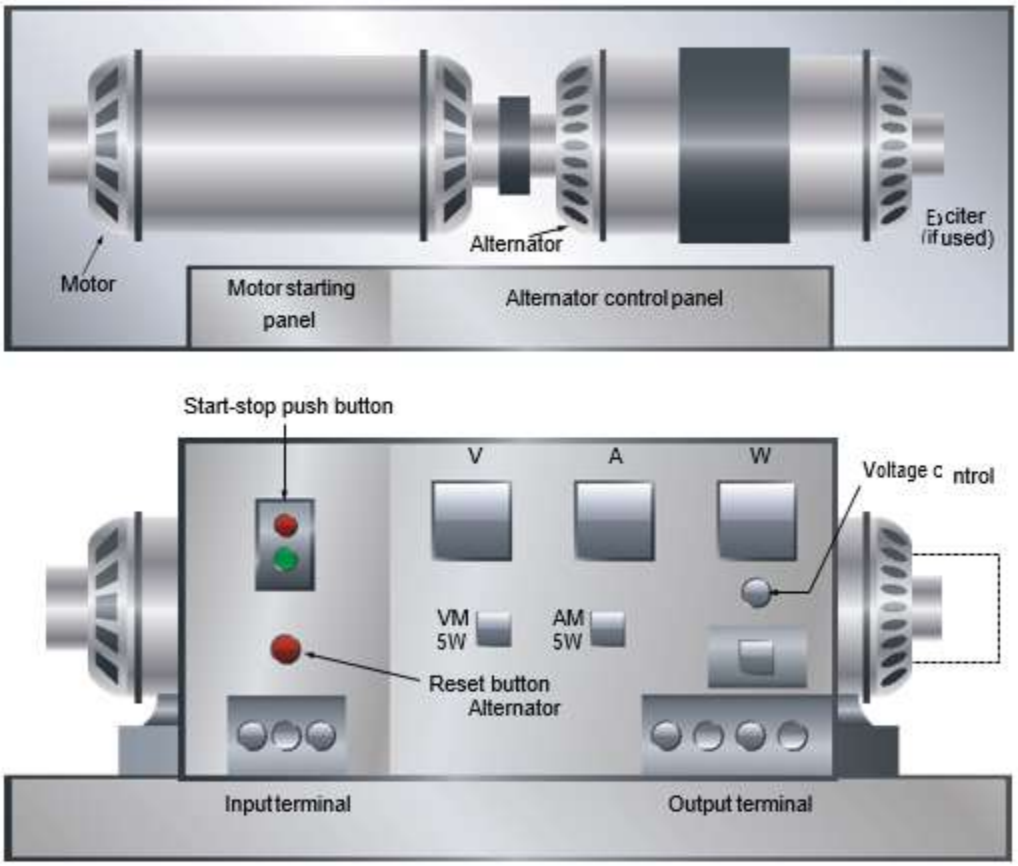
AC Motors, Alternators and Hydraulic Transmission



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AC Motors

Because of their advantages, many types of aircraft motors are designed to operate on alternating current. In general, AC motors are less expensive than comparable DC motors. In many instances, AC motors do not use brushes and commutators so sparking at the brushes is avoided. AC motors are reliable and require little maintenance. They are also well suited for constant speed applications and certain types are manufactured that have, within limits, variable speed characteristics. Alternating current motors are designed to operate on polyphase or single phase lines and at several voltage ratings.

The speed of rotation of an AC motor depends upon the number of poles and the frequency of the electrical source of power:

$$\text{rpm} = \frac{120 \times \text{Frequency}}{\text{Number of poles}}$$

Since airplane electrical systems typically operate at 400 cycles, an electric motor at this frequency operates at about seven times the speed of a 60 cycle commercial motor with the same number of poles. Because of this high speed of rotation, 400-cycle AC motors are suitable for operating small high-speed rotors, through reduction gears, in lifting and moving heavy loads, such as the wing flaps, the retractable landing gear, and the starting of engines. The 400-cycle induction type motor operates at speeds ranging from 6,000 rpm to 24,000 rpm. Alternating current motors are rated in horsepower output, operating voltage, full load current, speed, number of phases, and frequency. Whether the motors operate continuously or intermittently (for short intervals) is also considered in the rating.

Types of AC Motors

There are two general types of AC motors used in aircraft systems: induction motors and synchronous motors. Either type may be single phase, two phase, or three phase. Three phase induction motors are used where large amounts of power are required. They operate such devices as starters, flaps, landing gears, and hydraulic pumps. Single phase induction motors are used to operate devices such as surface locks, intercooler shutters, and oil shutoff valves in which the power requirement is low. Three phase synchronous motors operate at constant synchronous speeds and are commonly used to operate flux gate compasses and propeller synchronizer systems. Single phase synchronous motors are common sources of power to operate electric clocks and other small precision equipment. They require some auxiliary method to bring them up to synchronous speeds; that is, to start them. Usually the starting winding consists of an auxiliary stator winding.

Three Phase Induction Motor

The three phase AC induction motor is also called a squirrel cage motor. Both single phase and three phase motors operate on the principle of a rotating magnetic field. A horseshoe magnet held over a compass needle is a simple illustration of the principle of the rotating field. The needle will take a position parallel to the magnetic flux passing between the two poles of the magnet. If the magnet is rotated, the compass needle will follow. A rotating magnetic field can be produced by a two or three phase current flowing through two or more groups of coils wound on inwardly projecting poles of an iron frame. The coils on each group of poles are wound alternately in opposite directions to produce opposite polarity, and each group is connected to a separate phase of voltage. The operating principle depends on a revolving, or rotating, magnetic field to produce torque. The key to understanding the induction motor is a thorough understanding of the rotating magnetic field.

Rotating Magnetic Field

The field structure shown in Figure 10-292A has poles whose windings are energized by three AC voltages, a, b, and c. These voltages have equal magnitude but differ in phase, as shown in Figure 10-292B: at the instant of time shown as 0, the resultant magnetic field produced by the application of the three voltages has its greatest intensity in a direction extending from pole 1 to pole 4. Under this condition, pole 1 can be considered as a north pole and pole 4 as a south pole. At the instant of time shown as 1, the resultant magnetic field

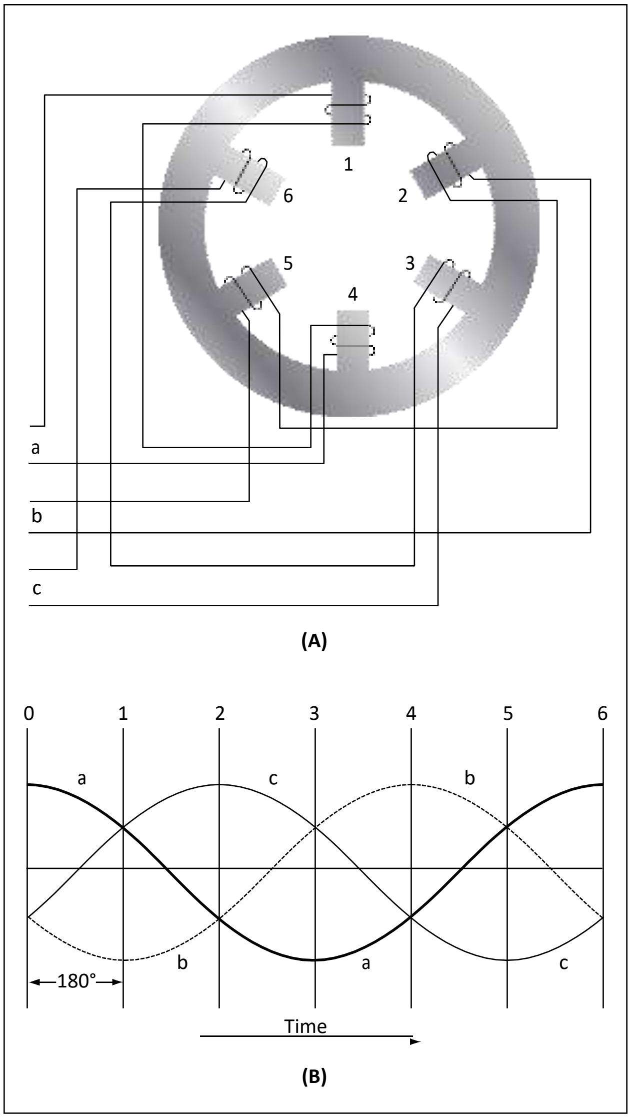

Figure 10-292. Rotating magnetic field developed by application of three phase voltages.

will have its greatest intensity in the direction extending from pole 2 to pole 5; in this case, pole 2 can be considered as a north pole and pole 5 as a south pole. Thus, between instant 0 and instant 1, the magnetic field has rotated clockwise. At instant 2, the resultant magnetic field has its greatest intensity in the direction from pole 3 to pole 6, and the resultant magnetic field has continued to rotate clockwise. At instant 3, poles 4 and 1 can be considered as north and south poles, respectively, and the field has rotated still farther. At later instants of time, the resultant magnetic field rotates to other positions while traveling in a clockwise direction, a single revolution of the field occurring in one cycle. If the exciting voltages have a frequency of 60 cps, the magnetic field makes 60 revolutions per second, or 3,600 rpm. This speed is known as the synchronous speed of the rotating field.

Construction of Induction Motor

The stationary portion of an induction motor is called a stator, and the rotating member is called a rotor. Instead of salient poles in the stator, as shown in A of Figure 10-292, distributed windings are used; these windings are placed in slots around the periphery of the stator. It is usually impossible to determine the number of poles in an induction motor by visual inspection, but the information can be obtained from the nameplate of the motor. The nameplate usually gives the number of poles and the speed at which the motor is designed to run. This rated, or nonsynchronous, speed is slightly less than the synchronous speed. To determine the number of poles per phase on the motor, divide 120 times the frequency by the rated speed. Written as an equation, it is:

$$P = \frac{120 \times f}{N}$$

Where: P is the number of poles per phase,
f is the frequency in cps,
N is the rated speed in rpm, and
120 is a constant.

The result will be very nearly equal to the number of poles per phase. For example, consider a 60 cycle, three phase motor with a rated speed of 1,750 rpm. In this case:

$$P = \frac{120 \times 60}{1{,}750} = \frac{7{,}200}{1{,}750} = 4.1$$

Therefore, the motor has four poles per phase. If the number of poles per phase is given on the nameplate, the synchronous speed can be determined by dividing 120 times the frequency by the number of poles per phase. In the example used above, the synchronous speed is equal to 7,200 divided by 4, or 1,800 rpm.

The rotor of an induction motor consists of an iron core having longitudinal slots around its circumference in which heavy copper or aluminum bars are embedded. These bars are welded to a heavy ring of high conductivity on either end. The composite structure is sometimes called a squirrel cage, and motors containing such a rotor are called squirrel cage induction motors. [Figure 10-293]

Induction Motor Slip

When the rotor of an induction motor is subjected to the revolving magnetic field produced by the stator windings, a voltage is induced in the longitudinal bars. The induced voltage causes a current to flow through

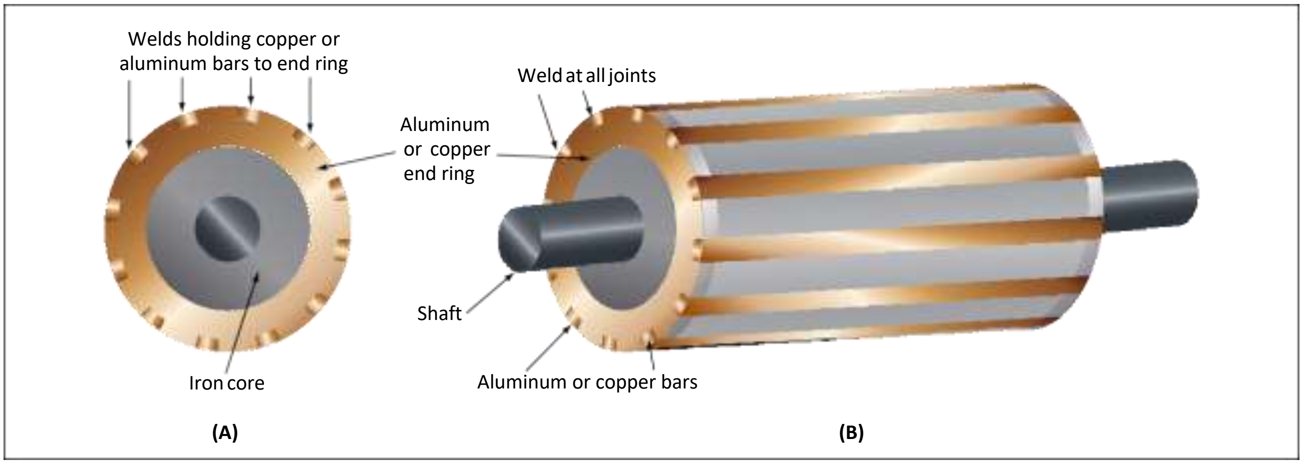

Figure 10-293. Squirrel cage rotor for an AC induction motor.

the bars. This current, in turn, produces its own magnetic field, which combines with the revolving field so that the rotor assumes a position in which the induced voltage is minimized. As a result, the rotor revolves at very nearly the synchronous speed of the stator field, the difference in speed being just sufficient enough to induce the proper amount of current in the rotor to overcome the mechanical and electrical losses in the rotor. If the rotor were to turn at the same speed as the rotating field, the rotor conductors would not be cut by any magnetic lines of force, no emf would be induced in them, no current could flow, and there would be no torque. The rotor would then slow down. For this reason, there must always be a difference in speed between the rotor and the rotating field. This difference in speed is called slip and is expressed as a percentage of the synchronous speed. For example, if the rotor turns at 1,750 rpm and the synchronous speed is 1,800 rpm, the difference in speed is 50 rpm. The slip is then equal to 50/1,800 or 2.78 percent.

Single Phase Induction Motor

The previous discussion has applied only to polyphase motors. A single-phase motor has only one stator winding. This winding generates a field, which merely pulsates, instead of rotating. When the rotor is stationary, the expanding and collapsing stator field induces currents in the rotor. These currents generate a rotor field opposite in polarity to that of the stator. The opposition of the field exerts a turning force on the upper and lower parts of the rotor trying to turn it 180° from its position. Since these forces are exerted through the center of the rotor, the turning force is equal in each direction. As a result, the rotor does not turn. If the rotor has started turning, it will continue to rotate in the direction in which it is started, since the turning force in that direction is aided by the momentum of the rotor.

Shaded Pole Induction Motor

The first effort in the development of a self-starting, single-phase motor was the shaded pole induction motor. [Figure 10-294] This motor has salient poles, a portion of each pole being encircled by a heavy copper ring. The presence of the ring causes the magnetic field through the ringed portion of the pole face to lag appreciably behind that through the other part of the pole face. The net effect is the production of a slight component of rotation of the field, sufficient to cause the rotor to revolve. As the rotor accelerates, the torque increases until the rated speed is obtained. Such

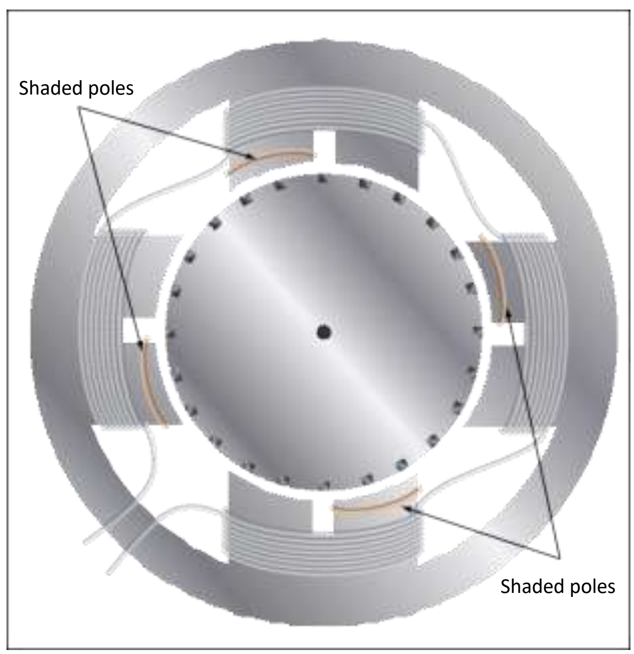

Figure 10-294. Shaded pole induction motor.

motors have low starting torque and find their greatest application in small fan motors where the initial torque required is low.

In Figure 10-295, a diagram of a pole and the rotor is shown. The poles of the shaded pole motor resemble those of a DC motor.

A low resistance, short-circuited coil or copper band is placed across one tip of each small pole, from which, the motor gets the name of shaded pole. The rotor of this motor is the squirrel cage type. As the current increases in the stator winding, the flux increases. A portion of this flux cuts the low resistance shading coil. This induces a current in the shading coil, and by Lenz's law, the current sets up a flux that opposes the flux inducing the current. Hence, most of the flux passes through the unshaded portion of the poles, as shown in Figure 10-295.

When the current in the winding and the main flux reaches a maximum, the rate of change is zero; thus, no emf is induced in the shading coil. A little later, the shading coil current, which causes the induced emf to lag, reaches zero, and there is no opposing flux. Therefore, the main field flux passes through the shaded portion of the field pole. The main field flux, which is now decreasing, induces a current in the shading coil. This current sets up a flux that opposes the decrease of the main field flux in the shaded portion of the pole. The effect is to concentrate the lines of force in the shaded portion of the pole face. In effect, the shading coil retards, in time phase, the portion of the flux passing through the shaded part of the pole. This lag in time phase of the flux in the shaded tip causes the flux to produce the effect of sweeping across the face of the pole, from left to right in the direction of the shaded tip. This behaves like a very weak rotating magnetic field, and sufficient torque is produced to start a small motor. The starting torque of the shaded pole motor is exceedingly weak, and the power factor is low. Consequently, it is built in sizes suitable for driving such devices as small fans.

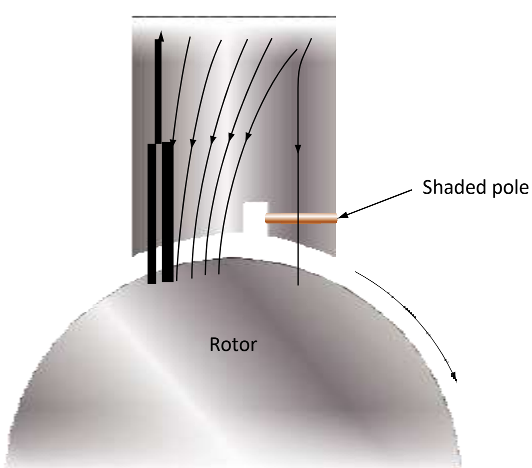

Figure 10-295. Diagram of a shaded pole motor.

Split Phase Motor

There are various types of self-starting motors, known as split phase motors. Such motors have a starting winding displaced 90 electrical degrees from the main or running winding. In some types, the starting winding has a fairly high resistance, which causes the current in this winding to be out of phase with the current in the running winding. This condition produces, in effect, a rotating field and the rotor revolves. A centrifugal switch disconnects the starting winding automatically, after the rotor has attained approximately 25 percent of its rated speed.

Capacitor Start Motor

With the development of high capacity electrolytic capacitors, a variation of the split phase motor, known as the capacitor start motor, has been made. Nearly all fractional horsepower motors in use today on refrigerators and other similar appliances are of this type. [Figure 10-296] In this adaptation, the starting winding and running winding have the same size and resistance value. The phase shift between currents of the two windings is obtained by using capacitors connected in series with the starting winding.

Capacitor start motors have a starting torque comparable to their torque at rated speed and can be used in applications where the initial load is heavy. Again, a centrifugal switch is required for disconnecting the starting winding when the rotor speed is approximately 25 percent of the rated speed.

Although some single phase induction motors are rated as high as 2 horsepower (hp), the major field of application is 1 hp, or less, at a voltage rating of 115 volts for the smaller sizes and 110 to 220 volts for one-fourth hp and up. For even larger power ratings, polyphase motors generally are used, since they have excellent starting torque characteristics.

Direction of Rotation of Induction Motors

The direction of rotation of a three phase induction motor can be changed by simply reversing two of the leads to the motor. The same effect can be obtained in a two phase motor by reversing connections to one phase. In a single phase motor, reversing connections to the starting winding will reverse the direction of rotation.

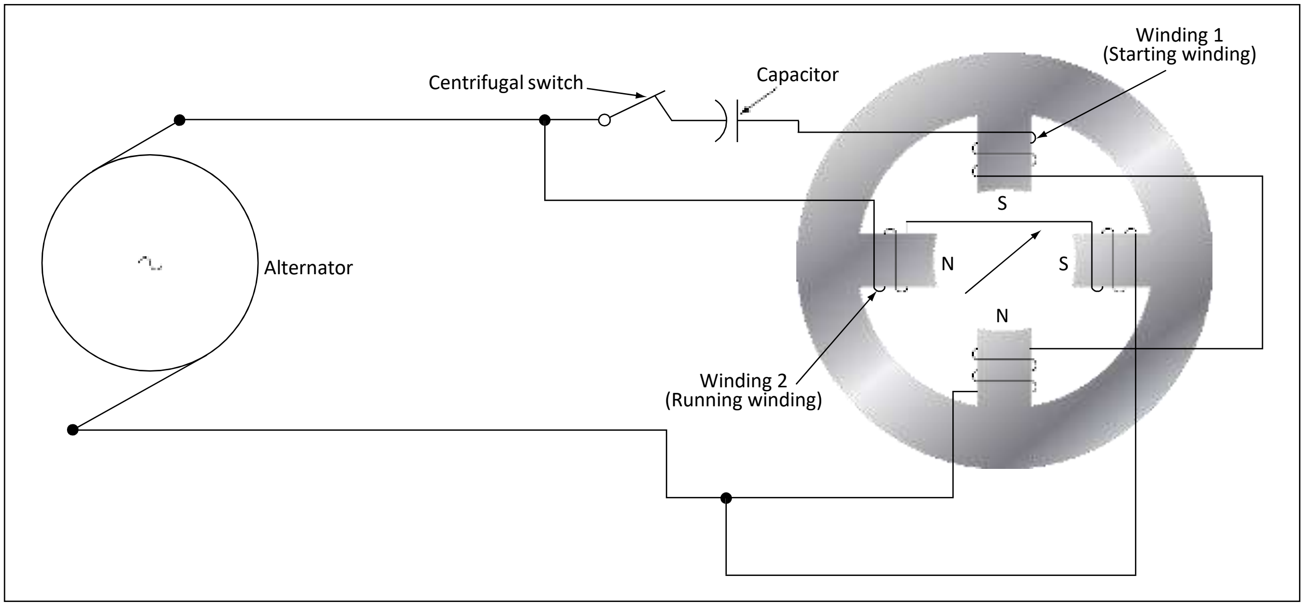

Figure 10-296. Single phase motor with capacitor starting winding.

Most single phase motors designed for general application have provision for readily reversing connections to the starting winding. Nothing can be done to a shaded pole motor to reverse the direction of rotation because the direction is determined by the physical location of the copper shading ring. If, after starting, one connection to a three phase motor is broken, the motor will continue to run but will deliver only one-third the rated power. Also, a two phase motor will run at one-half its rated power if one phase is disconnected. Neither motor will start under these abnormal conditions.

Synchronous Motor

The synchronous motor is one of the principal types of AC motors. Like the induction motor, the synchronous motor makes use of a rotating magnetic field. Unlike the induction motor, however, the torque developed does not depend on the induction of currents in the rotor. Briefly, the principle of operation of the synchronous motor is as follows: A multiphase source of AC is applied to the stator windings, and a rotating magnetic field is produced. A direct current is applied to the rotor winding, and another magnetic field is produced. The synchronous motor is so designed and constructed that these two fields react to each other in such a manner that the rotor is dragged along and rotates at the same speed as the rotating magnetic field produced by the stator windings.

An understanding of the operation of the synchronous motor can be obtained by considering the simple motor of Figure 10-297. Assume that poles A and B are being rotated clockwise by some mechanical means in order to produce a rotating magnetic field, they induce poles of opposite polarity in the soft iron rotor, and forces of attraction exist between corresponding north and south poles.

Consequently, as poles A and B rotate, the rotor is dragged along at the same speed. However, if a load is applied to the rotor shaft, the rotor axis will momentarily fall behind that of the rotating field but, thereafter, will continue to rotate with the field at the same speed, as long as the load remains constant. If the load is too large, the rotor will pull out of synchronism with the rotating field and, as a result, will no longer rotate with the field at the same speed. Thus the motor is said to be overloaded.

Such a simple motor as that shown in Figure 10-297 is never used. The idea of using some mechanical means of rotating the poles is impractical because another motor would be required to perform this work. Also, such an arrangement is unnecessary because a rotating magnetic field can be produced electrically by using phased AC voltages. In this respect, the synchronous motor is similar to the induction motor.

The synchronous motor consists of a stator field winding similar to that of an induction motor. The stator winding produces a rotating magnetic field. The rotor may be a permanent magnet, as in small single phase synchronous motors used for clocks and other small precision equipment, or it may be an electromagnet, energized from a DC source of power and fed through slip rings into the rotor field coils, as in an alternator.

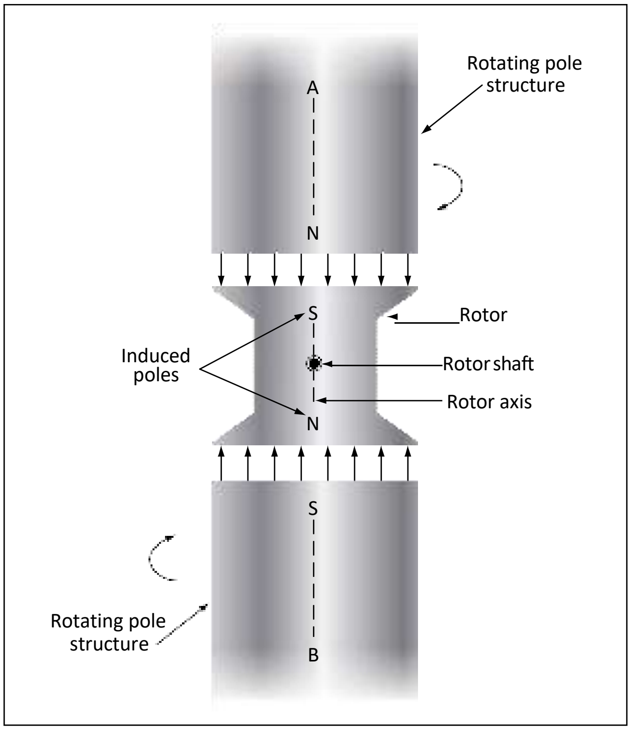

Figure 10-297. Illustrating the operation of a synchronous motor.

In fact, an alternator may be operated either as an alternator or a synchronous motor.

Since a synchronous motor has little starting torque, some means must be provided to bring it up to synchronous speed. The most common method is to start the motor at no load, allow it to reach full speed, and then energize the magnetic field. The magnetic field of the rotor locks with the magnetic field of the stator and the motor operates at synchronous speed.

The magnitude of the induced poles in the rotor shown in Figure 10-298 is so small that sufficient torque cannot be developed for most practical loads. To avoid such a limitation on motor operation, a winding is placed on the rotor and energized with DC. A rheostat placed in series with the DC source provides the operator of the machine with a means of varying the strength of the rotor poles, thus placing the motor under control for varying loads.

The synchronous motor is not a self-starting motor. The rotor is heavy and, from a dead stop, it is impossible to bring the rotor into magnetic lock with the rotating magnetic field. For this reason, all synchronous motors have some kind of starting device. One type

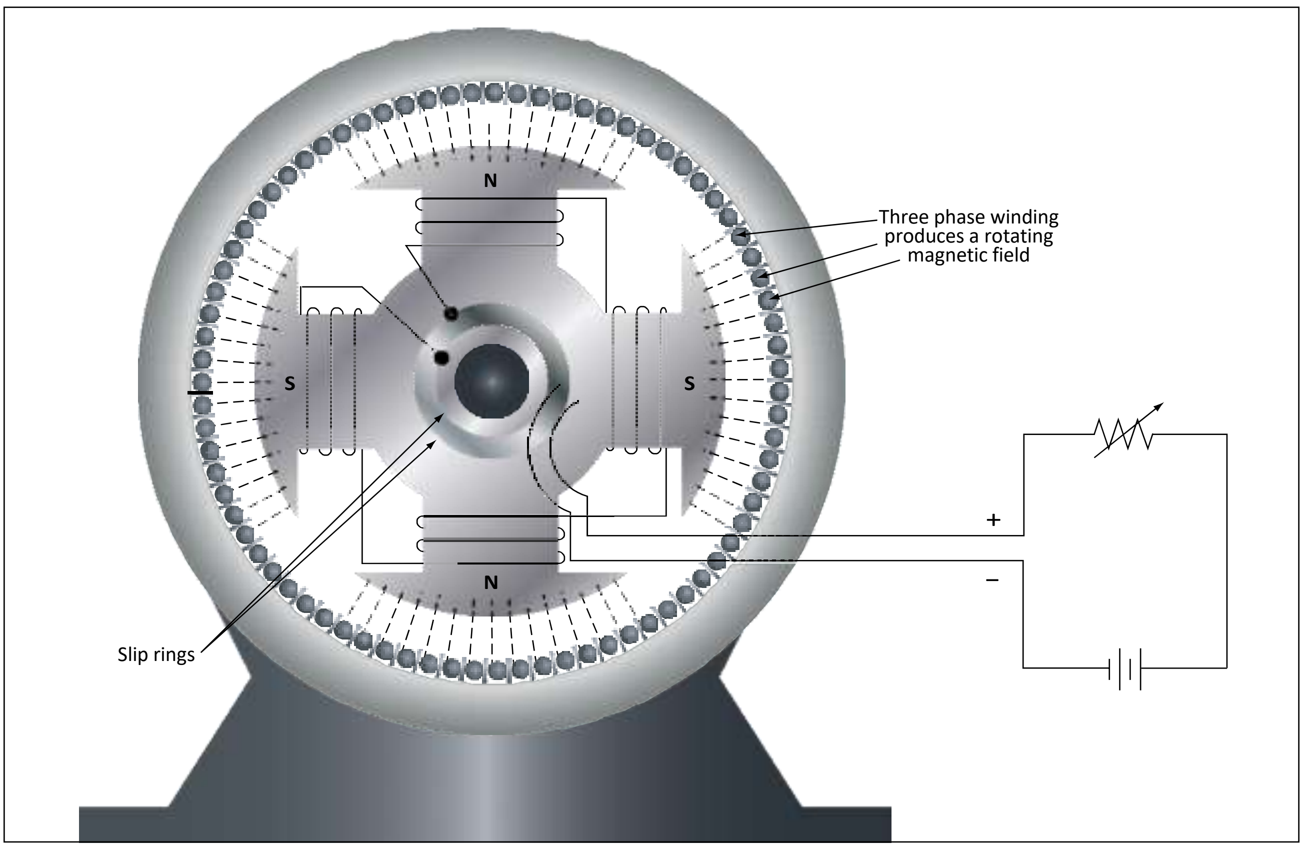

Figure 10-298. Synchronous motor.

of simple starter is another motor, either AC or DC, which brings the rotor up to approximately 90 percent of its synchronous speed. The starting motor is then disconnected, and the rotor locks in step with the rotating field. Another starting method is a second winding of the squirrel cage type on the rotor. This induction winding brings the rotor almost to synchronous speed, and when the DC is connected to the rotor windings, the rotor pulls into step with the field. The latter method is the more commonly used.

AC Series Motor

An alternating current series motor is a single phase motor, but is not an induction or synchronous motor. It resembles a DC motor in that it has brushes and a commutator. The AC series motor will operate on either AC or DC circuits. It will be recalled that the direction of rotation of a DC series motor is independent of the polarity of the applied voltage, provided the field and armature connections remain unchanged. Hence, if a DC series motor is connected to an AC source, a torque will be developed which tends to rotate the armature in one direction. However, a DC series motor does not operate satisfactorily from an AC supply for the following reasons:

1. The alternating flux sets up large eddy current and hysteresis losses in the unlaminated portions of the magnetic circuit and causes excessive heating and reduced efficiency.
2. The self induction of the field and armature windings causes a low power factor.
3. The alternating field flux establishes large currents in the coils, which are short circuited by the brushes; this action causes excessive sparking at the commutator.

To design a series motor for satisfactory operation on AC, the following changes are made:

1. The eddy current losses are reduced by laminating the field poles, frame and armature.
2. Hysteresis losses are minimized by using high permeability, transformer-type, silicon steel laminations.
3. The reactance of the field windings is kept satisfactorily low by using shallow pole pieces, few turns of wire, low frequency (usually 25 cycles for large motors), low flux density, and low reluctance (a short air gap).
4. The reactance of the armature is reduced by using a compensating winding embedded in the pole pieces. If the compensating winding is connected in series with the armature, as shown in Figure 10-299, the armature is conductively compensated.

If the compensating winding is designed as shown in Figure 10-300, the armature is inductively compensated. If the motor is designed for operation on both DC and AC circuits, the compensating winding is connected in series with the armature. The axis of the compensating winding is displaced from the main field axis by an angle of 90°. This arrangement is similar to the compensating winding used in some DC motors and generators to overcome armature reaction. The compensating winding establishes a counter magnetomotive force, neutralizing the effect of the armature magnetomotive force, preventing distortion of the main field flux, and reducing the armature reactance. The inductively compensated armature acts like the primary of a transformer, the secondary

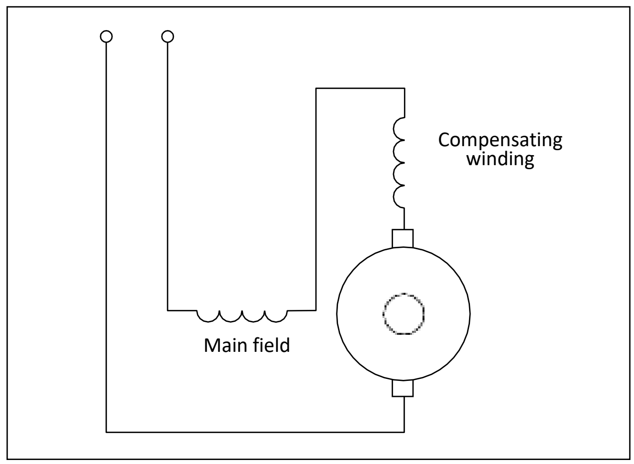

Figure 10-299. Conductivety compensated armature of AC series motor.

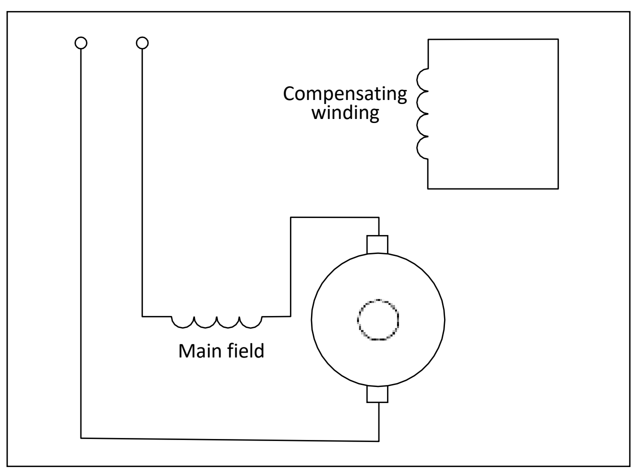

Figure 10-300. Inductively compensated armature of AC series motor.

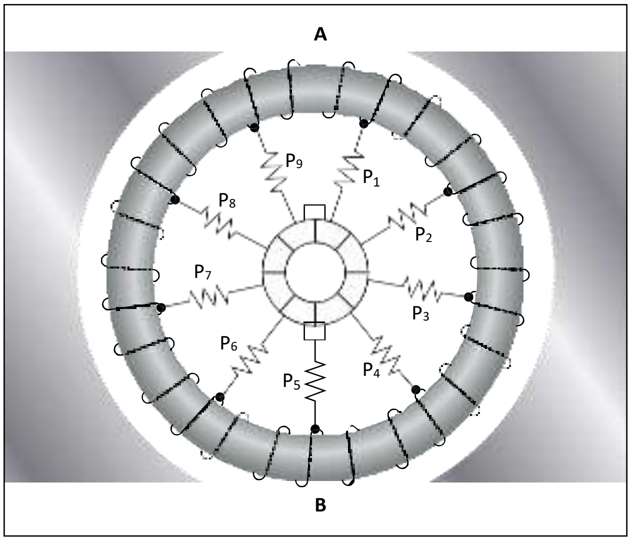

Figure 10-301. Preventive coils in AC series motor.

of which is the shorted compensating winding. The shorted secondary receives an induced voltage by the action of the alternating armature flux, and the resulting current flowing through the turns of the compensating winding establishes the opposing magnetomotive force, neutralizing the armature reactance.

5. Sparking at the commutator is reduced by the use of preventive leads P_1, P_2, P_3, and so forth, as shown in Figure 10-301, where a ring armature is shown for simplicity. When coils at A and B are shorted by the brushes, the induced current is limited by the relatively high resistance of the leads. Sparking at the brushes is also reduced by using armature coils having only a single turn and multipolar fields. High torque is obtained by having a large number of armature conductors and a large diameter armature. Thus, the commutator has a large number of very thin commutator bars and the armature voltage is limited to about 250 volts.

Fractional horsepower AC series motors are called universal motors. They do not have compensating windings or preventive leads. They are used extensively to operate fans and portable tools, such as drills, grinders, and saws.

Maintenance of AC Motors

The inspection and maintenance of AC motors is very simple. The bearings may or may not need frequent lubrication. If they are the sealed type, lubricated at the factory, they require no further attention. Be sure the coils are kept dry and free from oil or other abuse. The temperature of a motor is usually its only limiting operating factor. A good rule of thumb is that a temperature too hot for the hand is too high for safety. Next to the temperature, the sound of a motor or generator is the best trouble indicator. When operating properly, it should hum evenly. If it is overloaded it will "grunt." A three phase motor with one lead disconnected will refuse to turn and will "growl." A knocking sound generally indicates a loose armature coil, a shaft out of alignment, or armature dragging because of worn bearings.

In all cases, the inspection and maintenance of all AC motors should be performed in accordance with the applicable manufacturer's instructions.

Alternators

Basic Alternators and Classifications

An electrical generator is a machine, which converts mechanical energy into electrical energy by electromagnetic induction. A generator which produces alternating current is referred to as an AC generator and, through combination of the words "alternating" and "generator," the word "alternator" has come into widespread use. In some areas, the word "alternator" is applied only to small AC generators. This text treats the two terms synonymously and uses the term "alternator" to distinguish between AC and DC generators.

The major difference between an alternator and a DC generator is the method of connection to the external circuit; that is, the alternator is connected to the external circuit by slip rings, but the DC generator is connected by a commutator.

Method of Excitation

One means of classification is by the type of excitation system used. In alternators used on aircraft, excitation can be affected by one of the following methods:

1. *A direct connected, direct current generator.* This system consists of a DC generator fixed on the same shaft with the AC generator. A variation of this system is a type of alternator which uses DC from the battery for excitation, after which the alternator is self-excited.
2. *By transformation and rectification from the AC system.* This method depends on residual magnetism for initial AC voltage buildup, after which the field is supplied with rectified voltage from the AC generator.
3. *Integrated brushless type.* This arrangement has a direct current generator on the same shaft with

an alternating current generator. The excitation circuit is completed through silicon rectifiers rather than a commutator and brushes. The rectifiers are mounted on the generator shaft and their output is fed directly to the alternating current generator's main rotating field.

Number of Phases

Another method of classification is by the number of phases of output voltage. Alternating current generators may be single phase, two phase, three phase, or even six phase and more. In the electrical systems of aircraft, the three phase alternator is by far the most common.

Armature or Field Rotation

Still another means of classification is by the type of stator and rotor used. From this standpoint, there are two types of alternators: the revolving armature type and the revolving field type. The revolving armature alternator is similar in construction to the DC generator, in that the armature rotates through a stationary magnetic field. The revolving armature alternator is found only in alternators of low power rating and generally is not used. In the DC generator, the emf generated in the armature windings is converted into a unidirectional voltage (DC) by means of the commutator. In the revolving armature type of alternator, the generated AC voltage is applied unchanged to the load by means of slip rings and brushes.

The revolving field type of alternator has a stationary armature winding (stator) and a rotating field winding (rotor). [Figure 10-302] The advantage of having a stationary armature winding is that the armature can be connected directly to the load without having sliding contacts in the load circuit. A rotating armature would require slip rings and brushes to conduct the load current from the armature to the external circuit. Slip rings have a relatively short service life and arc over is a continual hazard; therefore, high voltage alternators are usually of the stationary armature, rotating field type. The voltage and current supplied to the rotating field are relatively small, and slip rings and brushes for this circuit are adequate. The direct connection to the armature circuit makes possible the use of large cross-section conductors, adequately insulated for high voltage. Since the rotating field alternator is used almost universally in aircraft systems, this type will be explained in detail, as a single phase, two phase, and three phase alternator.

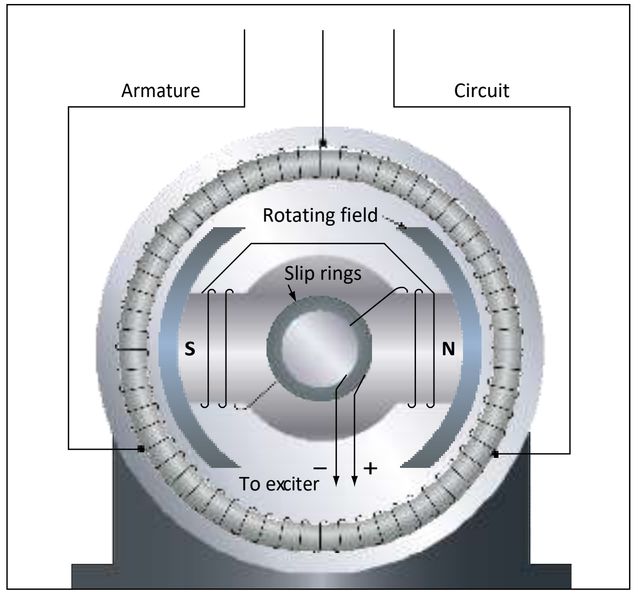

Figure 10-302. Alternator with stationary armature and rotating field.

Single Phase Alternator

Since the emf induced in the armature of a generator is alternating, the same sort of winding can be used on an alternator as on a DC generator. This type of alternator is known as a single phase alternator, but since the power delivered by a single phase circuit is pulsating, this type of circuit is objectionable in many applications.

A single phase alternator has a stator made up of a number of windings in series, forming a single circuit in which an output voltage is generated. Figure 10-303 illustrates a schematic diagram of a single phase alternator having four poles. The stator has four polar groups evenly spaced around the stator frame. The rotor has four poles, with adjacent poles of opposite polarity. As the rotor revolves, AC voltages are induced in the stator windings. Since one rotor pole is in the same position relative to a stator winding as any other rotor pole, all stator polar groups are cut by equal numbers of magnetic lines of force at any time.

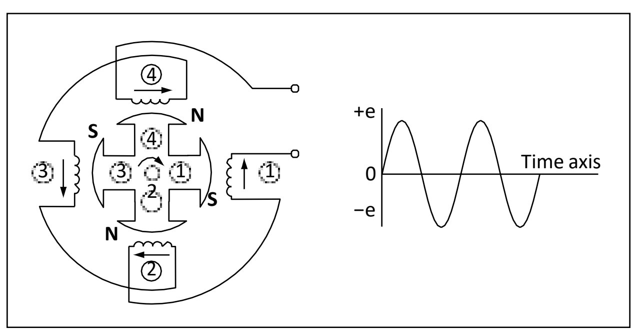

Figure 10-303. Single phase alternator.

As a result, the voltages induced in all the windings have the same amplitude, or value, at any given instant. The four stator windings are connected to each other so that the AC voltages are in phase, or "series adding." Assume that rotor pole 1, a south pole, induces a voltage in the direction indicated by the arrow in stator winding 1. Since rotor pole 2 is a north pole, it will induce a voltage in the opposite direction in stator coil 2 with respect to that in coil 1. For the two induced voltages to be in series addition, the two coils are connected as shown in the diagram. Applying the same reasoning, the voltage induced in stator coil 3 (clockwise rotation of the field) is the same direction (counterclockwise) as the voltage induced in coil 1. Similarly, the direction of the voltage induced in winding 4 is opposite to the direction of the voltage induced in coil 1. All four stator coil groups are connected in series so that the voltages induced in each winding add to give a total voltage that is four times the voltage in any one winding.

Two Phase Alternator

Two phase alternators have two or more single phase windings spaced symmetrically around the stator. In a two phase alternator, there are two single phase windings spaced physically so that the AC voltage induced in one is 90° out of phase with the voltage induced in the other. The windings are electrically separate from each other. When one winding is being cut by maximum flux, the other is being cut by no flux. This condition establishes a 90° relation between the two phases.

Three Phase Alternator

A three phase, or polyphase circuit, is used in most aircraft alternators, instead of a single or two phase alternator. The three phase alternator has three single phase windings spaced so that the voltage induced in each winding is 120° out of phase with the voltages in the other two windings. A schematic diagram of a three phase stator showing all the coils becomes complex and difficult to see what is actually happening.

A simplified schematic diagram, showing each of three phases, is illustrated in Figure 10-304. The rotor is omitted for simplicity. The waveforms of voltage are shown to the right of the schematic. The three voltages are 120° apart and are similar to the voltages which would be generated by three single phase alternators whose voltages are out of phase by angles of 120°. The three phases are independent of each other.

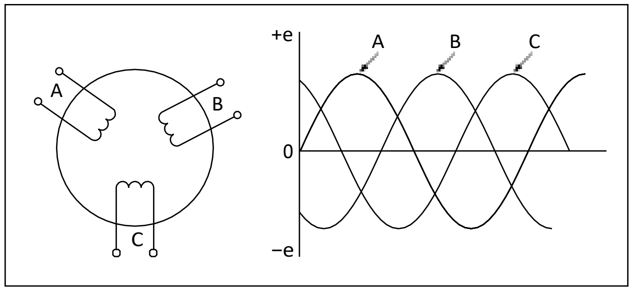

Figure 10-304. Simplified schematic of three phase alternator with output waveforms.

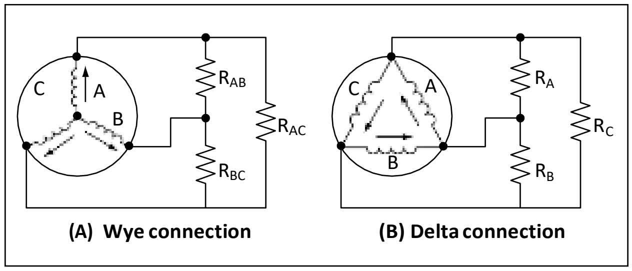

Figure 10-305. Wye- and delta-connected alternators.

Wye Connection (Three Phase)

Rather than have six leads from the three phase alternator, one of the leads from each phase may be connected to form a common junction. The stator is then called wye or star connected. The common lead may or may not be brought out of the alternator. If it is brought out, it is called the neutral lead. The simplified schematic (Figure 10-305A) shows a wye-connected stator with the common lead not brought out. Each load is connected across two phases in series. Thus, RAB is connected across phases A and B in series; RAC is connected across phases A and C in series; and RBC is connected across phases B and C in series. Therefore, the voltage across each load is larger than the voltage across a single phase. The total voltage, or line voltage, across any two phases is the vector sum of the individual phase voltages. For balanced conditions, the line voltage is 1.73 times the phase voltage. Since there is only one path for current in a line wire and the phase to which it is connected, the line current is equal to the phase current.

Delta Connection (Three Phase)

A three phase stator can also be connected so that the phases are connected end to end as shown in Figure 10-305B. This arrangement is called a delta connection. In a delta connection, the voltages are equal to the phase voltages; the line currents are equal to the vector sum of the phase currents; and the line current is equal to 1.73 times the phase current, when the loads are balanced. For equal loads (equal output), the delta connection supplies increased line current at a value of line voltage equal to phase voltage, and the wye connection supplies increased line voltage at a value of line current equal to phase current.

Alternator Rectifier Unit

A type of alternator used in the electrical system of many aircraft weighing less than 12,500 pounds is shown in Figure 10-306. This type of power source is sometimes called a DC generator, since it is used in DC systems. Although its output is a DC voltage, it is an alternator rectifier unit. This type of alternator rectifier is a self-excited unit but does not contain a permanent magnet. The excitation for starting is obtained from the battery; immediately after starting, the unit is self-exciting. Cooling air for the alternator is conducted into the unit by a blast air tube on the air inlet cover.

The alternator is directly coupled to the aircraft engine by means of a flexible drive coupling. The output of the alternator portion of the unit is three phase alternating current, derived from a three phase, delta connected system incorporating a three phases, full-wave bridge rectifier. [Figure 10-307] This unit operates in a speed range from 2,100 to 9,000 rpm, with a DC output voltage of 26–29 volts and 125 amperes.

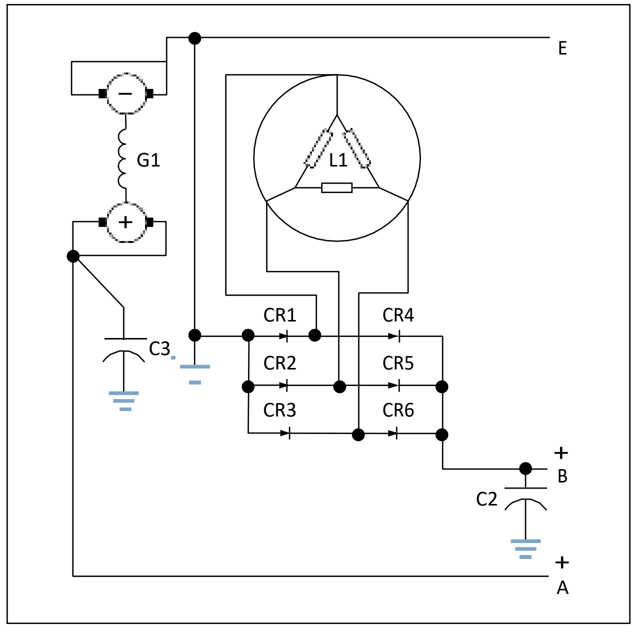

Figure 10-307. Wiring diagram of alternator-rectifier unit.

Brushless Alternator

This design is more efficient because there are no brushes to wear down or to arc at high altitudes. This generator consists of a pilot exciter, an exciter, and the main generator system. The need for brushes is eliminated by using an integral exciter with a rotating armature that has its AC output rectified for the main AC field, which is also of the rotating type. A brushless alternator is illustrated in Figure 10-308.

The pilot exciter is an 8 pole, 8,000 rpm, 533 cps, AC generator. The pilot exciter field is mounted on the main generator rotor shaft and is connected in series with the main generator field. The pilot exciter armature is mounted on the main generator stator. The AC output of the pilot exciter is supplied to the voltage regulator, where it is rectified and controlled, and is

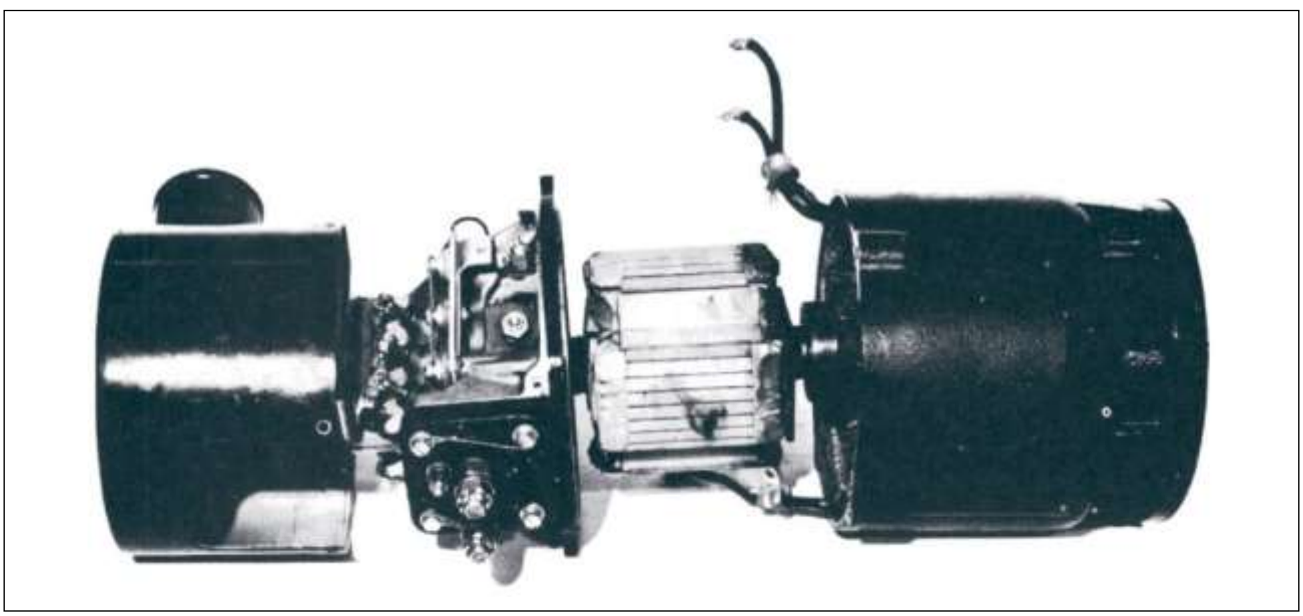
Figure 10-306. Exploded view of alternator rectifier.

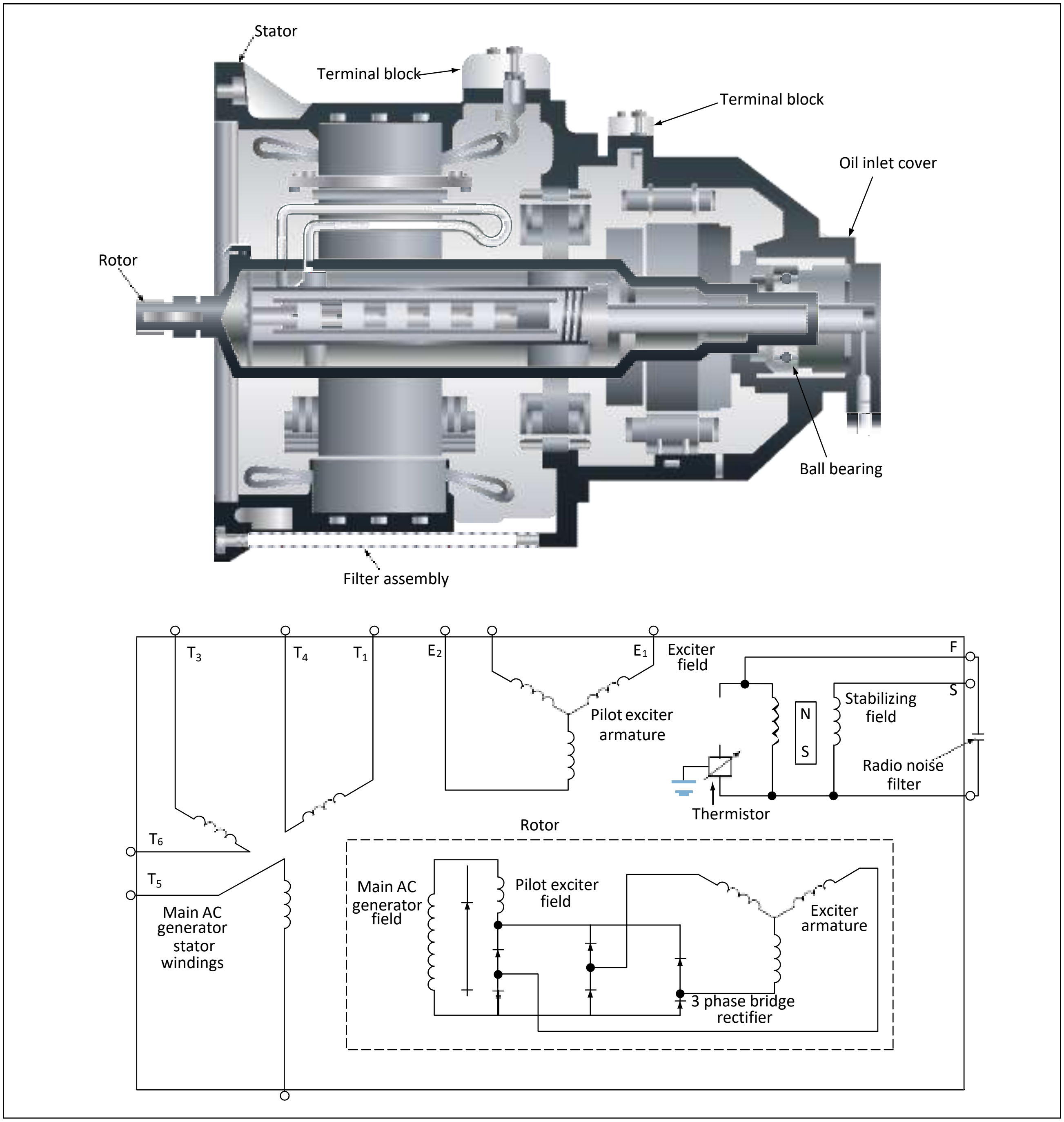

Figure 10-308. A typical brushless alternator.

then impressed on the exciter field winding to furnish excitation for the generator.

The exciter is a small AC generator with its field mounted on the main generator stator and its three phase armature mounted on the generator rotor shaft. Included in the exciter field are permanent magnets mounted on the main generator stator between the exciter poles.

The exciter field resistance is temperature compensated by a thermistor. This aids regulation by keeping a nearly constant resistance at the regulator output terminals. The exciter output is rectified and impressed on the main generator field and the pilot exciter field. The exciter stator has a stabilizing field, which is used to improve stability and to prevent voltage regulator over-corrections for changes in generator output voltage.

The AC generator shown in Figure 10-308 is a 6 pole, 8,000 rpm unit having a rating of 31.5 kilovoltamperes (kVA), 115⁄200 volts, 400 cps. This generator is three phase, 4 wire, wye connected with grounded neutrals. By using an integral AC exciter, the necessity for brushes within the generator has been eliminated. The AC output of the rotating exciter armature is fed directly into the three phase, full-wave, rectifier bridge located inside the rotor shaft, which uses high temperature silicon rectifiers. The DC output from the rectifier bridge is fed to the main AC generator rotating field.

Voltage regulation is accomplished by varying the strength of the AC exciter stationary fields. Polarity reversals of the AC generator are eliminated and radio noise is minimized by the absence of the brushes. A noise filter mounted on the alternator further reduces any existing radio noise. The rotating pole structure of the generator is laminated from steel punchings, containing all six poles and a connecting hub section. This provides optimum magnetic and mechanical properties.

Some alternators are cooled by circulating oil through steel tubes. The oil used for cooling is supplied from the constant speed drive assembly. Ports located in the flange connecting the generator and drive assemblies make oil flow between the constant speed drive and the generator possible.

Voltage is built up by using permanent magnet interpoles in the exciter stator. The permanent magnets assure a voltage buildup, precluding the necessity of field flashing. The rotor of the alternator may be removed without causing loss of the alternator's residual magnetism.

Alternator Rating

The maximum current that can be supplied by an alternator depends upon the maximum heating loss (I^2R power loss) that can be sustained in the armature and the maximum heating loss that can be sustained in the field. The armature current of an alternator varies with the load. This action is similar to that of DC generators. In AC generators, however, lagging power factor loads tend to demagnetize the field of an alternator, and terminal voltage is maintained only by increasing DC field current. For this reason, alternating current generators are usually rated according to kVA, power factor, phases, voltage, and frequency. One generator, for example, may be rated at 40 kVA, 208 volts, 400 cycles, three phase, at 75 percent power factor. The kVA indicates the apparent power. This is the kVA output, or the relationship between the current and voltage at which the generator is intended to operate. The power factor is the expression of the ratio between the apparent power (volt-amperes) and the true or effective power (watts). The number of phases is the number of independent voltages generated. Three phase generators generate three voltages 120 electrical degrees apart.

Alternator Frequency

The frequency of the alternator voltage depends upon the speed of rotation of the rotor and the number of poles. The faster the speed, the higher the frequency will be; the lower the speed, the lower the frequency becomes. The more poles on the rotor, the higher the frequency will be for a given speed. When a rotor has rotated through an angle so that two adjacent rotor poles (a north and a south pole) have passed one winding, the voltage induced in that winding will have varied through one complete cycle. For a given frequency, the greater the number of pairs of poles, the lower the speed of rotation will be. A two-pole alternator rotates at twice the speed of a four-pole alternator for the same frequency of generated voltage. The frequency of the alternator in cycles per minute is related to the number of poles and the speed, as expressed by the equation

$$F = \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120}$$

where P is the number of poles and N the speed in rpm. For example, a two pole, 3,600 rpm alternator has a frequency of

$$\frac{2 \times 3{,}600}{120} = 60 \text{ cps}$$

A four pole, 1,800 rpm alternator has the same frequency; a six pole, 500 rpm alternator has a frequency of

$$\frac{6 \times 500}{120} = 25 \text{ cps}$$

A 12 pole, 4,000 rpm alternator has a frequency of

$$\frac{2 \times 4{,}000}{120} = 400 \text{ cps}$$

Alternator Maintenance

Maintenance and inspection of alternator systems is similar to that of DC systems. Check the exciter brushes for wear and surfacing. On most large aircraft with two or four alternator systems, each power panel has three signal lights, one connected to each phase of the power bus, so the lamp will light when the panel power is on. The individual buses throughout the airplane can be checked by operating equipment from that particular bus. Consult the manufacturer's instructions on operation of equipment for the method of testing each bus.

Alternator test stands are used for testing alternators and constant speed drives in a repair facility. They are capable of supplying power to constant speed drive units at input speeds varying from 2,400 rpm to 9,000 rpm.

A typical test stand motor uses 220/440 volt, 60 cycle, three phase power. Blowers for ventilation, oil coolers, and necessary meters and switches are integral parts of the test stand. A load bank supplies test circuits. An AC motor generator set for ground testing is shown in Figure 10-309.

A typical, portable, AC electrical system test set is an analyzer, consisting of a multirange ohmmeter, a multirange combination AC DC voltmeter, an ammeter with a clip-on current transformer, a vibrating reed type frequency meter, and an unmounted continuity light.

A portable load bank unit furnishes a load similar to that on the airplane for testing alternators, either while mounted in the airplane or on the shop test stand. A complete unit consists of resistive and reactive loads controlled by selector switches and test meters mounted on a control panel. This load unit is compact and convenient, eliminating the difficulty of operating large loads on the airplane while testing and adjusting the alternators and control equipment.

Proper maintenance of an alternator requires that the unit be kept clean and that all electrical connections are tight and in good repair. If the alternator fails to build up voltage as designated by applicable manufacturer's technical instructions, test the voltmeter first by checking the voltages of other alternators, or by checking the voltage in the suspected alternator with another voltmeter and comparing the results. If the voltmeter is satisfactory, check the wiring, the brushes, and the drive unit for faults. If this inspection fails to reveal the trouble, the exciter may have lost its residual magnetism. Residual magnetism is restored to the exciter by flashing the field. Follow the applicable manufacturer's instructions when flashing the exciter field. If, after flashing the field, no voltage is indicated, replace the alternator, since it is probably faulty.

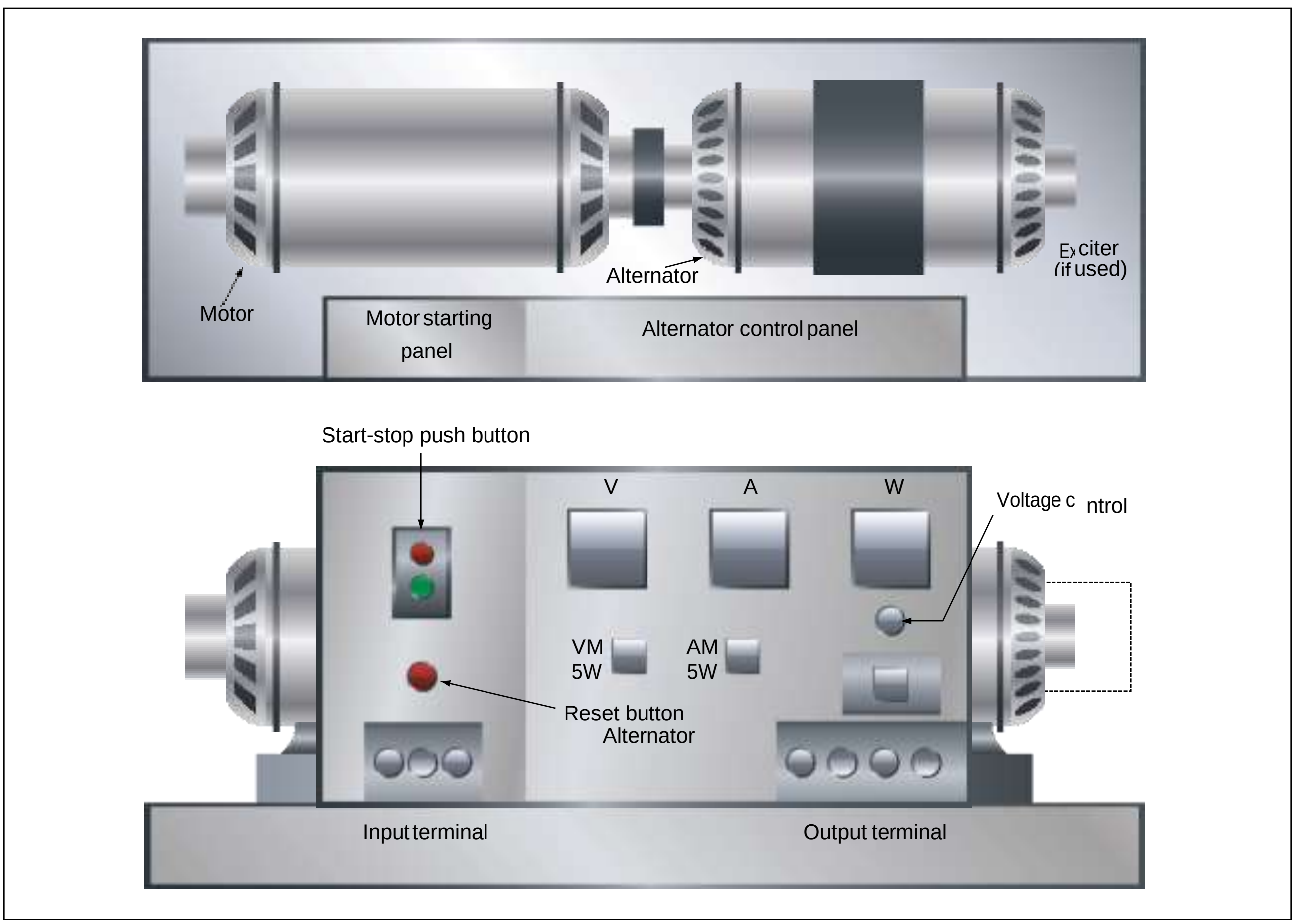

Figure 10-309. AC motor generator set for ground testing.

Clean the alternator exterior with an approved fluid; smooth a rough or pitted exciter commutator or slip ring with 000 sandpaper; then clean and polish with a clean, dry cloth. Check the brushes periodically for length and general condition. Consult the applicable manufacturer's instructions on the specific alternator to obtain information on the correct brushes.

Regulation of Generator Voltage

Efficient operation of electrical equipment in an airplane depends on a constant voltage supply from the generator. Among the factors, which determine the voltage output of a generator, only one, the strength of the field current, can be conveniently controlled. To illustrate this control, refer to the diagram in Figure 10-310, showing a simple generator with a rheostat in the field circuit. If the rheostat is set to increase the resistance in the field circuit, less current flows through the field winding and the strength of the magnetic field in which the armature rotates decreases. Consequently, the voltage output of the generator decreases. If the resistance in the field circuit is decreased with the rheostat, more current flows through the field windings, the magnetic field becomes stronger, and the generator produces a greater voltage.

Voltage Regulation with a Vibrating-Type Regulator

Refer to Figure 10-311. With the generator running at normal speed and switch K open, the field rheostat is adjusted so that the terminal voltage is about 60 percent of normal. Solenoid S is weak and contact B is held closed by the spring. When K is closed, a short circuit is placed across the field rheostat. This action causes the field current to increase and the terminal voltage to rise.

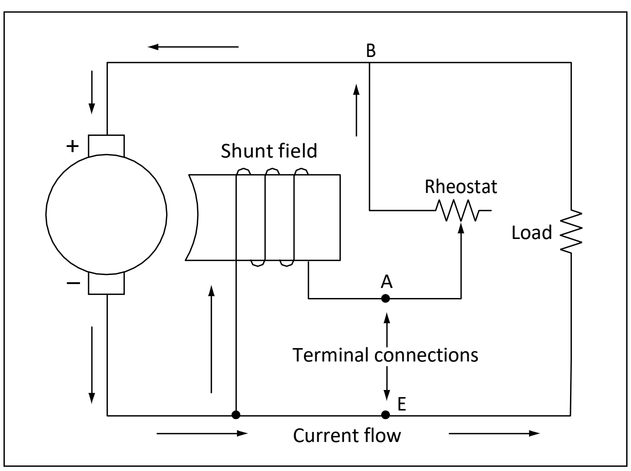

Figure 10-310. Regulation of generator voltage by field rheostat.

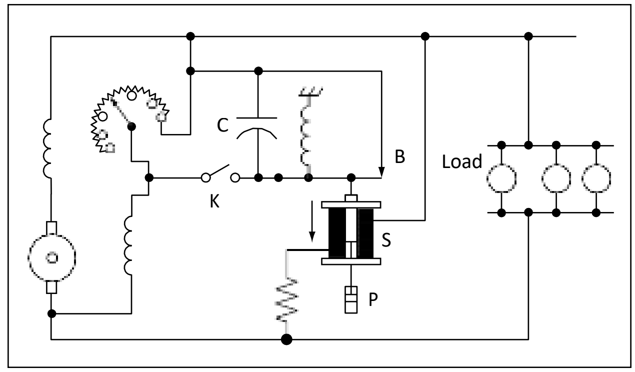

Figure 10-311. Vibrating-type voltage regulator.

When the terminal voltage rises above a certain critical value, the solenoid downward pull exceeds the spring tension and contact B opens, thus reinserting the field rheostat in the field circuit and reducing the field current and terminal voltage.

When the terminal voltage falls below a certain critical voltage, the solenoid armature contact B is closed again by the spring, the field rheostat is now shorted, and the terminal voltage starts to rise. The cycle repeats with a rapid, continuous action. Thus, an average voltage is maintained with or without load change.

The dashpot P provides smoother operation by acting as a damper to prevent hunting. The capacitor C across contact B eliminates sparking. Added load causes the field rheostat to be shorted for a longer period of time and, thus, the solenoid armature vibrates more slowly. If the load is reduced and the terminal voltage rises, the armature vibrates more rapidly and the regulator holds the terminal voltage to a steady value for any change in load, from no load to full load, on the generator.

Vibrating-type regulators cannot be used with generators, which require a high field current, since the contacts will pit, or burn. Heavy-duty generator systems require a different type of regulator, such as the carbon pile voltage regulator.

Three Unit Regulators

Many light aircraft employ a three unit regulator for their generator systems. This type of regulator includes a current limiter and a reverse current cutout in addition to a voltage regulator.

The action of the voltage regulator unit is similar to the vibrating-type regulator described earlier. The second of the three units is a current regulator to limit the output current of the generator. The third unit is a reverse current cutout that disconnects the battery from the generator. If the battery is not disconnected, it will discharge through the generator armature when the generator voltage falls below that of the battery, thus driving the generator as a motor. This action is called "motoring" the generator and, unless it is prevented, it will discharge the battery in a short time.

The operation of a three unit regulator is described in the following paragraphs. [Figure 10-312]

The action of vibrating contact C1 in the voltage regulator unit causes an intermittent short circuit between points R1 and L2. When the generator is not operating, spring S1 holds C1 closed; C2 is also closed by S2. The shunt field is connected directly across the armature.

When the generator is started, its terminal voltage will rise as the generator comes up to speed, and the armature will supply the field with current through closed contacts C2 and C1.

As the terminal voltage rises, the current flow through L1 increases and the iron core becomes more strongly magnetized. At a certain speed and voltage, when the magnetic attraction on the movable arm becomes strong enough to overcome the tension of spring S1, contact points C1 are separated. The field current now flows through R1 and L2. Because resistance is added to the field circuit, the field is momentarily weakened and the rise in terminal voltage is checked. Also, since the L2 winding is opposed to the L1 winding, the magnetic pull of L1 against S1 is partially neutralized, and spring S1 closes contact C1. Therefore, R1 and L2 are again shorted out of the circuit, and the field current again increases; the output voltage increases, and C1 is opened because of the action of L1. The cycle is rapid and occurs many times per second. The terminal voltage of the generator varies slightly, but rapidly, above

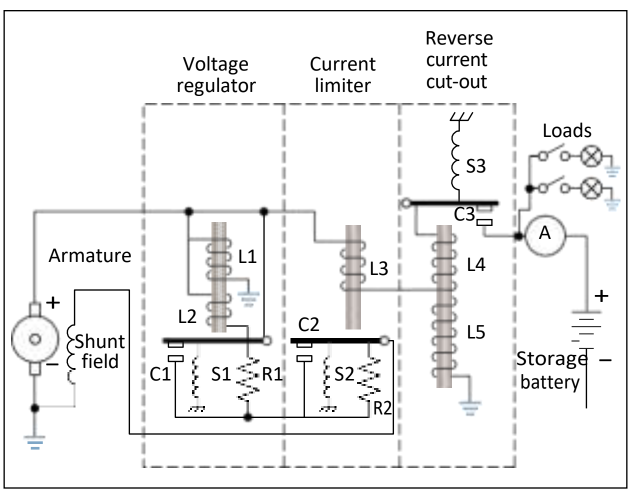

Figure 10-312. Three unit regulator for variable speed generators.

and below an average value determined by the tension of spring S1, which may be adjusted.

The purpose of the vibrator-type current limiter is to limit the output current of the generator automatically to its maximum rated value in order to protect the generator. As shown in Figure 10-312, L3 is in series with the main line and load. Thus, the amount of current flowing in the line determines when C2 will be opened and R2 placed in series with the generator field. By contrast, the voltage regulator is actuated by line voltage, whereas the current limiter is actuated by line current. Spring S2 holds contact C2 closed until the current through the main line and L3 exceeds a certain value, as determined by the tension of spring S2, and causes C2 to be opened. The increase in current is due to an increase in load. This action inserts R2 into the field circuit of the generator and decreases the field current and the generated voltage. When the generated voltage is decreased, the generator current is reduced. The core of L3 is partly demagnetized and the spring closes the contact points. This causes the generator voltage and current to rise until the current reaches a value sufficient to start the cycle again. A certain minimum value of load current is necessary to cause the current limiter to vibrate.

The purpose of the reverse current cutout relay is to automatically disconnect the battery from the generator when the generator voltage is less than the battery voltage. If this device were not used in the generator circuit, the battery would discharge through the generator. This would tend to make the generator operate as a motor, but because the generator is coupled to the engine, it could not rotate such a heavy load. Under this condition, the generator windings may be severely damaged by excessive current.

There are two windings, L4 and L5, on the soft iron core. The current winding, L4, consisting of a few turns of heavy wire, is in series with the line and carries the entire line current. The voltage winding, L5, consisting of a large number of turns of fine wire, is shunted across the generator terminals.

When the generator is not operating, the contacts, C3 are held open by the spring S3. As the generator voltage builds up, L5 magnetizes the iron core. When the current (as a result of the generated voltage) produces sufficient magnetism in the iron core, contact C3 is closed, as shown. The battery then receives a charging current. The coil spring, S3, is so adjusted that the voltage winding will not close the contact points until the voltage of the generator is in excess of the normal voltage of the battery. The charging current passing through L4 aids the current in L5 to hold the contacts tightly closed. Unlike C1 and C2, contact C3 does not vibrate. When the generator slows down or, for any other cause, the generator voltage decreases to a certain value below that of the battery, the current reverses through L4 and the ampere turns of L4 oppose those of L5. Thus, a momentary discharge current from the battery reduces the magnetism of the core and C3 is opened, preventing the battery from discharging into the generator and motoring it. C3 will not close again until the generator terminal voltage exceeds that of the battery by a predetermined value.

Differential Relay Switch

Aircraft electrical systems normally use some type of reverse current relay switch, which acts not only as a reverse current relay cutout but also serves as a remote control switch by which the generator can be disconnected from the electrical system at any time. One type of reverse current relay switch operates on the voltage level of the generator, but the type most commonly used on large aircraft is the differential relay switch, which is controlled by the difference in voltage between the battery bus and the generator.

The differential type relay switch connects the generator to the main bus bar in the electrical system when the generator voltage output exceeds the bus voltage by 0.35 to 0.65 volt. It disconnects the generator when a nominal reverse current flows from the bus to the generator. The differential relays on all the generators of a multiengine aircraft do not close when the electrical load is light. For example, in an aircraft having a load of 50 amperes, only two or three relays may close. If a heavy load is applied, the equalizing circuit will lower the voltage of the generators already on the bus and, at the same time, raise the voltage of the remaining generators, allowing their relays to close. If the generators have been paralleled properly, all the relays stay closed until the generator control switch is turned off or until the engine speed falls below the minimum needed to maintain generator output voltage.

The differential generator control relay shown in Figure 10-313 is made up of two relays and a coil-operated contactor. One relay is the voltage relay and the other is the differential relay. Both relays include permanent magnets, which pivot between the pole pieces of temporary magnets wound with relay coils. Voltages of one polarity set up fields about the temporary magnets with polarities that cause the permanent magnet to move in the direction necessary to close the relay contacts; voltages of the opposite polarity establish fields that cause the relay contacts to open. The differential relay has two coils wound on the same core. The coil-operated contactor, called the main contactor, consists of movable contacts that are operated by a coil with a movable iron core.

Closing the generator switch on the control panel connects the generator output to the voltage relay coil. When generator voltage reaches 22 volts, current flows through the coil and closes the contacts of the voltage relay. This action completes a circuit from the generator to the battery through the differential coil.

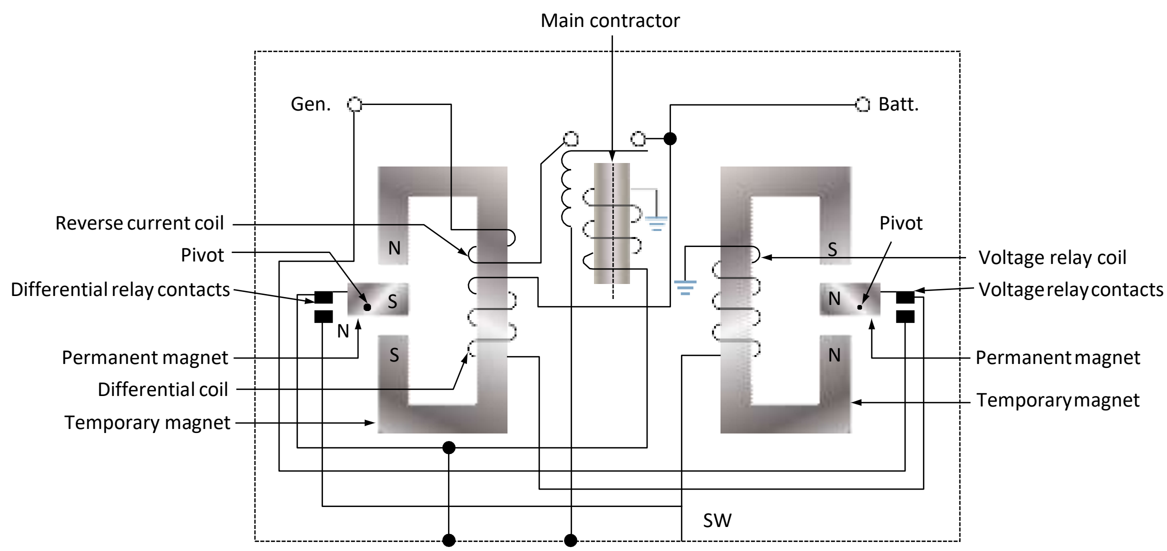

Figure 10-313. Differential generator control relay.

When the generator voltage exceeds the bus voltage by 0.35 volt, current will flow through the differential coil, the differential relay contact will close and, thus, complete the main contractor coil circuit. The contacts of the main contactor close and connect the generator to the bus.

When the generator voltage drops below the bus (or battery) voltage, a reverse current weakens the magnetic field about the temporary magnet of the differential relay. The weakened field permits a spring to open the differential relay contacts, breaking the circuit to the coil of the main contactor relay, opening its contacts, and disconnecting the generator from the bus. The generator battery circuit may also be broken by opening the cockpit control switch, which opens the contacts of the voltage relay, causing the differential relay coil to be de-energized.

Overvoltage and Field Control Relays

Two other items used with generator control circuits are the overvoltage control and the field control relay.

As its name implies, the overvoltage control protects the system when excessive voltage exists. The overvoltage relay is closed when the generator output reaches 32 volts and completes a circuit to the trip coil of the field control relay. The closing of the field control relay trip circuit opens the shunt field circuit and completes it through a resistor, causing generator voltage to drop; also, the generator switch circuit and the equalizer circuit (multiengine aircraft) are opened. An indicator light circuit is completed, warning that an overvoltage condition exists. A "reset" position of the cockpit switch is used to complete a reset coil circuit in the field control relay, returning the relay to its normal position.

Generator Control Units (GCU)

Basic Functions of a Generator Control Unit

The generator control unit (GCU) is more commonly found on turbine power aircraft. The most basic generator control units perform a number of functions related to the regulation, sensing, and protection of the DC generation system.

Voltage Regulation

The most basic of the GCU functions is that of voltage regulation. Regulation of any kind requires the regulation unit to take a sample of an output and to compare that sample with a controlled reference. If the sample taken falls outside of the limits set by the reference, then the regulation unit must provide an adjustment to the unit generating the output so as to diminish or increase the output levels. In the case of the GCU, the output voltage from a generator is sensed by the GCU and compared to a reference voltage. If there is any difference between the two, the error is usually amplified and then sent back to the field excitation control portion of the circuit. The field excitation control then makes voltage⁄excitation adjustments in the field winding of the generator in order to bring the output voltage back into required bus tolerances.

Overvoltage Protection

Like the voltage regulation feature of the GCU, the overvoltage protection system compares the sampled voltage to reference voltage. The output of the overvoltage protection circuit is used to open the relay that controls the output for the field excitation. These types of faults can occur for a number of reasons. The most common, however, is the failure of the voltage regulation circuit in the GCU.

Parallel Generator Operations

The paralleling feature of the GCU allows for two or more GCU/generator systems to work in a shared effort to provide current to the aircraft electrical system. Comparing voltages between the equalizer bus and the interpole/compensator voltage, and amplifying the differences accomplishes the control of this system. The difference is then sent to the voltage regulation circuit, where adjustments are then made in the regulation output. These adjustments will continue until all of the busses are equalized in their load sharing.

Over-Excitation Protection

When a GCU in a paralleled system fails, a situation can occur where one of the generators becomes overexcited and tries to carry more than its share of the load, if not all of the loads. When this condition is sensed on the equalizing bus, the faulted generation control system will shut down by receiving a de-excitation signal. This signal is then transmitted to the overvoltage circuit, and then opens the field excitation output circuit.

Differential Voltage

When the GCU allows the logic output to close the generator line contactor, the generator voltage must be within a close tolerance of the load bus. If the output is not within the specified tolerance, then the contactor is not allowed to connect the generator to the bus.

Reverse Current Sensing

If the generator is unable to maintain the required voltage level, it will eventually begin to draw current instead of providing it. In this case, the faulty generator will be seen as a load to the other generators and will need to be removed from the bus. Once the generator is off-line, it will not be permitted to be reconnected to the bus until such time that the generator faults are cleared and the generator is capable of providing a current to the bus. In most cases, the differential voltage circuit and the reverse current sensing circuit are one in the same.

Alternator Constant Speed Drive System

Alternators are not always connected directly to the airplane engine like DC generators. Since the various electrical devices operating on AC supplied by alternators are designed to operate at a certain voltage and at a specified frequency, the speed of the alternators must be constant; however, the speed of an airplane engine varies. Therefore, the engine, through a constant speed drive installed between the engine and the alternator, drives some alternators.

A typical hydraulic-type drive is shown in Figure 10-314. The following discussion of a constant speed drive system will be based on such a drive, found on large multiengine aircraft.

The constant speed drive is a hydraulic transmission, which may be controlled either electrically or mechanically.

The constant speed drive assembly is designed to deliver an output of 6,000 rpm, provided the input remains between 2,800 and 9,000 rpm. If the input, which is determined by engine speed, is below 6,000 rpm, the drive increases the speed in order to furnish the desired output. This stepping up of speed is known as overdrive.

In overdrive, an automobile engine will operate at about the same rpm at 60 mph as it does in conventional drive at 49 mph. In aircraft, this principle is applied in the same manner. The constant speed drive enables the alternator to produce the same frequency at slightly above engine idle rpm as it would at takeoff or cruising rpm.

With the input speed to the drive set at 6,000 rpm, the output speed will be the same. This is known as straight drive and might be compared to an automobile in high gear. However, when the input speed is greater than 6,000 rpm, it must be reduced to provide an output of 6,000 rpm. This is called underdrive, which is comparable to an automobile in low gear. Thus, the large

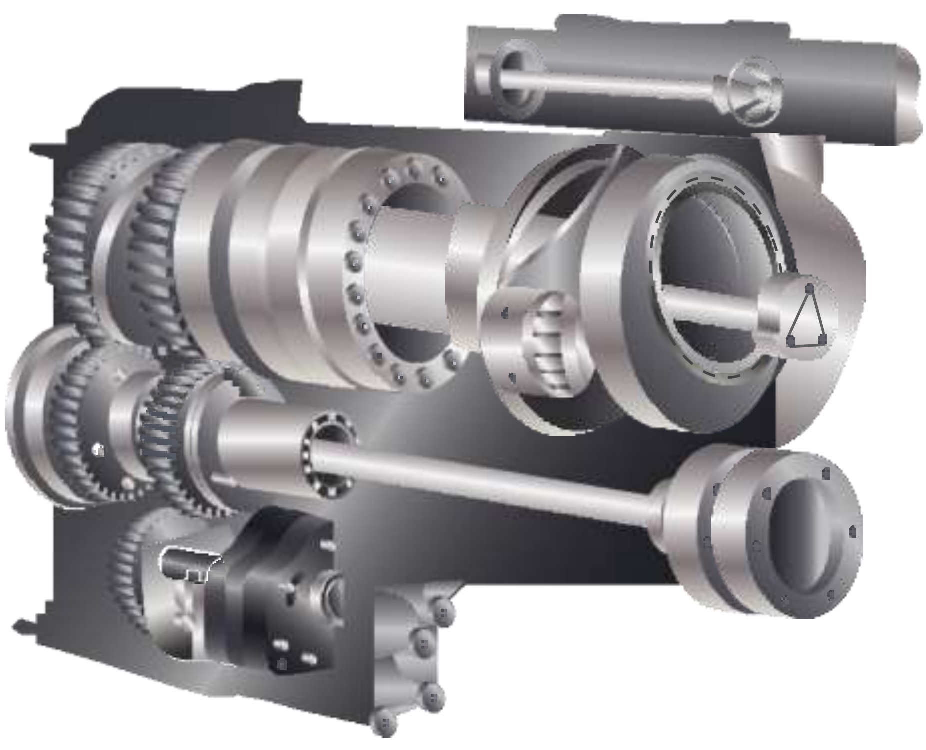

Figure 10-314. Constant speed drive.

input, caused by high engine rpm, is reduced to give the desired alternator speed.

As a result of this control by the constant speed drive, the frequency output of the generator varies from 420 cps at no load to 400 cps under full load.

This, in brief, is the function of the constant speed drive assembly. Before discussing the various units and circuits, the overall operation of the transmission should be discussed as follows.

Hydraulic Transmission

The transmission is mounted between the generator and the aircraft engine. Its name denotes that hydraulic oil is used, although some transmissions may use engine oil. Refer to the cutaway view of such a transmission in Figure 10-315. The input shaft D is driven from the drive shaft on the accessory section of the engine. The output drive F, on the opposite end of the transmission, engages the drive shaft of the generator.

The input shaft is geared to the rotating cylinder block gear, which it drives, as well as to the makeup and scavenger gear pumps E.

The makeup (charge) pump delivers oil (300 psi) to the pump and motor cylinder block, to the governor system, and to the pressurized case, whereas the scavenger pump returns the oil to the external reservoir.

The rotating cylinder assembly B consists of the pump and motor cylinder blocks, which are bolted to opposite

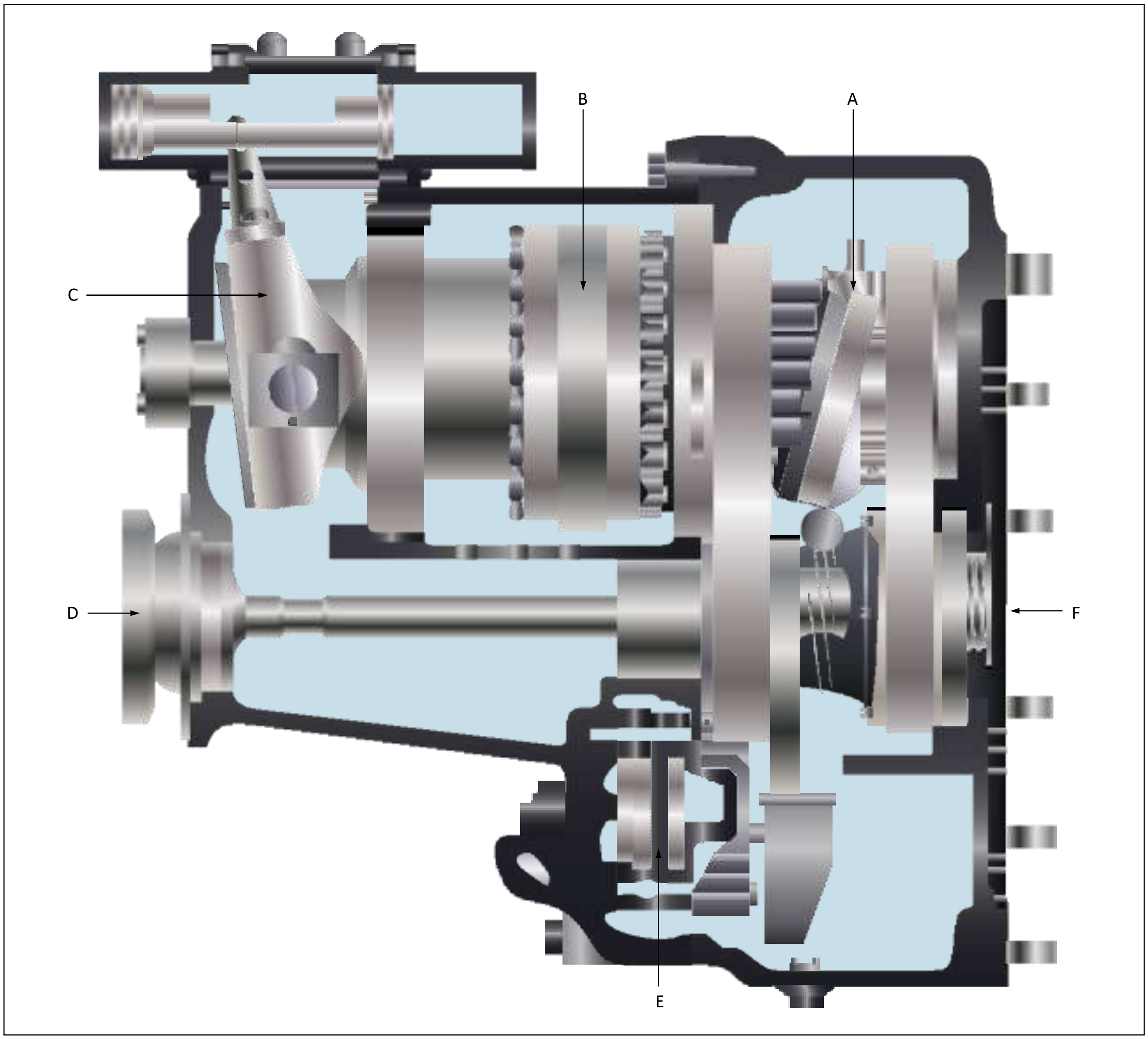

Figure 10-315. Cutaway of a hydraulic transmission.

sides of a port plate. The two other major parts are the motor wobbler A and the pump wobbler C. The governor system is the unit at the top of the left side in the illustration.

The cylinder assembly has two primary units. The block assembly of one of the units, the pump, contains 14 cylinders, each of which has a piston and pushrod. Charge pressure from the makeup pump is applied to each piston in order to force it outward against the pushrod. It, in turn, is pushed against the pump wobble plate.

If the plate remained as shown in Figure 10-316A, each of the 14 cylinders would have equal pressure, and all pistons would be in the same relative position in their respective cylinders. But with the plate tilted, the top portion moves outward and the lower portion inward, as shown in Figure 10-316B. As a result, more oil enters the interior of the upper cylinder, but oil will be forced from the cylinder of the bottom piston.

If the pump block were rotated while the plate remained stationary, the top piston would be forced inward because of the angle of the plate. This action would cause the oil confined within the cylinder to be subjected to increased pressure great enough to force it into the motor cylinder block assembly.

Before explaining what the high-pressure oil in the motor unit will do, it is necessary to know something about this part of the rotating cylinder block assembly. The motor block assembly has 16 cylinders, each with its piston and pushrod. These are constantly receiving charge pressure of 300 psi. The position of the piston depends upon the point at which each pushrod touches the motor wobble plate. These rods cause the wobble plate to rotate by the pressure they exert against its sloping surface.

The piston and pushrod of the motor are pushed outward as oil is forced through the motor valve plate from the pump cylinder. The pushrods are forced against the motor wobble plate, which is free to rotate but cannot change the angle at which it is set. Since the pushrods cannot move sideways, the pressure exerted against the motor wobble plate's sloping face causes it to rotate.

In the actual transmission, there is an adjustable wobble plate. The control cylinder assembly determines the tilt of the pump wobble plate. For example, it is set at an angle which causes the motor cylinders to turn the motor wobble plate faster than the motor assembly, if the transmission is in overdrive. The greater pressure in the pump and motor cylinders produces the result described.

With the transmission in underdrive, the angle is arranged so there is a reduction in pumping action. The subsequent slippage between the pushrods and motor wobble plate reduces the output speed of the transmission. When the pump wobble plate is not at an angle, the pumping action will be at a minimum and the transmission will have what is known as hydraulic lock. For this condition, the input and output speed will

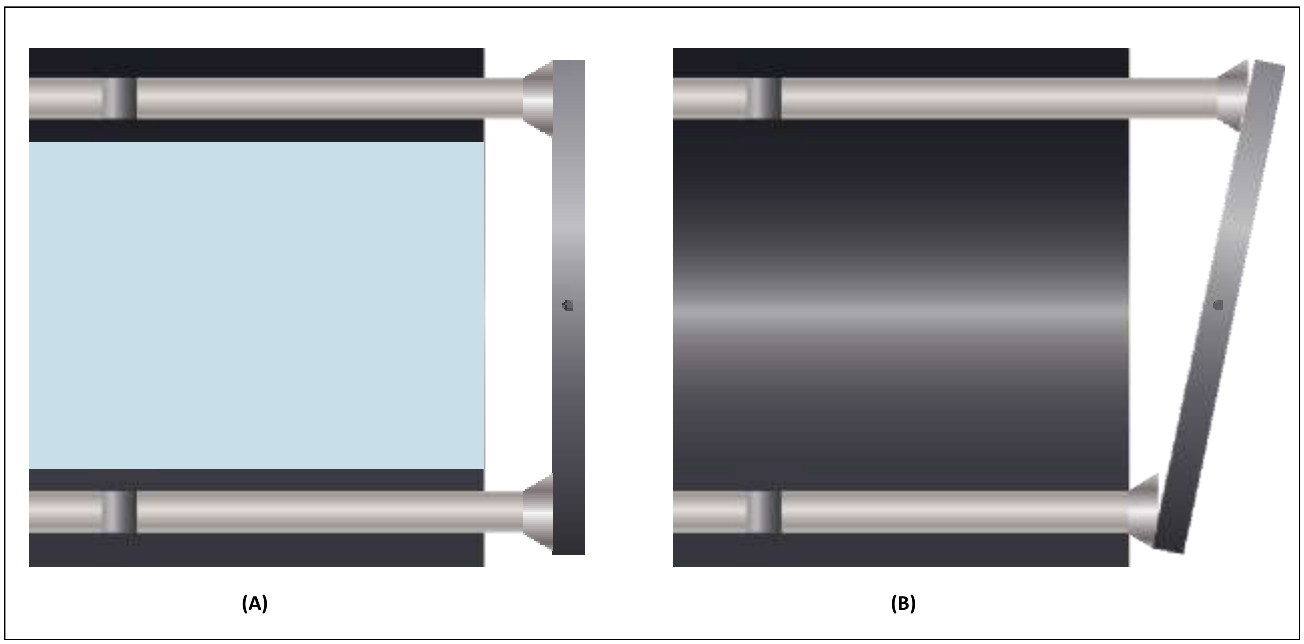

Figure 10-316. Wobble plate position.

be about the same, and the transmission is considered to be in straight drive.

To prevent the oil temperature from becoming excessively high within the cylinder block, the makeup pressure pump forces oil through the center of this block and the pressure relief valve. From this valve, the oil flows into the bottom of the transmission case. A scavenger pump removes the oil from the transmission case and circulates it through the oil cooler and filters before returning it to the reservoir. At the start of the cycle, oil is drawn from the reservoir, passed through a filter, and forced into the cylinder block by the makeup pressure pump.

The clutch, located in the output gear and clutch assembly, is an overrunning one way, sprag-type device. Its purpose is to ratchet if the alternator becomes motorized; otherwise, the alternator might turn the engine. Furthermore, the clutch provides a positive connection when the transmission is driving the alternator.

There is another unit of the drive that must be discussed — the governor system. The governor system, which consists of a hydraulic cylinder with a piston, is electrically controlled. Its duty is to regulate oil pressure flowing to the control cylinder assembly. [Figure 10-317]

The center of the system's hydraulic cylinder is slotted so the arm of the pump wobble plate can be connected to the piston. As oil pressure moves the piston, the pump wobble plate is placed in either overspeed, underspeed, or straight drive.

Figure 10-318 shows the electrical circuit used to govern the speed of the transmission. First, the main points of the complete electrical control circuit will be discussed. [Figures 10-318 and 10-319] Then, for simplification, two portions, the overspeed circuit and the load division circuit, will be considered as individual circuits.

Note, then, in Figure 10-318, that the circuit has a valve and solenoid assembly O and a control cylinder E, and that it contains such units as the tachometer generator D, the rectifier C, and adjustable resistor B, rheostat A, and the control coil Q.

Since it is driven by a drive gear in the transmission, the tachometer (often called tach) generator, a three phase unit, has a voltage proportional to the speed of the output drive. The rectifier changes its voltage from AC to DC. After rectification, the current flows through the resistor, rheostat, and valve and solenoid. Each of these units is connected in series. [Figure 10-319]

Under normal operating conditions, the output of the tach generator causes just enough current to enter the valve and solenoid coil to set up a magnetic field of sufficient strength to balance the spring force in the valve. When the alternator speed increases as the result of a decrease in load, the tach generator output also increases. Because of the greater output, the coil in the solenoid is sufficiently strengthened to overcome the spring force. Thus, the valve moves and, as a result, oil pressure enters the reduced speed side of the control cylinder.

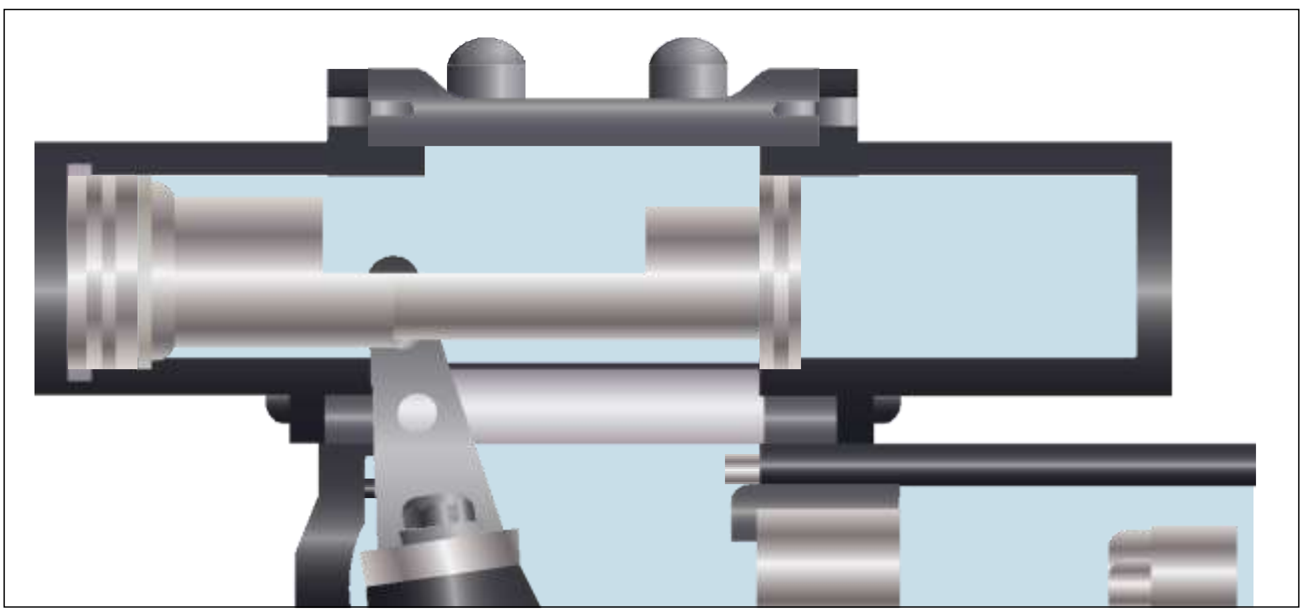

Figure 10-317. Control cylinder.

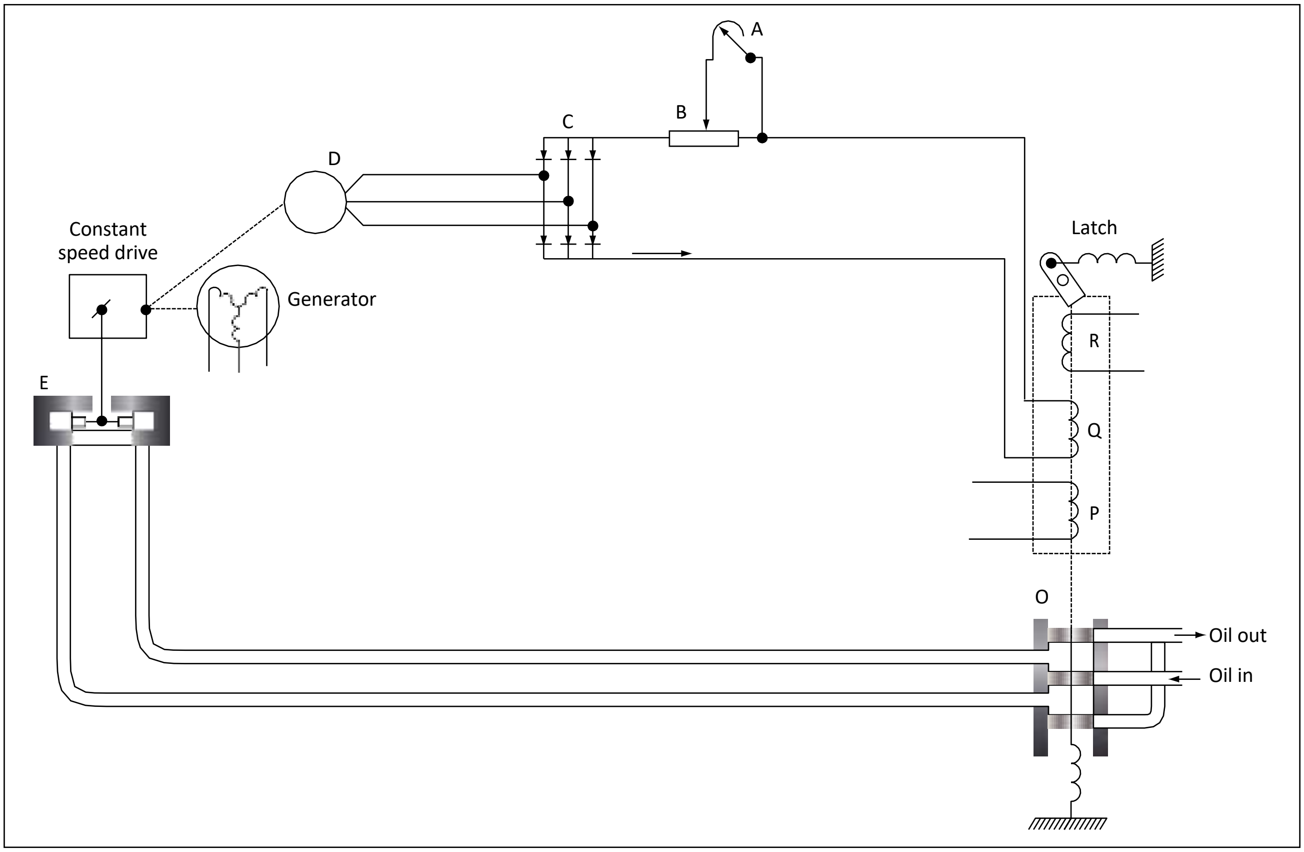

Figure 10-318. Electrical hydraulic control circuit.

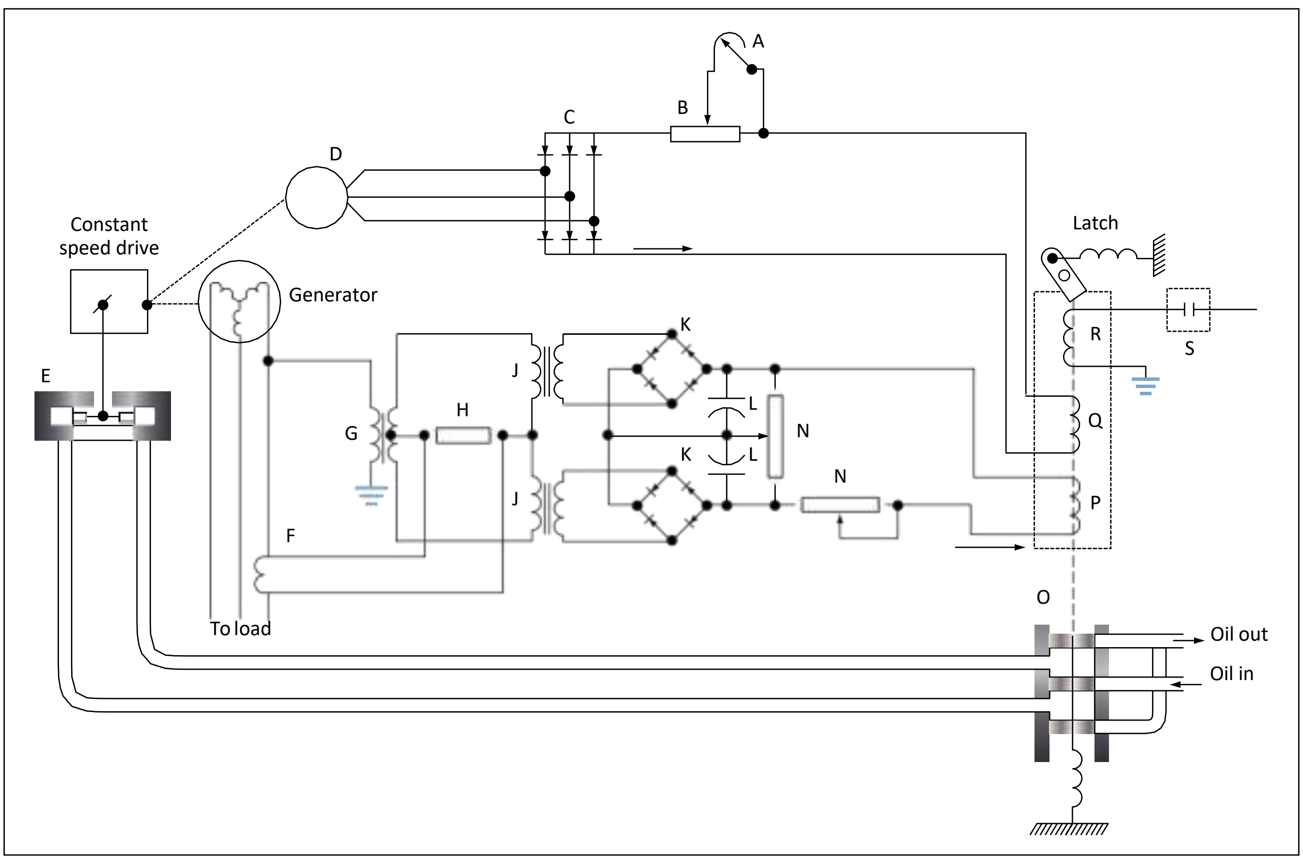

Figure 10-319. Speed control circuit.

In turn, the pressure moves the piston, causing the angle of the pump wobble plate to be reduced. The oil on the other side of the piston is forced back through the valve into the system return. Since the angle of the pump wobble plate is smaller, there is less pumping action in the transmission. The result is decreased output speed. To complete the cycle, the procedure is reversed.

With the output speed reduction, tach generator output decreases; consequently, the flow of current to the solenoid diminishes. Therefore, the magnetic field of the solenoid becomes so weak that the spring is able to overcome it and reposition the valve.

If a heavy load is put on the AC generator, its speed decreases. The generator is not driven directly by the engine; the hydraulic drive will allow slippage. This decrease will cause the output of the tach generator to taper off and, as a result, weaken the magnetic field of the solenoid coil. The spring in the solenoid will move the valve and allow oil pressure to enter the increase side of the control cylinder and the output speed of the transmission will be raised.

There are still two important circuits, which must be discussed: the overspeed circuit and the load division circuit. The generator is prevented from overspeeding by a centrifugal switch (S in Figure 10-320) and the overspeed solenoid coil R, which is located in the solenoid and valve assembly. The centrifugal switch is on the transmission and is driven through the same gear arrangement as the tach generator.

The aircraft DC system furnishes the power to operate the overspeed coil in the solenoid and coil assembly. If the output speed of the transmission reaches a speed of 7,000 to 7,500 rpm, the centrifugal switch closes the DC circuit and energizes the overspeed solenoid. This component then moves the valve and engages the latch that holds the valve in the underdrive position. To release the latch, energize the underdrive release solenoid.

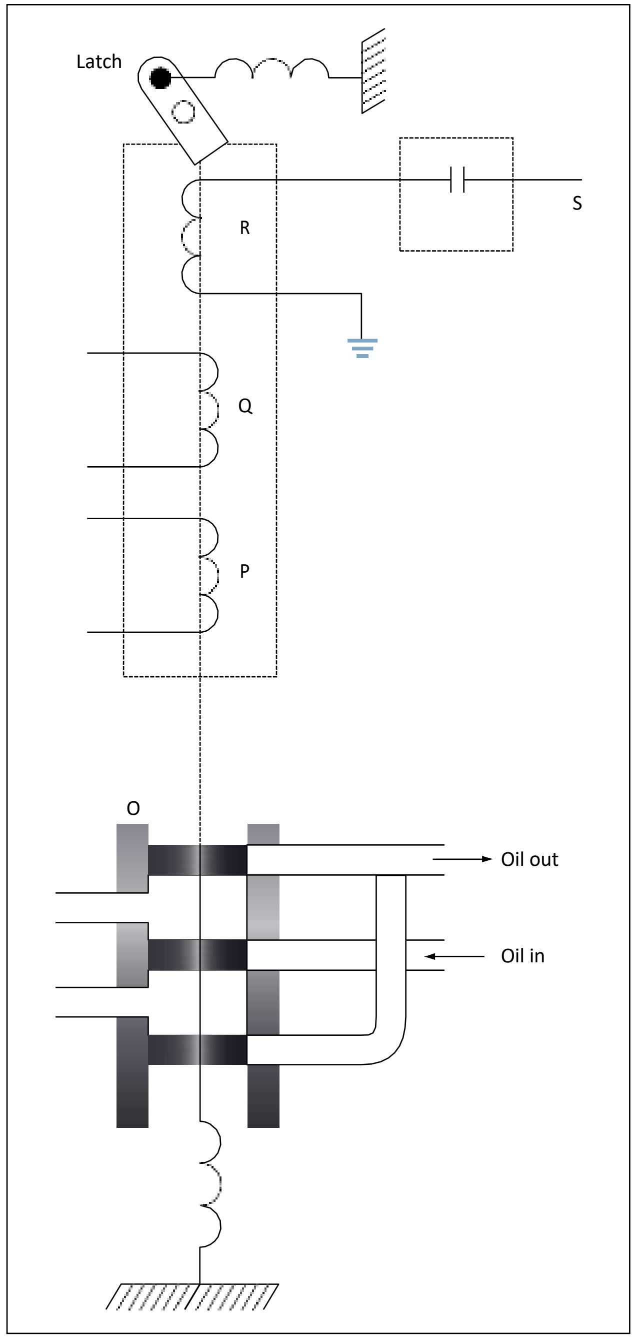

Figure 10-320. Overspeed circuit.

The load division circuit's function is to equalize the loads placed on each of the alternators, which is necessary to assure that each alternator assumes its share; otherwise, one alternator might be overloaded while another would be carrying only a small load.

In Figure 10-321, one phase of the alternator provides power for the primary in transformer G, whose secondary supplies power to the primaries of two other transformers, J1 and J2. Rectifiers K then change the output of the transformer secondaries from AC to DC.

The function of the two capacitors, L, is to smooth out the DC pulsations.

The output of the current transformer F depends upon the amount of current flowing in the line of one phase. In this way, it measures the real load of the generator. The output voltage of the current transformer is applied across resistor H. This voltage will be added vectorially to the voltage applied to the upper winding of transformer J by the output of transformer F. At the same time as it adds vectorially to the upper winding of

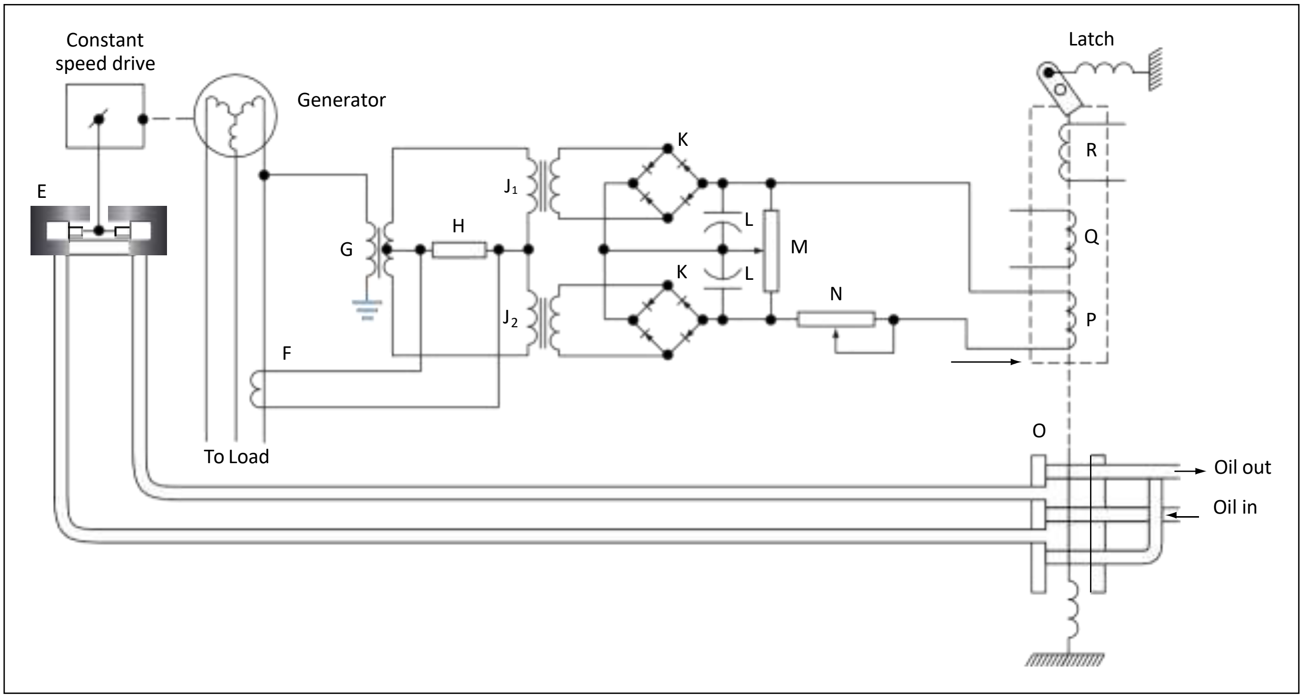

Figure 10-321. Droop circuit.

transformer J, it subtracts vectorially from the voltage applied to the lower winding of J.

This voltage addition and subtraction depends on the real load of the generator. The amount of real load determines the phase angle and the amount of voltage impressed across resistor H. The greater the real load, the greater the voltage across H, and hence, the greater the difference between the voltages applied to the two primaries of transformer J. The unequal voltages applied to resistor M by the secondaries of transformer J cause a current flow through the control coil P.

The control coil is wound so that its voltage supplements the voltage for the control coil in the valve and solenoid assembly. The resulting increased voltage moves the valve and slows down the generator's speed. Why should the speed be decreased if the load has been increased? Actually, systems using only one generator would not have decreased speed, but for those having two or more generators, a decrease is necessary to equalize the loads.

The load division circuit is employed only when two or more generators supply power. In such systems, the control coils are connected in parallel. If the source voltage for one of these becomes higher than the others, it determines the direction of current flow throughout the entire load division circuit. As explained before, the real load on the generator determines the amount of voltage on the control coil; therefore, the generator with the highest real load has the highest voltage.

As shown in Figure 10-322, current through No. 1 control coil, where the largest load exists, aids the control coil of the valve and solenoid, thereby slowing down the generator. (The source voltage of the control coils is represented by battery symbols in the illustration.) The current in the remaining control coils opposes the control coil of the valve and solenoid, in order to increase the speed of the other generators so the load will be more evenly distributed.

On some drives, instead of an electrically controlled governor, a flyweight-type governor is employed, which consists of a recess-type revolving valve driven by the output shaft of the drive, flyweights, two coil springs, and a nonrotating valve stem. Centrifugal force, acting on the governor flyweights, causes them

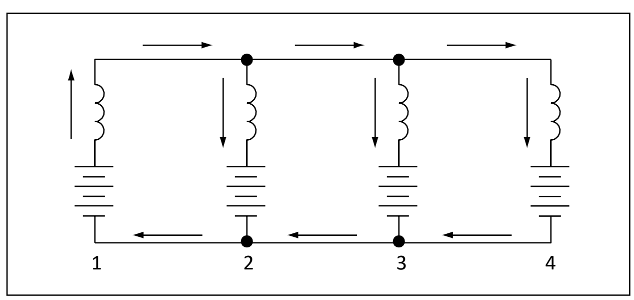

Figure 10-322. Relative direction of current in droop coil circuit with unequal loads.

to move outward, lifting the valve stem against the opposition of a coil spring.

The valve stem position controls the directing of oil to the two oil outlines. If the output speed tends to exceed 6,000 rpm, the flyweights will lift the valve stem to direct more oil to the side of the control piston, causing the piston to move in a direction to reduce the pump wobble plate angle. If the speed drops below 6,000 rpm, oil is directed to the control piston so that it moves to increase the wobble plate angle.

Overspeed protection is installed in the governor. The drive starts in the underdrive position. The governor coil springs are fully extended and the valve stem is held at the limit of its downward travel. In this condition, pressure is directed to the side of the control piston giving minimum wobble plate angle. The maximum angle side of the control piston is open to the hollow stem. As the input speed increases, the flyweights start to move outward to overcome the spring bias. This action lifts the valve stem and starts directing oil to the maximum side of the control piston, while the minimum side is opened to the hollow stem.

At about 6,000 rpm, the stem is positioned to stop drainage of either side, and the two pressures seek a balance point as the flyweight force is balanced against the spring bias. Thus, a mechanical failure in the governor will cause an underdrive condition. The flyweight's force is always tending to move the valve stem to the decrease speed position so that, if the coil spring breaks and the stem moves to the extreme position in that direction, output speed is reduced. If the input to the governor fails, the spring will force the stem all the way to the start position to obtain minimum output speed.

An adjustment screw on the end of the governor regulates the output speed of the constant speed drive. This adjustment increases or decreases the compression of a coil spring, opposing the action of the flyweights. The adjustment screws turn in an indented collar, which provides a means of making speed adjustments in known increments. Each "click" provides a small change in generator frequency.

Voltage Regulation of Alternators

The problem of voltage regulation in an AC system does not differ basically from that in a DC system. In each case, the function of the regulator system is to control voltage, maintain a balance of circulating current throughout the system, and eliminate sudden changes in voltage (anti-hunting) when a load is applied to the system. However, there is one important difference between the regulator system of DC generators and alternators operated in a parallel configuration. The load carried by any particular DC generator in either a two or four generator system depends on its voltage as compared with the bus voltage, while the division of load between alternators depends upon the adjustments of their speed governors, which are controlled by the frequency and droop circuits discussed in the previous section on alternator constant-speed drive systems.

When AC generators are operated in parallel, frequency and voltage must both be equal. Where a synchronizing force is required to equalize only the voltage between DC generators, synchronizing forces are required to equalize both voltage and speed (frequency) between AC generators. On a comparative basis, the synchronizing forces for AC generators are much greater than for DC generators. When AC generators are of sufficient size and are operating at unequal frequencies and terminal voltages, serious damage may result if they are suddenly connected to each other through a common bus. To avoid this, the generators must be synchronized as closely as possible before connecting them together.

Regulating the voltage output of a DC exciter, which supplies current to the alternator rotor field, best controls the output voltage of an alternator. This is accomplished by the regulation of a 28-volt system connected in the field circuit of the exciter. A regulator controls the exciter field current and thus regulates the exciter output voltage applied to the alternator field.

Alternator Transistorized Regulators

Many aircraft alternator systems use a transistorized voltage regulator to control the alternator output. Before studying this section, a review of transistor principles may be helpful.

A transistorized voltage regulator consists mainly of transistors, diodes, resistors, capacitors, and, usually, a thermistor. In operation, current flows through a diode and transistor path to the generator field. When the proper voltage level is reached, the regulating components cause the transistor to cut off conduction to control the alternator field strength. The regulator operating range is usually adjustable through a narrow range. The thermistor provides temperature compensation for the circuitry. The transistorized voltage regulator shown in Figure 10-323 will be referred to in explaining the operation of this type of regulator.

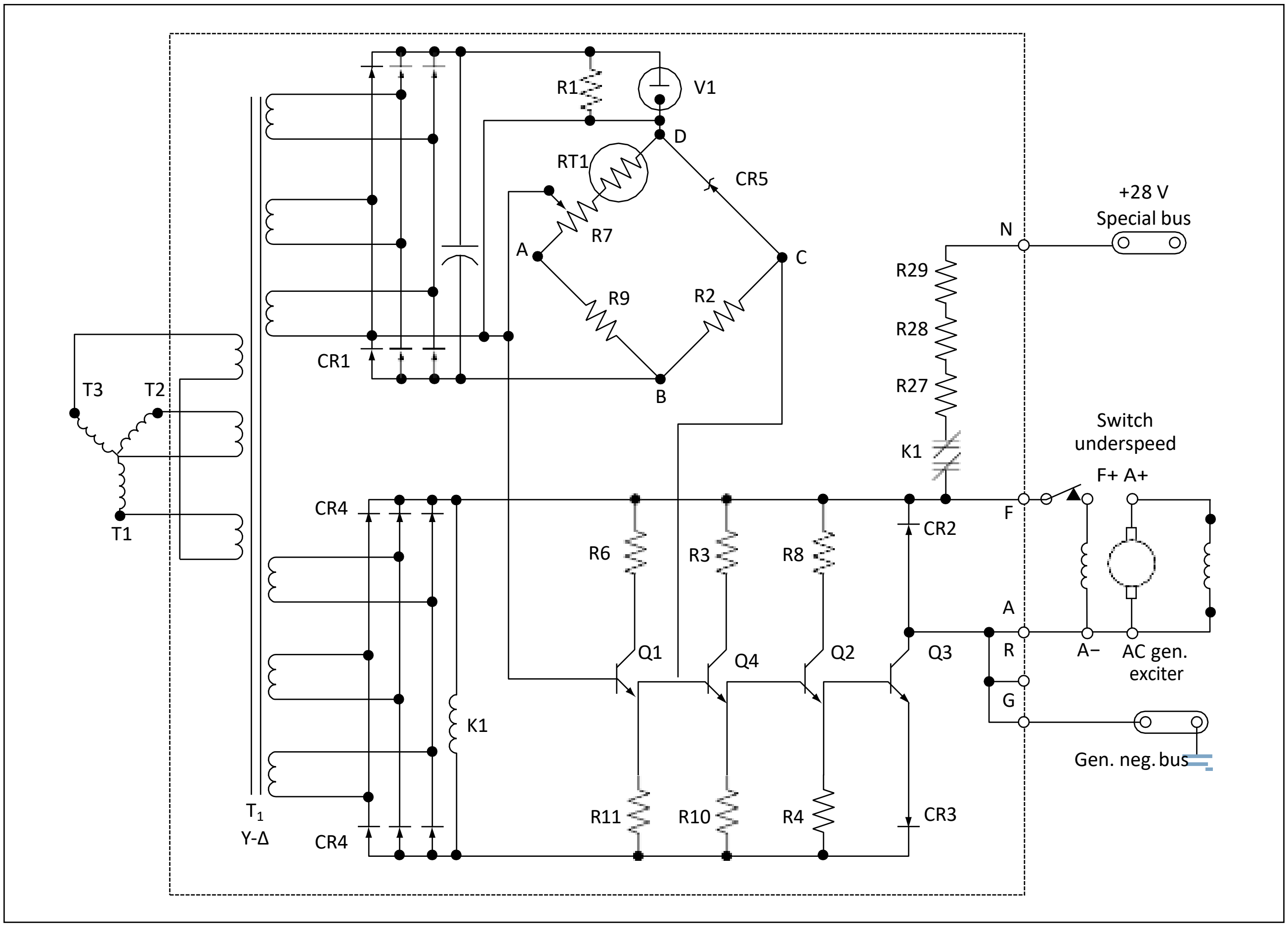

Figure 10-323. Transistorized voltage regulator.

The AC output of the generator is fed to the voltage regulator, where it is compared to a reference voltage, and the difference is applied to the control amplifier section of the regulator. If the output is too low, field strength of the AC exciter generator is increased by the circuitry in the regulator. If the output is too high, the field strength is reduced.

The power supply for the bridge circuit is CR1, which provides full-wave rectification of the three phase output from transformer T1. The DC output voltages of CR1 are proportional to the average phase voltages. Power is supplied from the negative end of the power supply through point B, R2, point C, zener diode (CR5), point D, and to the parallel hookup of V1 and R1. Takeoff point C of the bridge is located between resistor R2 and the zener diode. In the other leg of the reference bridge, resistors R9, R7, and the temperature compensating resistor RT1 are connected in series with V1 and R1 through points B, A, and D. The output of this leg of the bridge is at the wiper arm of R7.

As generator voltage changes occur, for example, if the voltage lowers, the voltage across R1 and V1 (once V2 starts conducting) will remain constant. The total voltage change will occur across the bridge circuit. Since the voltage across the zener diode remains constant (once it starts conducting), the total voltage change occurring in that leg of the bridge will be across resistor R2. In the other leg of the bridge, the voltage change across the resistors will be proportional to their resistance values. Therefore, the voltage change across R2 will be greater than the voltage change across R9 to wiper arm of R7. If the generator output voltage drops, point C will be negative with respect to the wiper arm of R7. Conversely, if the generator voltage output increases, the polarity of the voltage between the two points will be reversed.

The bridge output, taken between points C and A, is connected between the emitter and the base of transistor Q1. With the generator output voltage low, the voltage from the bridge will be negative to the emitter and positive to the base. This is a forward bias signal to the transistor, and the emitter to collector current will therefore increase. With the increase of current, the voltage across emitter resistor R11 will increase.

This, in turn, will apply a positive signal to the base of transistor Q4, increasing its emitter to collector current and increasing the voltage drop across the emitter resistor R10.

This will give a positive bias to the base of Q2, which will increase its emitter to collector current and increase the voltage drop across its emitter resistor R4. This positive signal will control output transistor Q3. The positive signal on the base of Q3 will increase the emitter to collector current.

The control field of the exciter generator is in the collector circuit. Increasing the output of the exciter generator will increase the field strength of the AC generator, which will increase the generator output.

To prevent exciting the generator when the frequency is at a low value, there is an underspeed switch located near the F+ terminal. When the generator reaches a suitable operating frequency, the switch will close and allow the generator to be excited.

Another item of interest is the line containing resistors R27, R28, and R29 in series with the normally closed contacts of the K1 relay. The operating coil of this relay is found in the lower left-hand part of the schematic. Relay K1 is connected across the power supply (CR4) for the transistor amplifier. When the generator is started, electrical energy is supplied from the 28-volt DC bus to the exciter generator field, to "flash the field" for initial excitation. When the field of the exciter generator has been energized, the AC generator starts to produce, and as it builds up, relay K1 is energized, opening the "field flash" circuit.