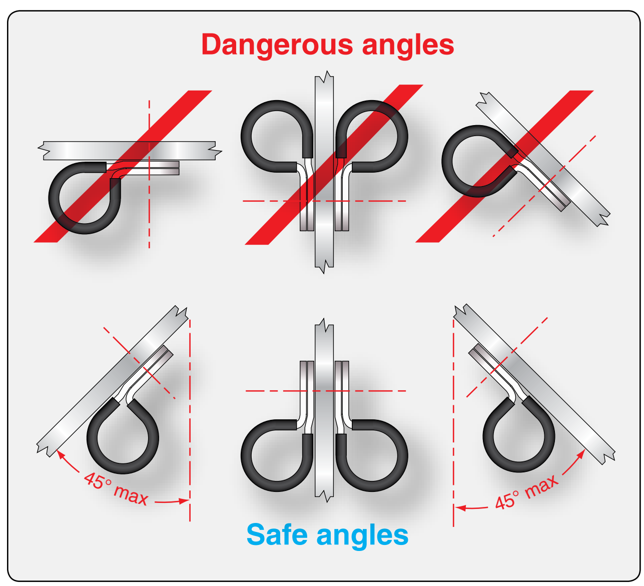


Figure 4-99. *Proper mounting angle for cable clamps.*

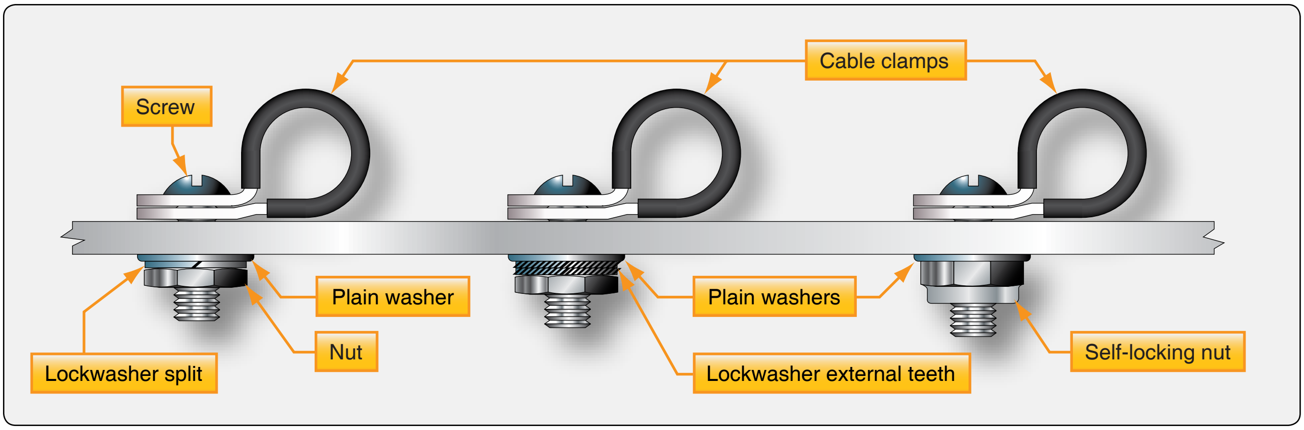


Figure 4-100. *Typical mounting hardware for cable clamps.*

Lacing & Tying Wire Bundles

Wire groups and bundles are laced or tied with cord to provide ease of installation, maintenance, and inspection. This section describes and illustrates recommended procedures for lacing and tying wires with knots that hold tightly under all conditions. For the purposes of this discussion, the following terms are defined:

1. Tying is the securing together of a group or bundle of wires by individual pieces of cord tied around the group or bundle at regular intervals.
2. Lacing is the securing together of a group or bundle of wires by a continuous piece of cord forming loops at regular intervals around the group or bundle.

The material used for lacing and tying is either cotton or nylon cord. Nylon cord is moisture- and fungus-resistant, but cotton cord must be waxed before using to give it these necessary protective characteristics.

Single-Cord Lacing

Figure 4-103 shows the steps in lacing a wire bundle with a single cord. The lacing procedure is started at the thick end of the wire group or bundle with a knot consisting of a clove hitch with an extra loop. The lacing is then continued at regular intervals with half hitches along the wire group or bundle and at each point where a wire or wire group branches off. The half hitches should be spaced so that the bundle is neat and secure.

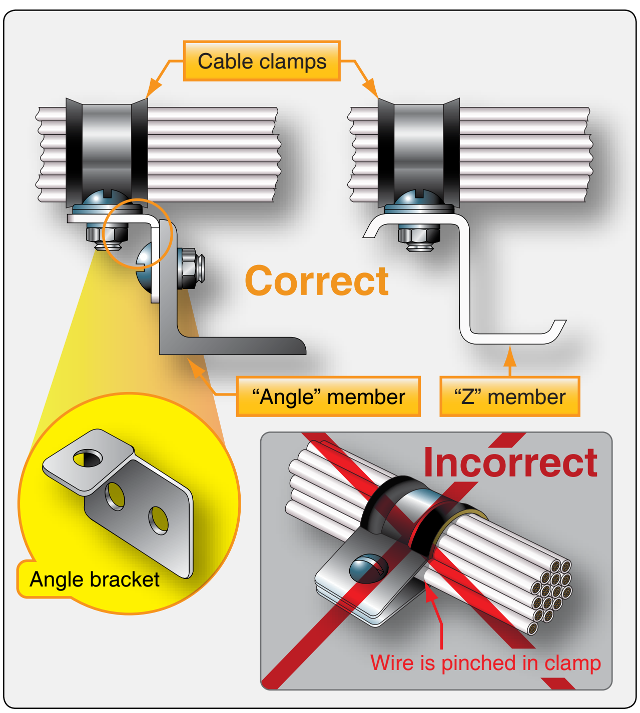


Figure 4-101. *Mounting cable clamps to structure.*

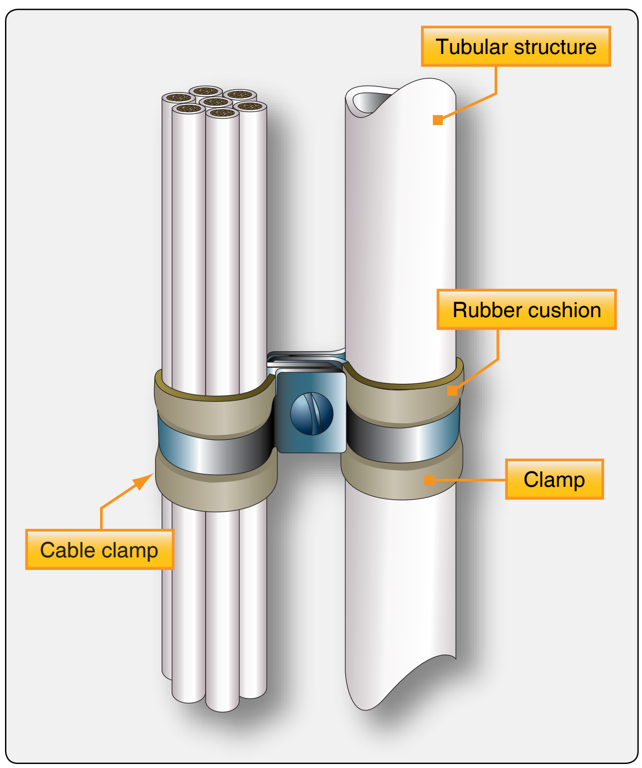


Figure 4-102. *Installing cable clamps to tubular structure.*

The lacing is ended by tying a knot consisting of a clove hitch with an extra loop. After the knot is tied, the free ends of the lacing cord should be trimmed to approximately ⅜ inch.

Double-Cord Lacing

Figure 4-104 illustrates the procedure for double-cord lacing. The lacing is started at the thick end of the wire group or bundle with a bowline-on-a-bight knot. *[Figure 4-104A]* At regular intervals along the wire group or bundle, and at each point where a wire branches off, the lacing is continued using half hitches, with both cords held firmly together. The half hitches should be spaced so that the group or bundle is neat and secure. The lacing is ended with a knot consisting of a half hitch, continuing one of the cords clockwise and the other counterclockwise and then tying the cord ends with a square knot. The free ends of the lacing cord should be trimmed to approximately ⅜ inch.

Lacing Branch-Offs

Figure 4-105 illustrates a recommended procedure for lacing a wire group that branches off the main wire bundle. The branch-off lacing is started with a knot located on the main bundle just past the branch-off point. Continue the lacing along the branched-off wire group using regularly spaced half hitches. If a double cord is used, both cords should be held snugly together. The half hitches should be spaced to lace the bundle neatly and securely. End the lacing with the regular terminal knot used in single- or double-cord lacing, as applicable, and trim the free ends of the lacing cord neatly.

Tying

All wire groups or bundles should be tied where supports are more than 12 inches apart. Ties are made using waxed cotton cord, nylon cord, or fiberglass cord. Some manufacturers permit the use of pressure-sensitive vinyl electrical tape. When permitted, the tape should be wrapped three turns around the bundle and the ends heat sealed to prevent unwinding of the tape. *Figure 4-106* illustrates a recommended procedure for tying a wire group or bundle. The tie is started by wrapping the cord around the wire group to tie a clove-hitch knot. Then, a square knot with an extra loop is tied and the free ends of the cord trimmed.

Temporary ties are sometimes used in making up and installing wire groups and bundles. Colored cord is normally used to make temporary ties, since they are removed when the installation is complete.

Whether lacing or tying, bundles should be secured tightly enough to prevent slipping, but not so tightly that the cord cuts into or deforms the insulation. This applies especially to coaxial cable, which has a soft dielectric insulation between the inner and outer conductor. Coaxial cables have been damaged by the use of lacing materials or by methods of lacing or tying wire bundles that cause a concentrated force on the cable insulation. Elastic lacing materials, small-diameter lacing cord, and excessive tightening deform the interconductor insulation and result in short circuits or impedance changes. Flat nylon braided waxed lacing tape

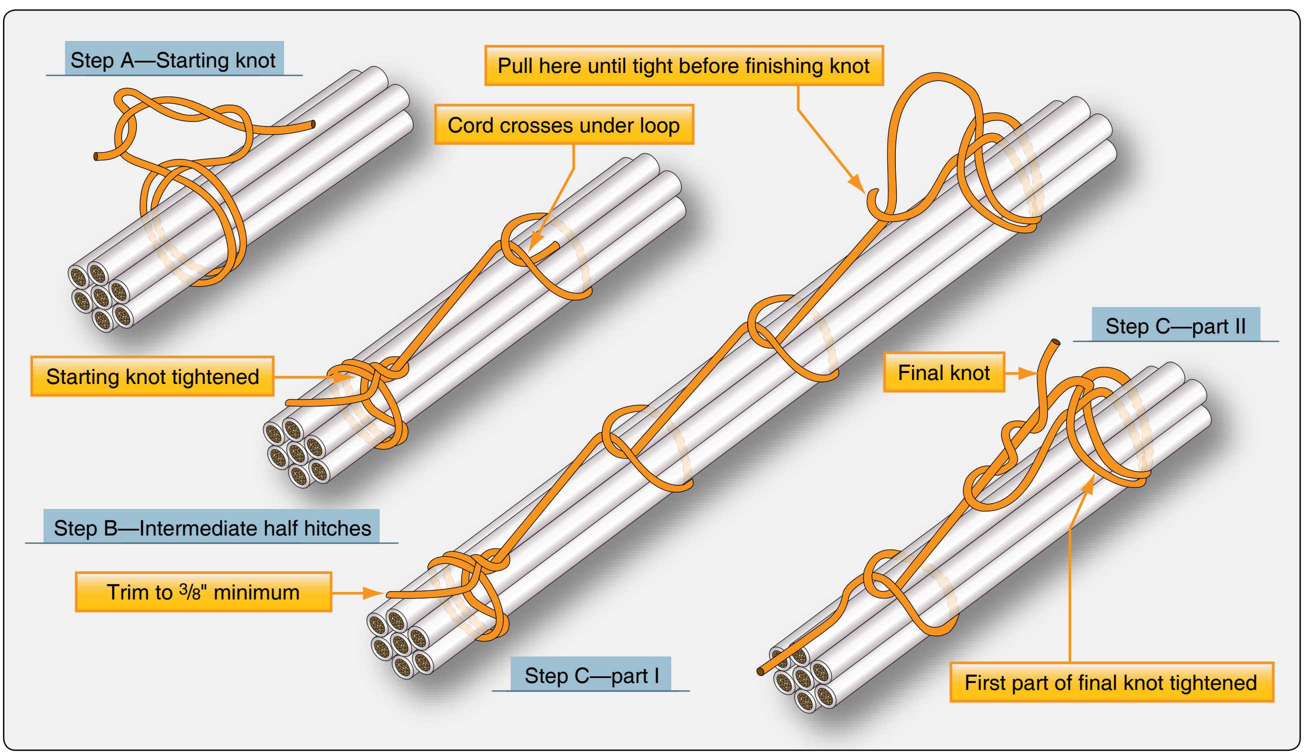


Figure 4-103. *Single cord lacing.*

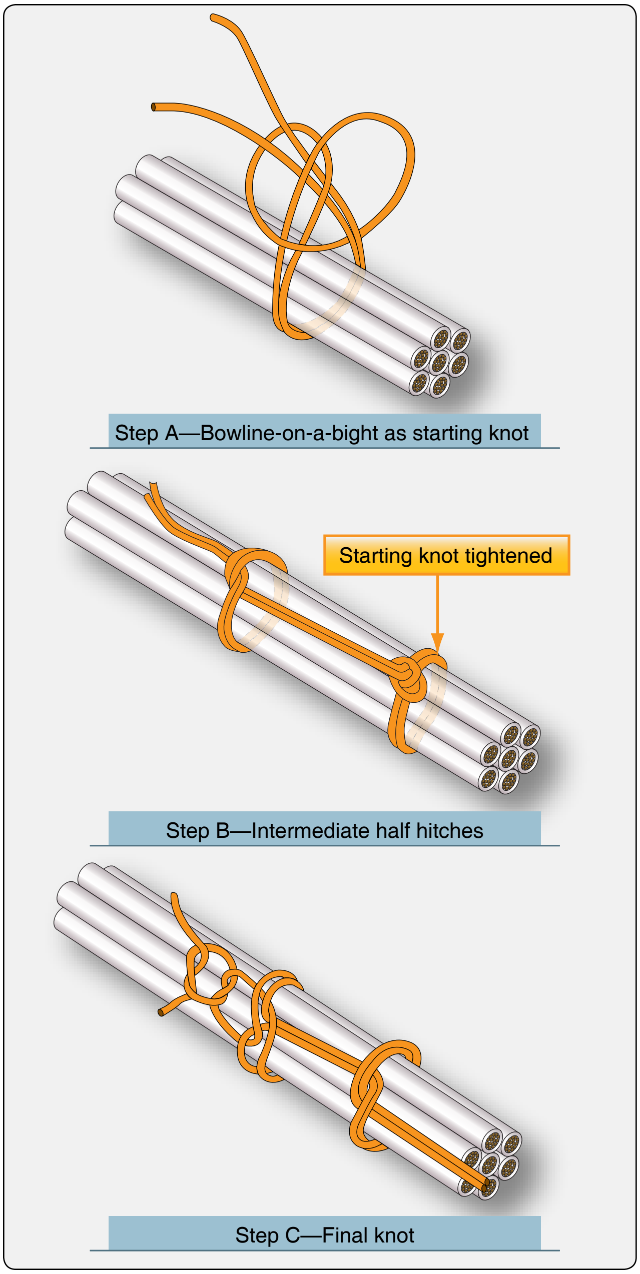


Figure 4-104. *Double cord lacing.*

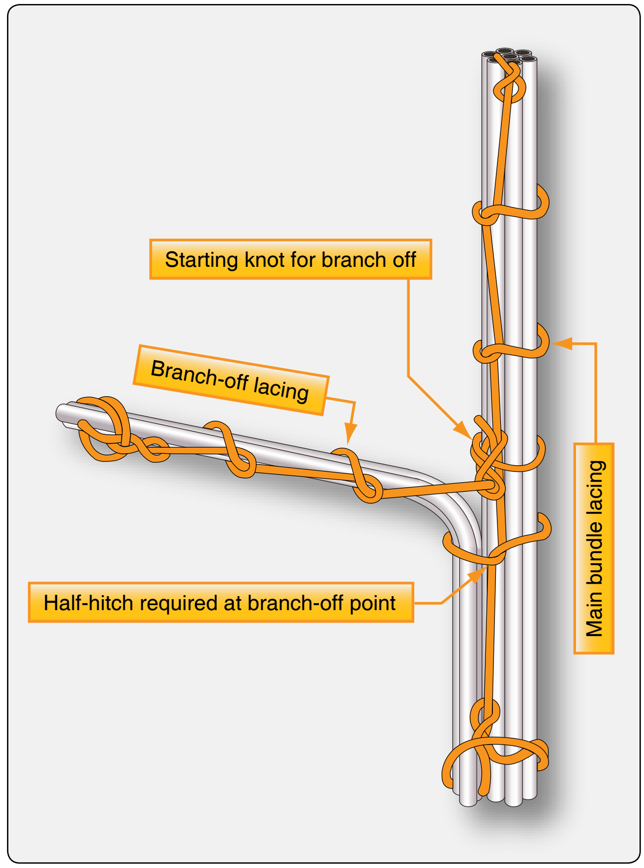


Figure 4-105. *Lacing a branch off.*

should be used for lacing or tying any wire bundles containing coaxial cables.

The part of a wire group or bundle located inside a conduit is not tied or laced; however, wire groups or bundles inside enclosures, such as junction boxes, should be laced only.

Cutting Wire & Cable

To make installation, maintenance, and repair easier, runs of wire and cable in aircraft are broken at specified locations by junctions, such as connectors, terminal blocks, or buses.

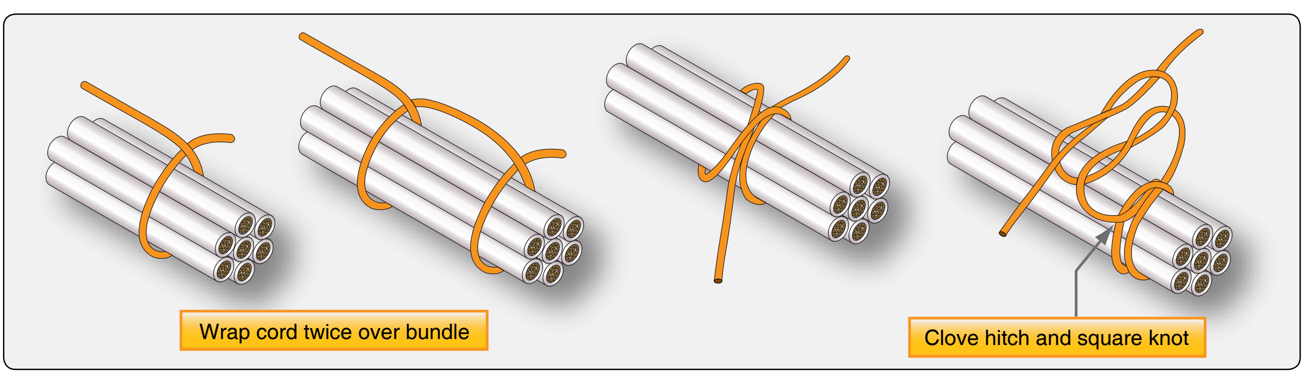


Figure 4-106. *Tying a wire group of bundle.*

Before assembly to these junctions, wires and cables must be cut to length.

All wires and cables should be cut to the lengths specified on drawings and wiring diagrams. The cut should be made clean and square, and the wire or cable should not be deformed. If necessary, large diameter wire should be reshaped after cutting. Good cuts can be made only if the blades of cutting tools are sharp and free from nicks. A dull blade deforms and extrudes wire ends.

Stripping Wire & Cable

Nearly all wire and cable used as electrical conductors are covered with some type of insulation. In order to make electrical connections with the wire, a part of this insulation must be removed to expose the bare conductor. Copper wire can be stripped in a number of ways depending on the size and insulation. *Figure 4-107* lists some types of stripping tools recommended for various wire sizes and types of insulation. Aluminum wire must be stripped using extreme care, since individual strands break very easily after being nicked.

The following general precautions are recommended when stripping any type of wire:

1. When using any type of wire stripper, hold the wire so that it is perpendicular to the cutting blades.
2. Adjust automatic stripping tools carefully; follow the manufacturer's instructions to avoid nicking, cutting, or otherwise damaging strands. This is especially important for aluminum wires and for copper wires smaller than No. 10. Examine stripped wires for damage. Cut off and restrip, if length is sufficient, or reject and replace any wires with more than the allowable number of nicked or broken strands listed in the manufacturer's instructions.
3. Make sure insulation is clean cut with no frayed or ragged edges. Trim, if necessary.
4. Make sure all insulation is removed from stripped area. Some types of wires are supplied with a transparent layer of insulation between the conductor and the primary insulation. If this is present, remove it.
5. When using hand wire strippers to remove lengths of insulation longer than ¾ inch, it is easier to accomplish in two or more operations.
6. Retwist copper strands by hand or with pliers, if necessary, to restore natural lay and tightness of strands.

Stripper	Wire Size	Insulations
Hot blade	#26–#4	All except asbestos
Rotary, electric	#26–#4	All
Bench	#20–#6	All
Hand pliers	#26–#8	All
Knife	#2–#0000	All

Figure 4-107. *Wire strippers for copper wire.*

A pair of hand wire strippers is shown in *Figure 4-108*. This tool is commonly used to strip most types of wire. The following general procedures describe the steps for stripping wire with a hand stripper. *[Figure 4-109]*

1. Insert wire into exact center of correct cutting slot for wire size to be stripped. Each slot is marked with wire size.
2. Close handles together as far as they will go.
3. Release handles allowing wire holder to return to the open position.
4. Remove stripped wire.

Solderless Terminals & Splices

Splicing of electrical cable should be kept to a minimum and avoided entirely in locations subject to extreme vibrations. Individual wires in a group or bundle can usually be spliced if the completed splice is located where it can be inspected periodically. The splices should be staggered so that the bundle does not become excessively enlarged. Many types of aircraft splice connectors are available for splicing individual wires. Self-insulated splice connectors are usually preferred; however, a noninsulated splice connector can be used if the splice is covered with plastic sleeving secured at both ends. Solder splices may be used, but they are particularly brittle and not recommended.

Electric wires are terminated with solderless terminal lugs to permit easy and efficient connection to and disconnection from terminal blocks, bus bars, or other electrical equipment. Solderless splices join electric wires to form permanent continuous runs. Solderless terminal lugs and splices are made of copper or aluminum and are preinsulated or uninsulated, depending on the desired application.

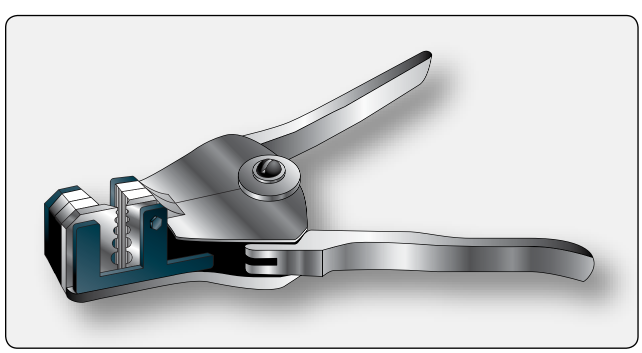


Figure 4-108. *Light duty hand wire strippers.*

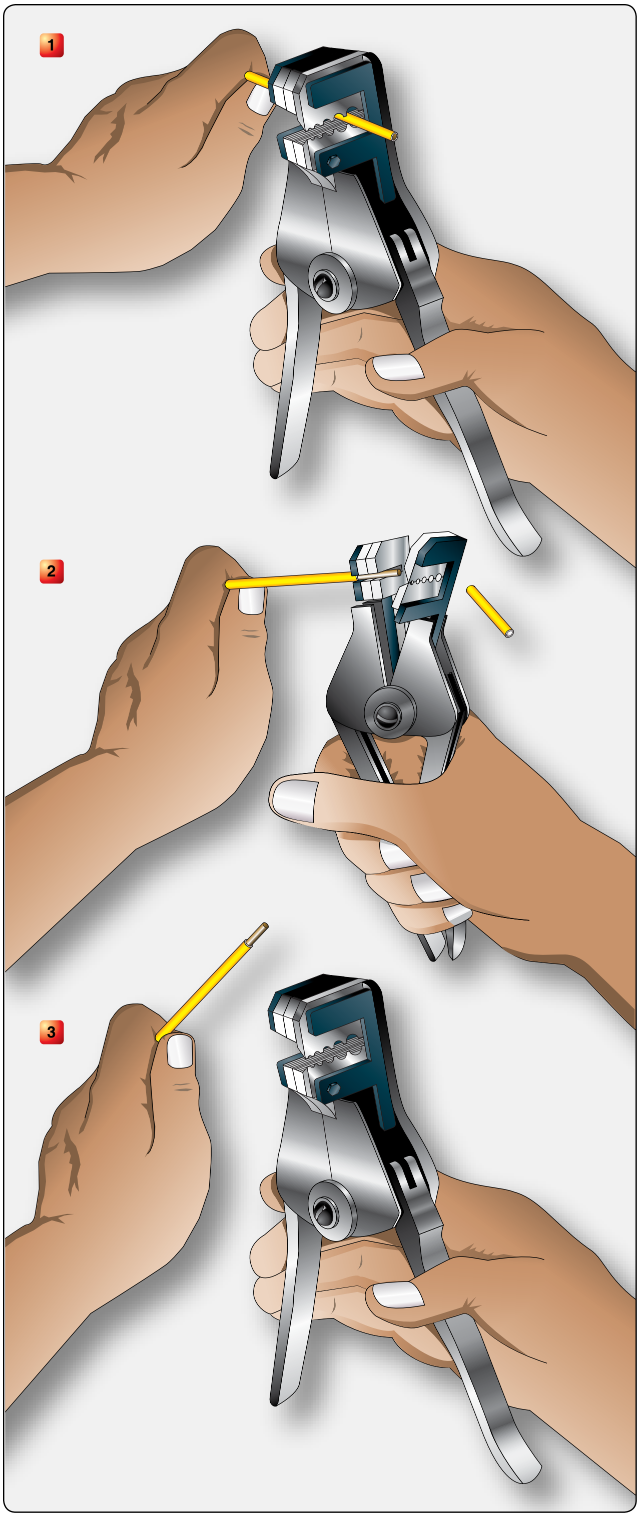


Figure 4-109. *Stripping wire with hand strippers.*

Terminal lugs are generally available in three types for use in different space conditions. These are the flag, straight, and right-angle lugs. Terminal lugs are crimped, sometimes called staked or swaged, to the wires by means of hand or power crimping tools.

Copper Wire Terminals

Copper wires are terminated with solderless, preinsulated straight copper terminal lugs. The insulation is part of the terminal lug and extends beyond its barrel so that it covers a portion of the wire insulation, making the use of an insulation sleeve unnecessary. *[Figure 4-110]*

In addition, preinsulated terminal lugs contain an insulation grip (a metal reinforcing sleeve) beneath the insulation for extra gripping strength on the wire insulation. Preinsulated terminals accommodate more than one size of wire; the insulation is usually color coded to identify the wire sizes that can be terminated with each of the terminal lug sizes.

Crimping Tools

Hand, portable power, and stationary power tools are available for crimping terminal lugs. These tools crimp the barrel of the terminal lug to the conductor and simultaneously crimp the insulation grip to the wire insulation.

Hand crimping tools all have a self-locking ratchet that prevents opening the tool until the crimp is complete. Some hand crimping tools are equipped with a nest of various size inserts to fit different size terminal lugs. Others are used on one terminal lug size only. All types of hand crimping tools are checked by gauges for proper adjustment of crimping jaws.

Figure 4-111 shows a terminal lug inserted into a hand tool. The following general guidelines outline the crimping procedure:

1. Strip the wire insulation to proper length.
2. Insert the terminal lug, tongue first, into the hand tool barrel crimping jaws until the terminal lug barrel butts flush against the tool stop.
3. Insert the stripped wire into the terminal lug barrel until the wire insulation butts flush against the end of the barrel.

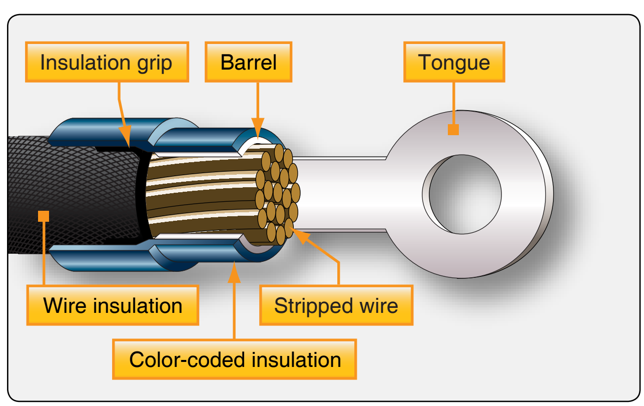


Figure 4-110. *Preinsulated terminal lug.*

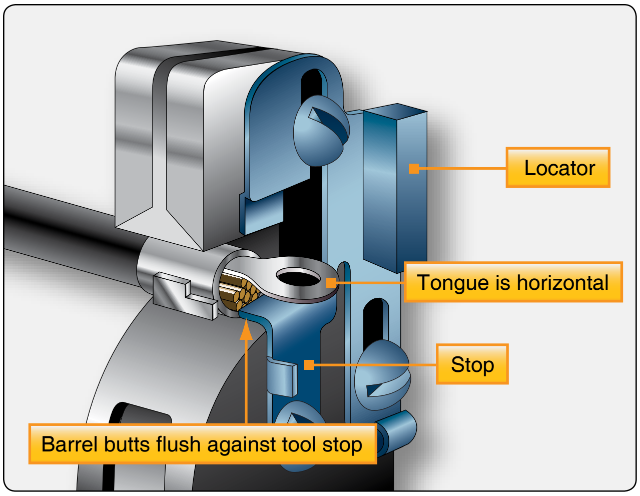


Figure 4-111. *Inserting terminal lug into hand tool.*

4. Squeeze the tool handles until the ratchet releases.
5. Remove the completed assembly and examine it for proper crimp.

Some types of uninsulated terminal lugs are insulated after assembly to a wire by means of pieces of transparent flexible tubing called sleeves. The sleeve provides electrical and mechanical protection at the connection. When the size of the sleeves used is such that it fits tightly over the terminal lug, the sleeves need not be tied; otherwise, it should be tied with lacing cord *[Figure 4-112]*

Aluminum Wire Terminals

Aluminum wire is being used increasingly in aircraft systems because of its weight advantage over copper. However, bending aluminum causes "work hardening" of the metal, making it brittle. This results in failure or breakage of strands much sooner than in a similar case with copper wire. Aluminum also forms a high-resistant oxide film immediately upon exposure to air. To compensate for these disadvantages, it is important to use the most reliable installation procedures. Only aluminum terminal lugs are used to terminate aluminum wires.

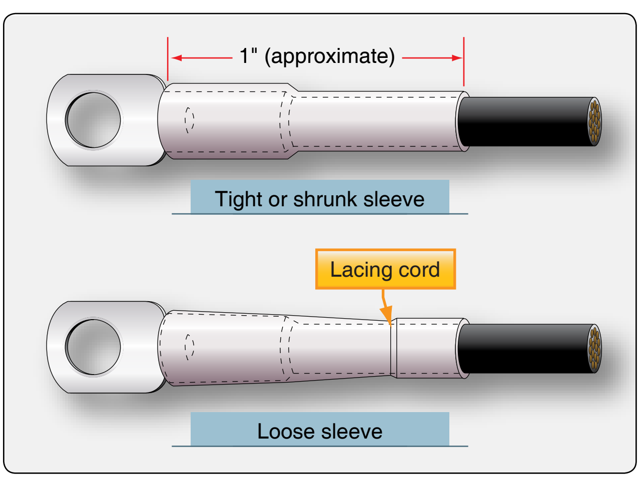


Figure 4-112. *Insulating sleeves.*

All aluminum terminals incorporate an inspection hole that permits checking the depth of wire insertion. *[Figure 4-113]* The barrel of aluminum terminal lugs is filled with a petrolatum-zinc dust compound. This compound removes the oxide film from the aluminum by a grinding process during the crimping operation. The compound also minimizes later oxidation of the completed connection by excluding moisture and air. The compound is retained inside the terminal lug barrel by a plastic or foil seal at the end of the barrel.

Splicing Copper Wires Using Preinsulated Wires

Preinsulated permanent copper splices join small wires of sizes 22 through 10. Each splice size can be used for more than one wire size. Splices are usually color coded in the same manner as preinsulated, small copper terminal lugs. Some splices are insulated with white plastic. Splices are also used to reduce wire sizes *[Figure 4-114]*

Crimping tools are used to accomplish this type of splice. The crimping procedures are the same as those used for terminal lugs, except that the crimping operation must be done twice, one for each end of the splice.

Emergency Splicing Repairs

Broken wires can be repaired by means of crimped splices, by using terminal lugs from which the tongue has been cut off, or by soldering together and potting broken strands. These repairs are applicable to copper wire. Damaged aluminum wire must not be temporarily spliced. These repairs are for temporary emergency use only and should be replaced as soon as possible with permanent repairs. Since some manufacturers prohibit splicing, the applicable manufacturer's instructions should always be consulted.

Splicing with Solder & Potting Compound

When neither a permanent splice nor a terminal lug is available, a broken wire can be repaired as follows *[Figure 4-115]*:

1. Install a piece of plastic sleeving about 3 inches long and of the proper diameter to fit loosely over the insulation on one piece of the broken wire.
2. Strip approximately 1½ inches from each broken end of the wire.
3. Lay the stripped ends side by side and twist one wire around the other with approximately four turns.
4. Twist the free end of the second wire around the first

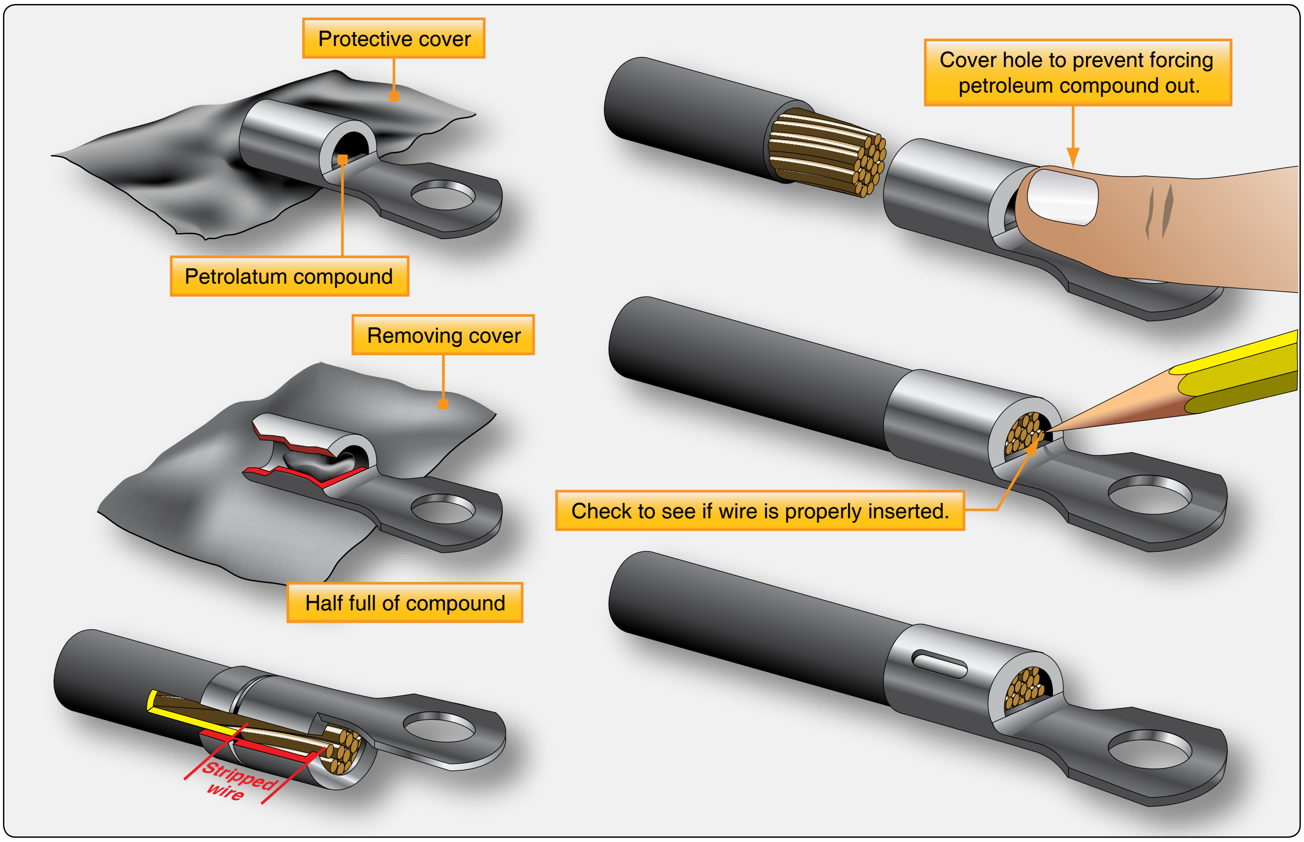


Figure 4-113. *Inserting aluminum wire into aluminum terminal lugs.*

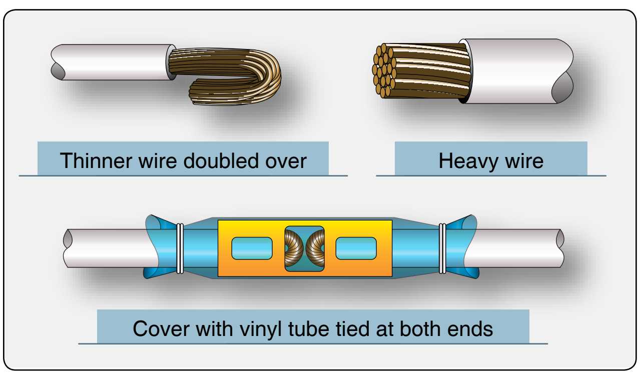


Figure 4-114. *Reducing wire size with a permanent splice.*

wire with approximately four turns. Solder the wire turns together using 60/40 tin-lead resin-core solder.

5. When solder is cool, draw the sleeve over the soldered wires and tie at one end. If potting compound is available, fill the sleeve with potting material and tie securely.
6. Allow the potting compound to set without touching for 4 hours. Full cure and electrical characteristics are achieved in 24 hours.

Connecting Terminal Lugs to Terminal Blocks

Terminal lugs should be installed on terminal blocks in such a manner that they are locked against movement in the direction of loosening. *[Figure 4-116]*

Terminal blocks are normally supplied with studs secured in place by a plain washer, an external tooth lockwasher, and a nut. In connecting terminals, a recommended practice is to place copper terminal jugs directly on top of the nut, followed with a plain washer and elastic stop nut, or with a plain washer, split steel lockwasher, and plain nut.

Aluminum terminal lugs should be placed over a plated brass plain washer, followed with another plated brass plain washer, split steel lockwasher, and plain nut or elastic stop nut. The plated brass washer should have a diameter equal to the tongue width of the aluminum terminal lug. Consult the manufacturer's instructions for recommended dimensions of these plated brass washers. Do not place any washer in the current path between two aluminum terminal lugs or between two copper terminal lugs. Also, do not place a lockwasher directly against the tongue or pad of the aluminum terminal. To join a copper terminal lug to an aluminum terminal lug, place a plated brass plain washer over the nut that holds the stud in place; follow with the aluminum terminal lug, a plated

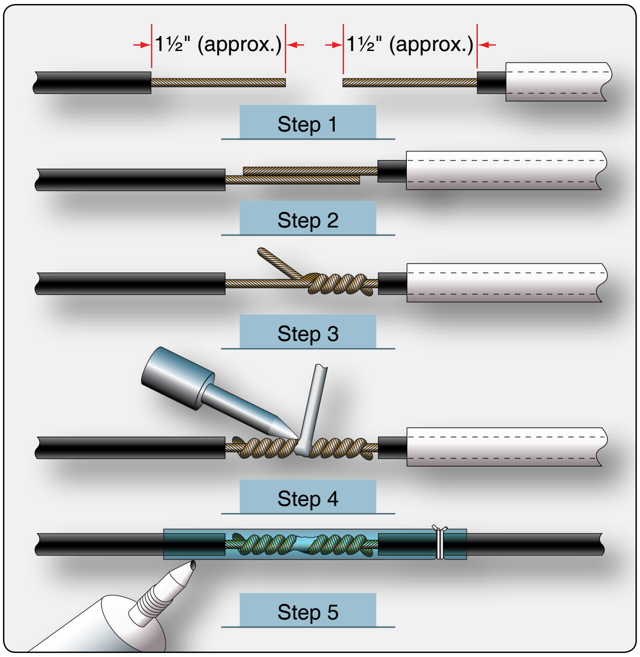


Figure 4-115. *Repairing broken wire by soldering and potting.*

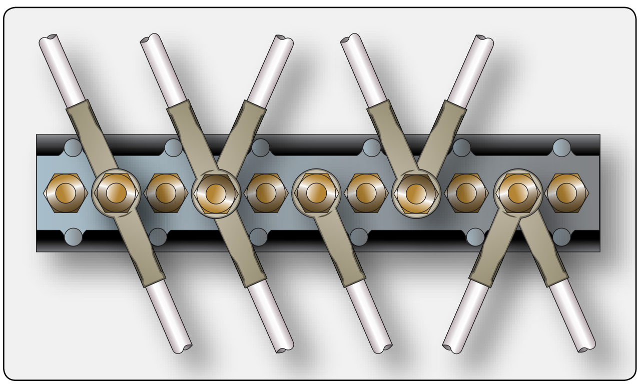


Figure 4-116. *Connecting terminals to terminal block.*

brass plain washer, the copper terminal lug, plain washer, split steel lockwasher and plain nut or self-locking, all metal nut. As a general rule, use a torque wrench to tighten nuts to ensure sufficient contact pressure. Manufacturer's instructions provide installation torques for all types of terminals.

Bonding & Grounding

Bonding is the electrical connecting of two or more conducting objects not otherwise connected adequately. Grounding is the electrical connecting of a conducting object to the primary structure for return of current. Primary structure is the main frame, fuselage, or wing structure of the aircraft. Bonding and grounding connections are made in aircraft electrical systems to:

1. Protect aircraft and personnel against hazards from lightning discharge,
2. Provide current return paths,
3. Prevent development of radio-frequency potentials,
4. Protect personnel from shock hazard,
5. Provide stability of radio transmission and reception, and
6. Prevent accumulation of static charge.

General Bonding & Grounding Procedures

The following general procedures and precautions are recommended when making bonding or grounding connections.

1. Bond or ground parts to the primary aircraft structure, where practicable.
2. Make bonding or grounding connections in such a manner that no part of the aircraft structure is weakened.
3. Bond parts individually, if possible.
4. Install bonding or grounding connections against smooth, clean surfaces.
5. Install bonding or grounding connections so that vibration, expansion or contraction, or relative movement in normal service does not break or loosen the connection.
6. Install bonding and grounding connections in protected areas whenever possible.

Bonding jumpers should be kept as short as practicable, and installed so that the resistance of each connection does not exceed 0.003 ohm. The jumper should not interfere with the operation of movable aircraft elements, such as surface controls; normal movement of these elements should not result in damage to the bonding jumper.

To be sure a low resistance connection has been made, nonconducting finishes, such as paint and anodizing films, should be removed from the surface to be contacted by the bonding terminal.

Electrolytic action can rapidly corrode a bonding connection if suitable precautions are not observed. Aluminum alloy jumpers are recommended for most cases; however, copper jumpers can be used to bond together parts made of stainless steel, cadmium-plated steel, copper, brass, or bronze. Where contact between dissimilar metals cannot be avoided, the choice of jumper and hardware should be such that corrosion is minimized, and the part most likely to corrode is the jumper or associated hardware. Parts A and B of *Figure 4-117* illustrate some proper hardware combinations for making bonding connections. At locations where finishes are removed, a protective finish should be applied to the completed connection to prevent corrosion.

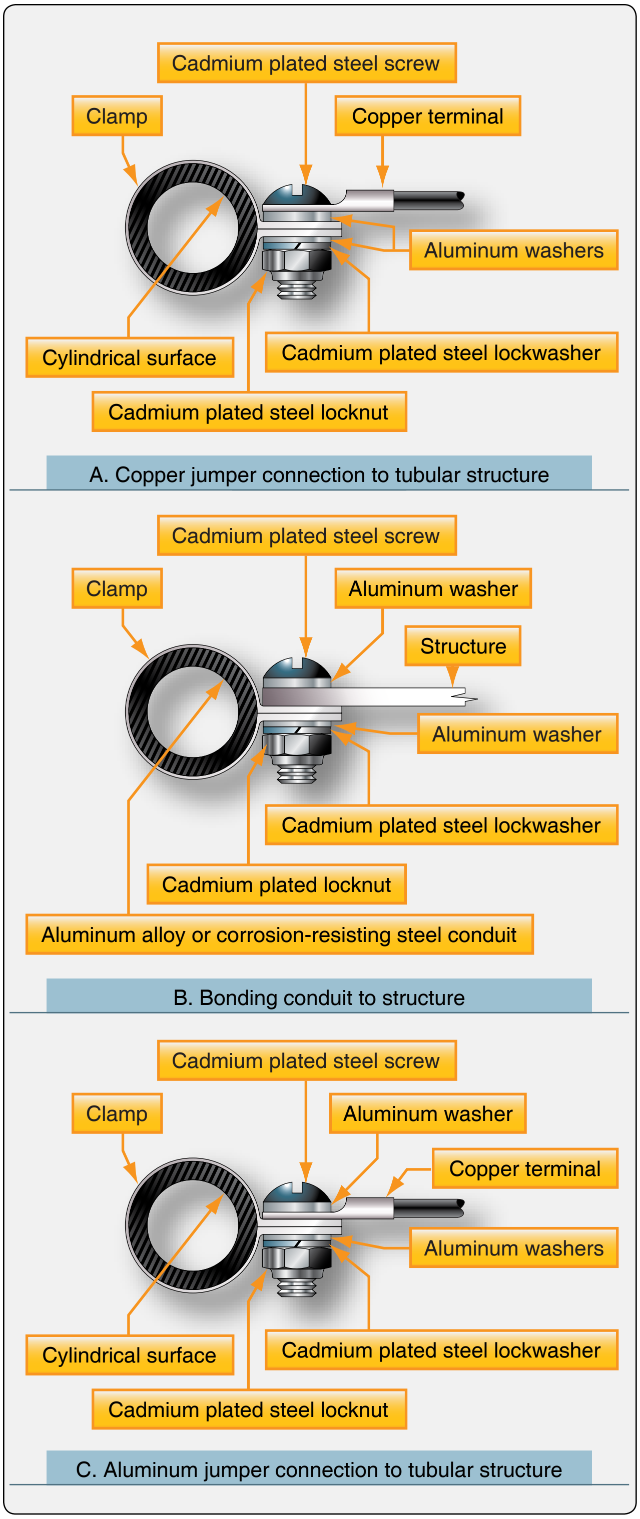


Figure 4-117. *Hardware combinations used in making bonding connections.*

The use of solder to attach bonding jumpers should be avoided. Tubular members should be bonded by means of clamps to which the jumper is attached. The proper choice of clamp material minimizes the probability of corrosion. When bonding jumpers carry a substantial amount of ground return current, the current rating of the jumper should be adequate, and it should be determined that a negligible voltage drop is produced.

Bonding and grounding connections are normally made to flat surfaces by means of through-bolts or screws where there is easy access for installation. The general types of bolted connections are:

1. In making a stud connection, a bolt or screw is locked securely to the structure becoming a stud. *[Figure 4-118]* Grounding or bonding jumpers can be removed or added to the shank of the stud without removing the stud from the structure.
2. Nutplates are used where access to the nut for repairs is difficult. Nutplates are riveted or welded to a clean area of the structure. *[Figure 4-119]*

Bonding and grounding connections are also made to a tab riveted to a structure. *[Figure 4-120]* In such cases, it is important to clean the bonding or grounding surface and make the connection as though the connection were being made to the structure. If it is necessary to remove the tab for any reason, the rivets should be replaced with rivets one size larger, and the mating surfaces of the structure and the tab should be clean and free of anodic film.

Bonding or grounding connections can be made to aluminum alloy, magnesium, or corrosion-resistant steel tubular

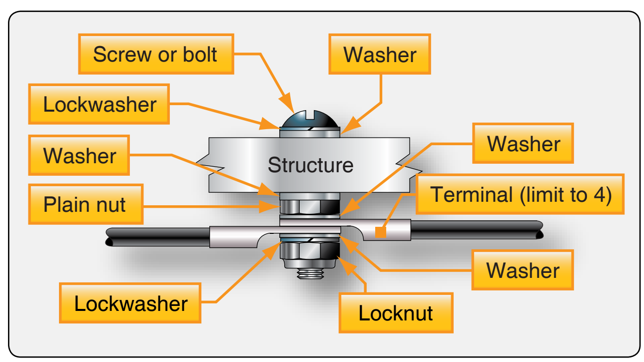


Figure 4-118. *Stud bonding or grounding to a flat surface.*

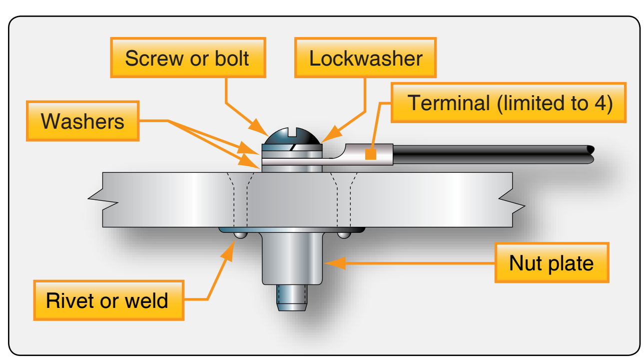


Figure 4-119. *Nut plate bonding or grounding to flat surface.*

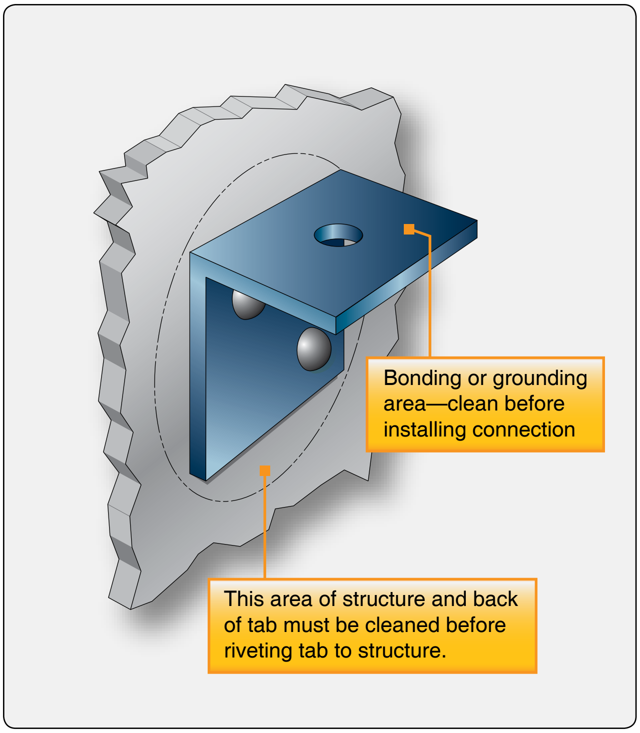


Figure 4-120. *Bonding or grounding tab riveted to structure.*

structure. *Figure 4-121* shows the arrangement of hardware for bonding with an aluminum jumper. Because of the ease with which aluminum is deformed, it is necessary to distribute screw and nut pressure by means of plain washers.

Hardware used to make bonding or grounding connections should be selected on the basis of mechanical strength, current to be carried, and ease of installation. If connection is made by aluminum or copper jumpers to the structure of a dissimilar material, a washer of suitable material should be installed between the dissimilar metals so that any corrosion occurs on the washer.

Hardware material and finish should be selected on the basis of the material of the structure to which attachment is made and on the material of the jumper and terminal specified for the bonding or grounding connection. Either a screw or bolt of the proper size for the specified jumper terminal should be used. When repairing or replacing existing bonding or grounding connections, the same type of hardware used in the original connection should always be used.

Connectors

Connectors (plugs and receptacles) facilitate maintenance when frequent disconnection is required. Since the cable is soldered to the connector inserts, the joints should be individually installed and the cable bundle firmly supported to avoid damage by vibration. Connectors have been particularly vulnerable to corrosion in the past, due to condensation within the shell. Special connectors with waterproof features have been developed that may replace nonwaterproof plugs in areas where moisture causes a problem. A connector of the same basic type and design should be used when replacing a connector. Connectors that are susceptible to corrosion difficulties may be treated with a chemically inert waterproof jelly. When replacing connector assemblies, the socket-type insert should be used on the half that is " live" or "hot" after the connector is disconnected to prevent unintentional grounding.

Types of Connectors

Connectors are identified by Air Force-Navy (AN) numbers and are divided into classes with the manufacturer's variations in each class. The manufacturer's variations are differences in appearance and in the method of meeting a specification. Some commonly used connectors are shown in *Figure 4-122*. There are five basic classes of AN connectors used in most aircraft. Each class of connector has slightly different construction characteristics. Classes A, B, C, and D are made of aluminum, and class K is made of steel.

1. Class A—solid, one-piece back shell general-purpose connector.

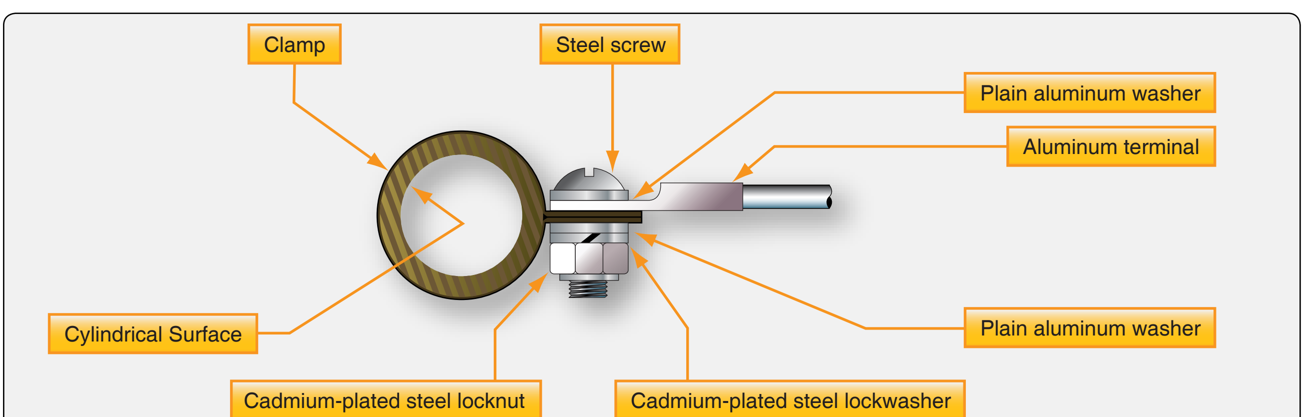


Figure 4-121. *Bonding or grounding connections to a cylindrical structure.*

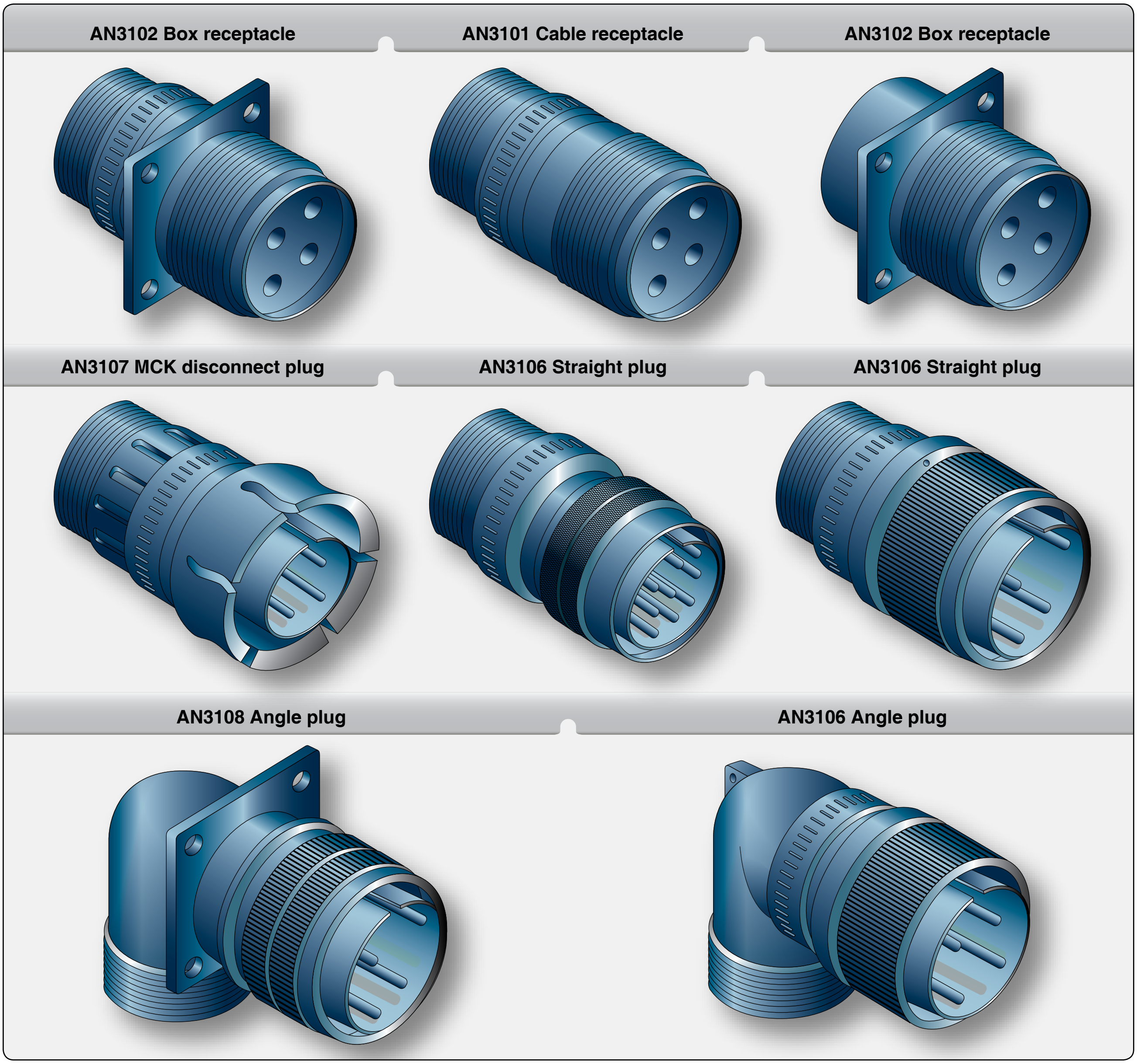


Figure 4-122. *AN connectors.*

2. Class B—connector back shell separates into two parts lengthwise. Used primarily where it is important that the soldered connectors are readily accessible. The back shell is held together by a threaded ring or by screws.
3. Class C—a pressurized connector with inserts that are not removable. Similar to a class A connector in appearance, but the inside sealing arrangement is sometimes different. It is used on walls or bulkheads of pressurized equipment.
4. Class D—moisture and vibration resistant connector that has a sealing grommet in the back shell. Wires are threaded through tight fitting holes in the grommet, sealing against moisture.
5. Class K—a fireproof connector used in areas where it is vital that the electric current is not interrupted, even though the connector may be exposed to continuous open flame. Wires are crimped to the pin or socket contacts and the shells are made of steel. This class of connector is normally longer than other connectors.

Connector Identification

Code letters and numbers are marked on the coupling ring or shell to identify a connector. This code provides all the information necessary to obtain the correct replacement for a defective or damaged part. *[Figure 4-123]*

Many special-purpose connectors have been designed for use in aircraft applications. These include subminiature and rectangular shell connectors, and connectors with short body shells, or of split-shell construction.

Installation of Connectors

The following procedures outline one recommended method of assembling connectors to receptacles:

1. Locate the proper position of the plug in relation to the receptacle by aligning the key of one part with the groove or keyway of the other part.
2. Start the plug into the receptacle with a slight forward pressure and engage the threads of the coupling ring and receptacle.
3. Alternately push in the plug and tighten the coupling ring until the plug is completely seated.
4. Use connector pliers to tighten coupling rings one-sixteenth to one-eighth turn beyond finger tight if space around the connector is too small to obtain a good finger grip.
5. Never use force to mate connectors to receptacles.

Do not hammer a plug into its receptacle and never use a torque wrench or pliers to lock coupling rings.

A connector is generally disassembled from a receptacle in the following manner:

1. Use connector pliers to loosen coupling rings that are too tight to be loosened by hand.
2. Alternately pull on the plug body and unscrew the coupling ring until the connector is separated.
3. Protect disconnected plugs and receptacles with caps or plastic bags to keep debris from entering and causing faults.
4. Do not use excessive force and do not pull on attached wires.

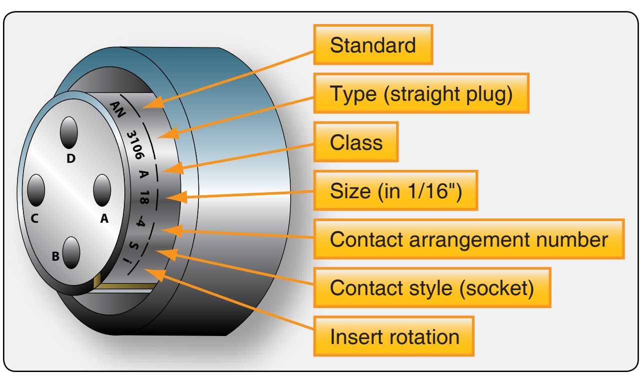


Figure 4-123. *AN connector markings.*

Conduit

Conduit is used in aircraft installations for the mechanical protection of wires and cables. It is available in metallic and nonmetallic materials and in both rigid and flexible form.

When selecting conduit size for a specific cable bundle application, it is common practice to allow for ease in maintenance and possible future circuit expansion by specifying the conduit inner diameter about 25 percent larger than the maximum diameter of the conductor bundle. The nominal diameter of a rigid metallic conduit is the outside diameter. Therefore, to obtain the inside diameter, subtract twice the tube wall thickness.

From the abrasion standpoint, the conductor is vulnerable at the ends of the conduit. Suitable fittings are affixed to conduit ends in such a manner that a smooth surface comes in contact with the conductor within the conduit. When fittings are not used, the conduit end should be flared to prevent wire insulation damage. The conduit is supported by clamps along the conduit run.

Many of the common conduit installation problems can be avoided by proper attention to the following details:

1. Do not locate conduit where it can be used as a handhold or footstep.
2. Provide drain holes at the lowest point in a conduit run. Drilling burrs should be carefully removed from the drain holes.
3. Support the conduit to prevent chafing against the structure and to avoid stressing its end fittings.

Damaged conduit sections should be repaired to prevent injury to the wires or wire bundle. The minimum acceptable tube bend radii for rigid conduit as prescribed by the manufacturer's instructions should be carefully followed. Kinked or wrinkled bends in a rigid conduit are normally not considered acceptable.

Flexible aluminum conduit is widely available in two types: bare flexible and rubber-covered conduit. Flexible brass conduit is normally used instead of flexible aluminum where it is necessary to minimize radio interference. Flexible conduit may be used where it is impractical to use rigid conduit, such as areas that have motion between conduit ends or where complex bends are necessary. Transparent adhesive tape is recommended when cutting flexible conduit with a hacksaw to minimize fraying of the braid.

Electrical Equipment Installation

This section provides general procedures and safety precautions for installation of commonly used aircraft electrical equipment and components. Electrical load limits, acceptable means of controlling or monitoring electrical loads, and circuit protection devices are subjects with which mechanics must be familiar to properly install and maintain aircraft electrical systems.

Electrical Load Limits

When installing additional electrical equipment that consumes electrical power in an aircraft, the total electrical load must be safely controlled or managed within the rated limits of the affected components of the aircraft's power-supply system. Regulation of the field current strength is used to control DC generator voltage.

Before any aircraft electrical load is increased, the associated wires, cables, and circuit-protection devices, such as fuses or circuit breakers, should be checked to determine that the new electrical load—previous maximum load plus added load—does not exceed the rated limits of the existing wires, cables, or protection devices.

The generator or alternator output ratings prescribed by the manufacturer should be compared with the electrical loads that can be imposed on the affected generator or alternator by installed equipment. When the comparison shows that the probable total connected electrical load can exceed the output load limits of the generator(s) or alternator(s), the load should be reduced so that an overload cannot occur. When a storage battery is part of the electrical power system, ensure that the battery is continuously charged in flight, except when short intermittent loads are connected, such as a radio transmitter, a landing gear motor, or other similar devices that may place short-time demand loads on the battery.

Controlling or Monitoring the Electrical Load

Placards are recommended to inform crewmembers of an aircraft about the combinations of loads that can safely be connected to the power source.

In installations where the ammeter is in the battery lead and the regulator system limits the maximum current that the generator or alternator can deliver, a voltmeter can be installed on the system bus. As long as the ammeter does not read discharge, except for short intermittent loads such as operating the gear and flaps, and the voltmeter remains at system voltage, the generator or alternator is not overloaded.

The ammeter can be redlined at 100 percent of the generator or alternator rating in installations with the ammeter in the generator or alternator lead, and the regulator system does not limit the maximum current that the generator or alternator can deliver. If the ammeter reading is never allowed to exceed the red line, except for short, intermittent loads, the generator or alternator is not overloaded.

Where the use of placards or monitoring devices is not practical or desired, and where assurance is needed that the battery in a typical small aircraft generator or battery power source is charged in flight, the total continuous connected electrical load may be held to approximately 80 percent of the total rated generator output capacity. When more than one generator is used in parallel, the total rated output is the combined output of the installed generators.

Means must be provided for quickly coping with the sudden overloads that can be caused by generator or engine failure if two or more generators are operated in parallel and the total connected system load can exceed the rated output of one generator. A quick load-reduction system can be employed or a specified procedure where the total load is reduced to a quantity that is within the rated capacity of the remaining operable generator or generators.

Electrical loads should be connected to inverters, alternators, or similar aircraft electrical power sources in such a manner that the rated limits of the power source are not exceeded, unless some type of effective monitoring means is provided to keep the load within prescribed limits.

Circuit Protection Devices

Conductors should be protected with circuit breakers or fuses located as close as possible to the electrical power source bus. Normally, the manufacturer of the electrical equipment specifies the fuse or circuit breaker to be used when installing the equipment.

The circuit breaker or fuse should open the circuit before the conductor emits smoke. To accomplish this, the time/current characteristic of the protection device must fall below that of the associated conductor. Circuit protector characteristics should be matched to obtain the maximum utilization of the connected equipment.

Figure 4-124 shows an example of the table used in selecting the circuit breaker and fuse protection for copper conductors. This limited table is applicable to a specific set of ambient temperatures and wire bundle sizes and is presented as a typical example only. It is important to consult such guides before selecting a conductor for a specific purpose. For example, a wire run individually in the open air may be protected by the circuit breaker of the next higher rating to that shown in the table.

Wire AN Gauge Copper	Circuit Breaker Amperage	Fuse Amperage
22	5.0	5
20	7.5	5
18	10.0	10
16	15.0	10
14	20.0	15
12	30.0	20
10	40.0	30
8	50.0	50
6	80.0	70
4	100.0	70
2	125.0	100
1		150
0		150

Figure 4-124. *Wire and circuit protector table.*

All resettable circuit breakers should open the circuit in which they are installed, regardless of the position of the operating control when an overload or circuit fault exists. Such circuit breakers are referred to as trip-free. Automatic reset circuit breakers automatically reset themselves periodically. They should not be used as circuit protection devices in aircraft.

Switches

A specifically designed switch should be used in all circuits in which a switch malfunction would be hazardous. Such switches are of rugged construction and have sufficient contact capacity to break, make, and carry continuously the connected load current. Snap-action design is generally preferred to obtain rapid opening and closing of contacts regardless of the speed of the operating toggle or plunger, thereby minimizing contact arcing.

The nominal current rating of the conventional aircraft switch is usually stamped on the switch housing. This rating represents the continuous current rating with the contacts closed. Switches should be derated from their nominal current rating for the following types of circuits:

1. High rush-in circuits—circuits containing incandescent lamps can draw an initial current that is 15 times greater than the continuous current. Contact burning or welding may occur when the switch is closed.
2. Inductive circuits—magnetic energy stored in solenoid coils or relays is released and appears as an arc as the control switch is opened.
3. Motors—direct current motors draw several times their rated current during starting, and magnetic energy stored in their armature and field coils is released when the control switch is opened.

Figure 4-125 is typical of those tables available for selecting the proper nominal switch rating when the continuous load current is known. This selection is essentially a derating to obtain reasonable switch efficiency and service life.

Hazardous errors in switch operation can be avoided by logical and consistent installation. Two position on-off switches should be mounted so that the on position is reached by an upward or forward movement of the toggle. When the switch controls movable aircraft elements, such as landing gear or flaps, the toggle should move in the same direction as the desired motion. Inadvertent operation of a switch can be prevented by mounting a suitable guard over the switch.

Relays

Relays are used as switching devices in which a weight reduction can be achieved or electrical controls can be simplified. A relay is an electrically operated switch and is therefore subject to dropout under low system voltage conditions. The previous discussion of switch ratings is generally applicable to relay contact ratings.

Nominal System Voltage	Type of Load	Derating Factor
24 VDC	Lamp	8
24 VDC	Inductive (Relay-Solenoid)	4
24 VDC	Resistive (Heater)	2
24 VDC	Motor	3
12 VDC	Lamp	5
12 VDC	Inductive (Relay-Solenoid)	2
12 VDC	Resistive (Heater)	1
12 VDC	Motor	2

Figure 4-125. *Switch derating factors.*