Chapter 5
Engine Starting Systems

Introduction

Most aircraft engines, reciprocating or turbine, require help during the starting process. Hence, this device is termed the starter. A starter is an electromechanical mechanism capable of developing large amounts of mechanical energy that can be applied to an engine, causing it to rotate. Reciprocating engines need only to be turned through at a relatively slow speed until the engine starts and turns on its own. Once the reciprocating engine has fired and started, the starter is disengaged and has no further function until the next start. In the case of a turbine engine, the starter must turn the engine up to a speed that provides enough airflow through the engine for fuel to be ignited. Then, the starter must continue to help the engine accelerate to a self-sustaining speed. Turbine engine starters have a critical role in starting of the engine.

If the starter turns the turbine engine up to a self-sustaining speed, the engine start process will be successful. There are only a few types or methods used to turn the engine. Almost all reciprocating engines use a form of electric motor geared to the engine. Modern turbine engines use electric motors, starter/generators (electric motor and a generator in the same housing), and air turbine starters. Air turbine starters are driven by compressed air through a turbine wheel that is mechanically connected through reduction gears to one of the engine's compressors, generally the highest pressure compressor.

Reciprocating Engine Starting Systems

In the early stages of aircraft development, relatively low powered reciprocating engines were started by pulling the propeller through a part of a revolution by hand. Difficulty was often experienced in cold weather starting when lubricating oil temperatures were near the congealing point. In addition, the magneto systems delivered a weak starting spark at the very low cranking speeds. This was often compensated for by providing a hot spark using such ignition system devices as the booster coil, induction vibrator, or impulse coupling.

Some small, low-powered aircraft which use hand-cranking of the propeller, or propping, for starting are still being operated. For general instructions on starting this type of aircraft, refer to the Aviation Maintenance Technician—General Handbook, Chapter 1, Safety, Ground Operations, and Servicing. Throughout the development of the aircraft reciprocating engine from the earliest use of starting systems to the present, a number of different starter systems have been used. Most reciprocating engine starters are the direct cranking electric type. A few older model aircraft are still equipped with inertia starters. Thus, only a brief description of these starting systems is included in this section.

Inertia Starters

There are three general types of inertia starters: hand, electric, and combination hand and electric. The operation of all types of inertia starters depends on the kinetic energy stored in a rapidly rotating flywheel for cranking ability. Kinetic energy is energy possessed by a body by virtue of its state of motion, which may be movement along a line or spinning action.

In the inertia starter, energy is stored slowly during an energizing process by a manual hand crank or electrically

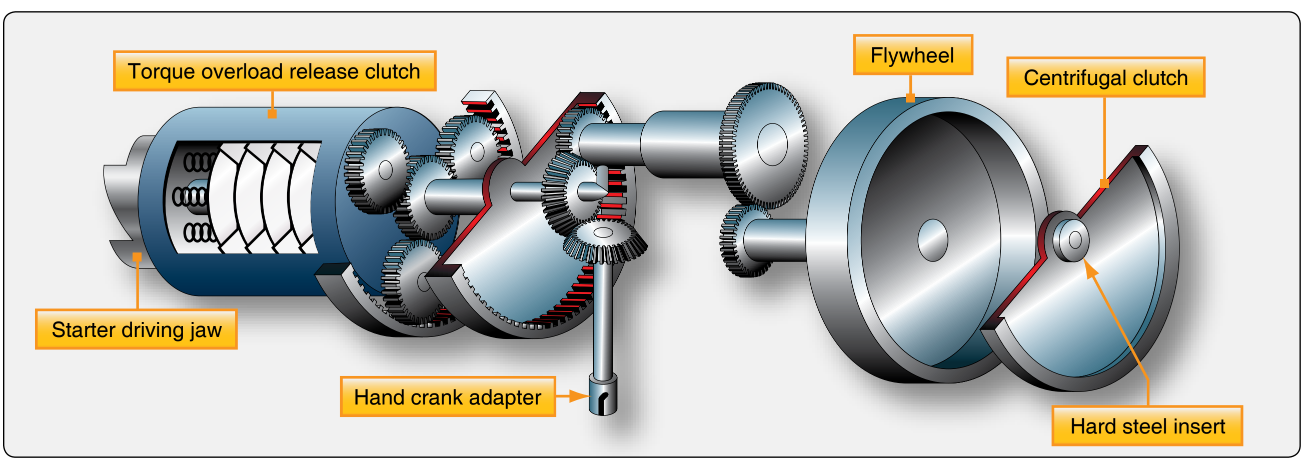

Figure 5-1. *Combination hand and electric inertia starter.*

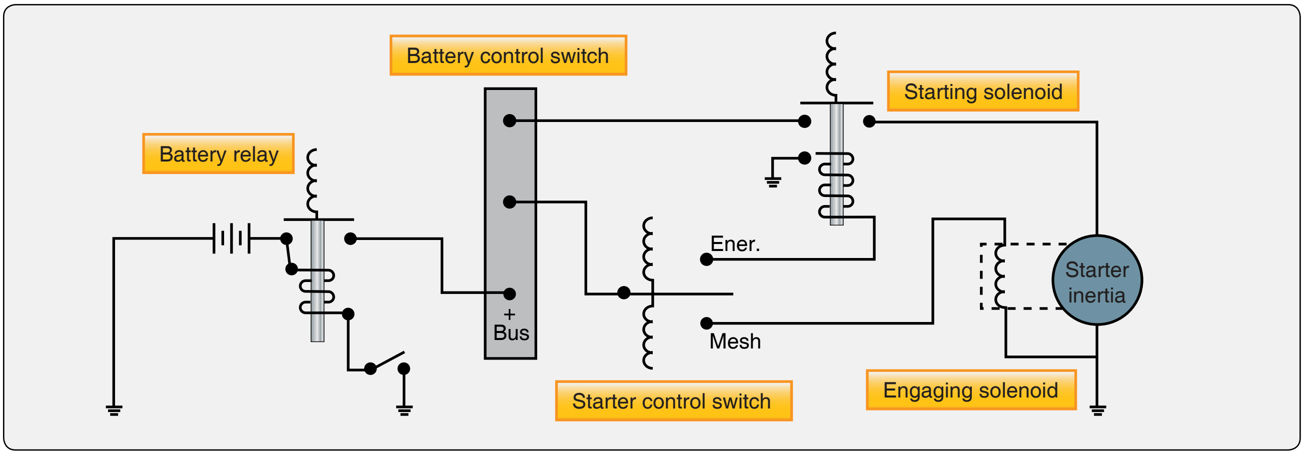

Figure 5-2. *Electric inertia starting circuit.*

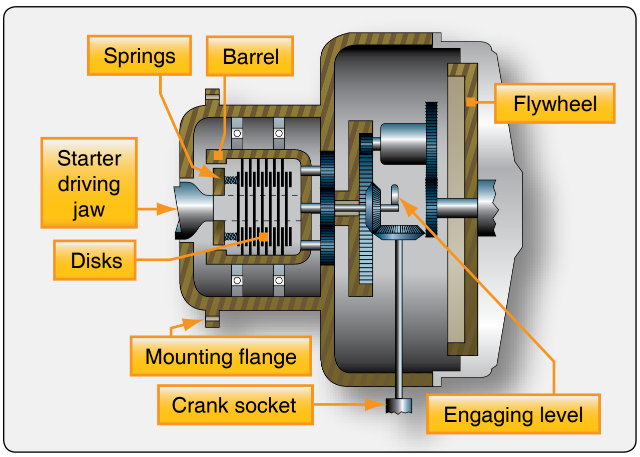

Figure 5-3. *Torque overload release clutch.*

with a small motor. The flywheel and movable gears of a combination hand electric inertia starter are shown in *Figure 5-1*. The electrical circuit for an electric inertia starter is shown in *Figure 5-2*. During the energizing of the starter, all movable parts within it, including the flywheel, are set in motion. After the starter has been fully energized, it is engaged to the crankshaft of the engine by a cable pulled manually or by a meshing solenoid that is energized electrically. When the starter is engaged, or meshed, flywheel energy is transferred to the engine through sets of reduction gears and a torque overload release clutch. *[Figure 5-3]*

Direct Cranking Electric Starter

The most widely used starting system on all types of reciprocating engines utilizes the direct cranking electric starter. This type of starter provides instant and continual cranking when energized. The direct cranking electric starter consists basically of an electric motor, reduction gears, and an automatic engaging and disengaging mechanism that is operated through an adjustable torque overload release clutch. A typical circuit for a direct cranking electric starter is shown in *Figure 5-4*. The engine is cranked directly when the starter solenoid is closed. As shown in *Figure 5-4*, the main cables leading from the starter to the battery are heavy duty to carry the high current flow, which may be in a range from as high as 350 amperes to 100 amperes (amps), depending on the starting torque required. The use of solenoids and heavy wiring with a remote control switch reduces overall cable weight and total circuit voltage drop.

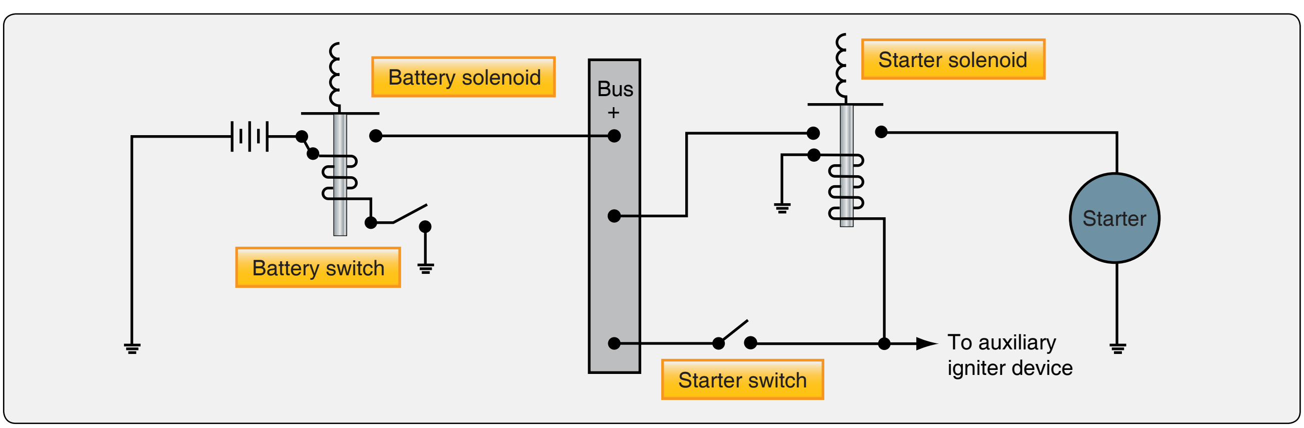

Figure 5-4. *Typical starting circuit using a direct cranking electric starter.*

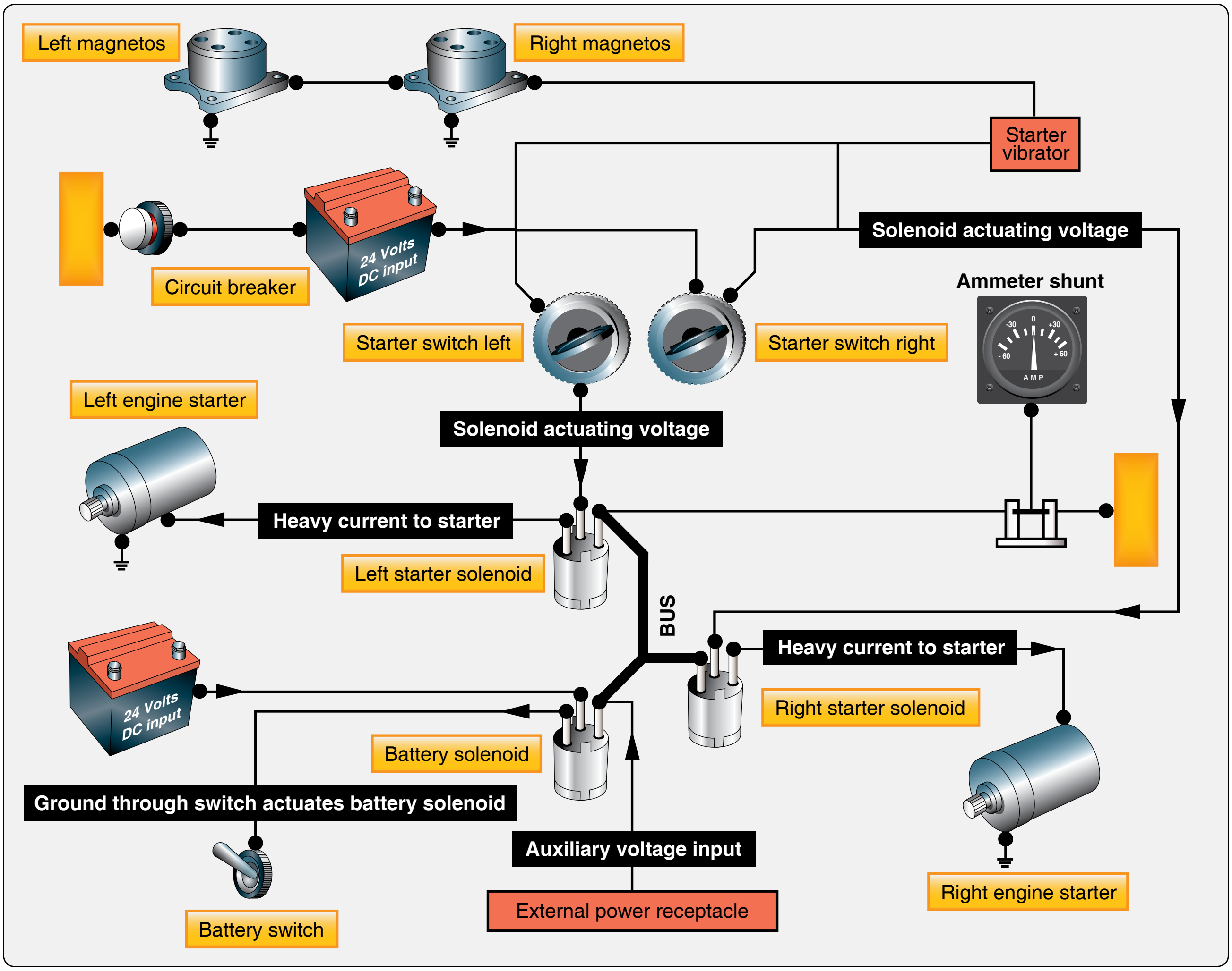

Figure 5-5. *Engine starting schematic for a light twin-engine aircraft.*

The typical starter motor is a 12- or 24-volt, series-wound motor that develops high starting torque. The torque of the motor is transmitted through reduction gears to the overload release clutch. Typically, this action actuates a helically-splined shaft moving the starter jaw outward to engage the engine cranking jaw before the starter jaw begins to rotate. After the engine reaches a predetermined speed, the starter automatically disengages. The schematic in *Figure 5-5* provides a pictorial arrangement of an entire starting system for a light twin-engine aircraft.

Direct Cranking Electric Starting System for Large Reciprocating Engines

In a typical high horsepower reciprocating engine starting system, the direct cranking electric starter consists of two basic components: a motor assembly and a gear section. The gear section is bolted to the drive end of the motor to form a complete unit.

The motor assembly consists of the armature and motor pinion assembly, the end bell assembly, and the motor housing assembly. The motor housing also acts as the magnetic yoke for the field structure.

The starter motor is a nonreversible, series interpole motor. Its speed varies directly with the applied voltage and inversely with the load. The starter gear section consists of an external housing with an integral mounting flange, planetary gear reduction, a sun and integral gear assembly, a torque-limiting clutch, and a jaw and cone assembly. *[Figure 5-6]* When the starter circuit is closed, the torque developed in the starter motor is transmitted to the starter jaw through the reduction gear train and clutch. The starter gear train converts the high speed low torque of the motor to the low speed high torque required to crank the engine. In the gear section, the motor pinion engages the gear on the intermediate countershaft. *[Figure 5-6]* The pinion of the countershaft engages the internal gear. The internal gear is an integral part of the sun gear assembly and is rigidly attached to the sun gear shaft. The sun gear drives three planet gears that are part of the

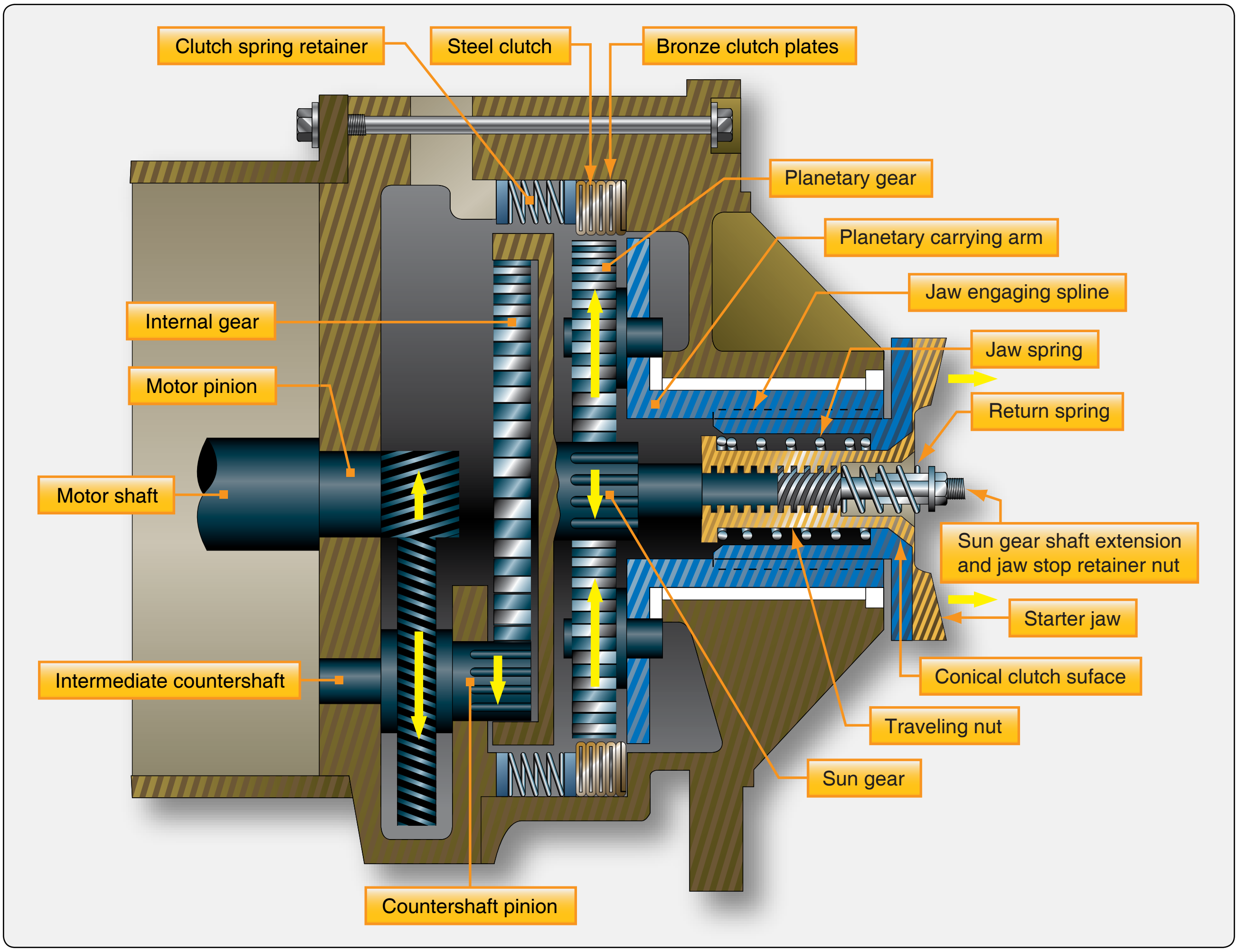

Figure 5-6. *Starter gear section.*

planetary gear assembly. The individual planet gear shafts are supported by the planetary carrying arm, a barrel-like part shown in *Figure 5-6*.

The carrying arm transmits torque from the planet gears to the starter jaw as follows:

1. The cylindrical portion of the carrying arm is splined longitudinally around the inner surface.
2. Mating splines are cut on the exterior surface of the cylindrical part of the starter jaw.
3. The jaw slides fore and aft inside the carrying arm to engage and disengage with the engine.

The three planet gears also engage the surrounding internal teeth on the six steel clutch plates. *[Figure 5-6]* These plates are interleaved with externally splined bronze clutch plates that engage the sides of the housing, preventing them from turning. The proper pressure is maintained upon the clutch pack by a clutch spring retainer assembly. A cylindrical traveling nut inside the starter jaw extends and retracts the jaw. Spiral jaw-engaging splines around the inner wall of the nut mate with similar splines cut on an extension of the sun gear shaft. *[Figure 5-6]*

Being splined in this fashion, rotation of the shaft forces the nut out and the nut carries the jaw with it. A jaw spring around the traveling nut carries the jaw with the nut and tends to keep a conical clutch surface around the inner wall of the jaw head seated against a similar surface around the underside of the nut head. A return spring is installed on the sun gear shaft extension between a shoulder, formed by the splines around the inner wall of the traveling nut, and a jaw stop retaining nut on the end of the shaft. Because the conical clutch surfaces of the traveling nut and the starter jaw are engaged by jaw spring pressure, the two parts tend to rotate at the same speed. However, the sun gear shaft extension turns six times faster than the jaw. The spiral splines on it are cut left hand, and the sun gear shaft extension, turning to the right in relation to the jaw, forces the traveling nut and the jaw out from the starter its full travel (about ⁵⁄₁₆ inches) in approximately 12° of rotation of the jaw.

The jaw moves out until it is stopped either by engagement with the engine or by the jaw stop retaining nut. The travel nut continues to move slightly beyond the limit of jaw travel, just enough to relieve some of the spring pressure on the conical clutch surfaces. As long as the starter continues to rotate, there is just enough pressure on the conical clutch surfaces to provide torque on the spiral splines that balance most of the pressure of the jaw spring. If the engine fails to start, the starter jaw does not retract since the starter mechanism provides no retracting force. However, when the engine fires and the engine jaw overruns the starter jaw, the sloping ramps of the jaw teeth force the starter jaw into the starter against the jaw spring pressure. This disengages the conical clutch surfaces entirely, and the jaw spring pressure forces the traveling nut to slide in along the spiral splines until the conical clutch surfaces are again in contact.

When the starter and engine are both running, there is an engaging force keeping the jaws in contact that continue until the starter is de-energized. However, the rapidly moving engine jaw teeth, striking the slowly moving starter jaw teeth, hold the starter jaw disengaged. As soon as the starter comes to rest, the engaging force is removed, and the small return spring throws the starter jaw into its fully retracted position where it remains until the next start. When the starter jaw first engages the engine jaw, the motor armature has had time to reach considerable speed because of its high starting torque. The sudden engagement of the moving starter jaw with the stationary engine jaw would develop forces sufficiently high enough to severely damage the engine or the starter were it not for the plates in the clutch pack that slip when the engine torque exceeds the clutch-slipping torque.

In normal direct cranking action, the internal steel gear clutch plates are held stationary by the friction of the bronze plates with which they are interleaved. When the torque imposed by the engine exceeds the clutch setting, however, the internal gear clutch plates rotate against the clutch friction, allowing the planet gears to rotate while the planetary carrying arm and the jaw remain stationary. When the engine reaches the speed that the starter is trying to achieve, the torque drops off to a value less than the clutch setting, the internal gear clutch plates are again held stationary, and the jaw rotates at the speed that the motor is attempting to drive it. The starter control switches are shown schematically in *Figure 5-7*.

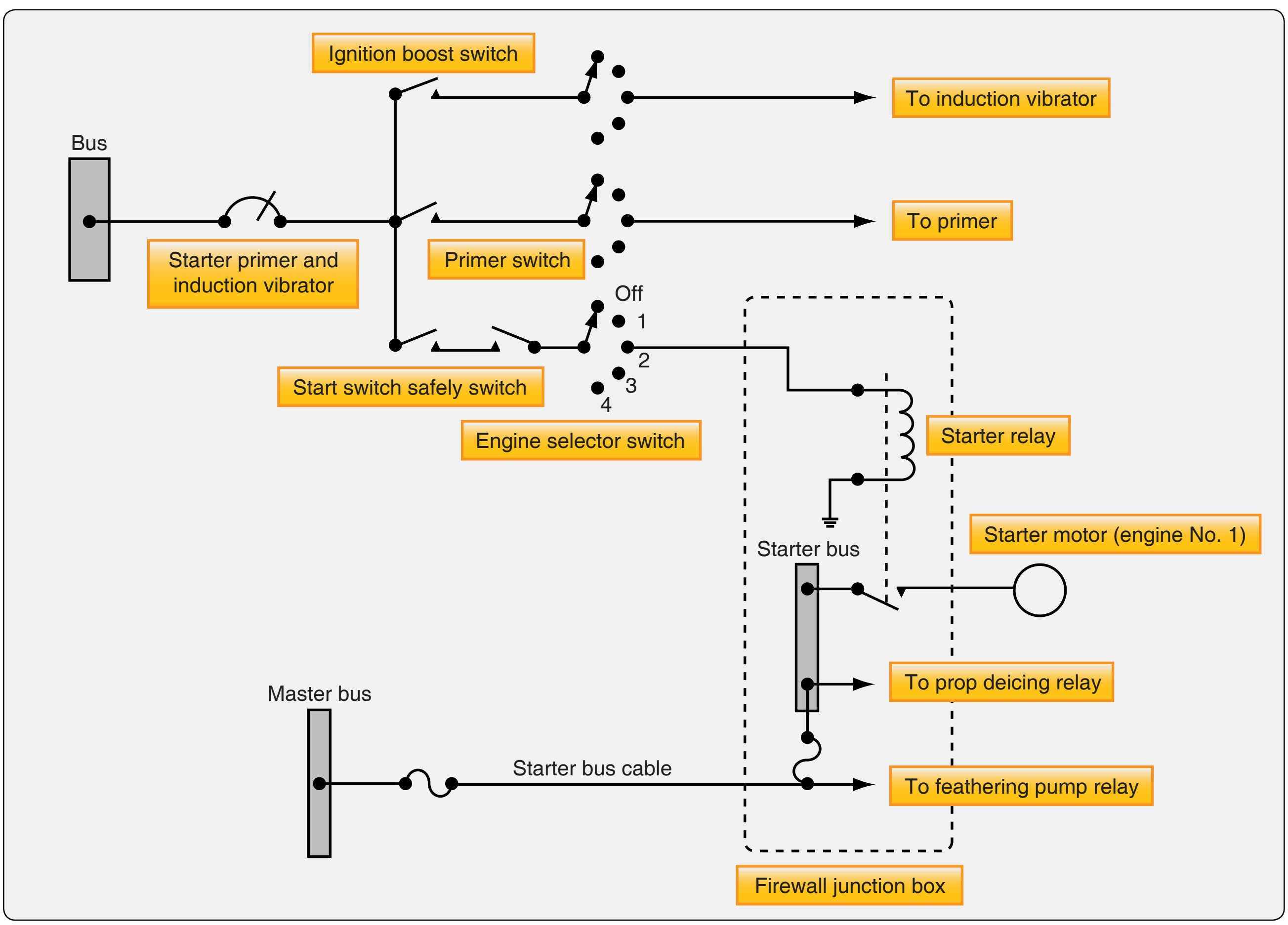

Figure 5-7. *Starter control circuit.*

The engine selector switch must be positioned and the starter switch and the safety switch—wired in series—must be closed before the starter can be energized. Current is supplied to the starter control circuit through a circuit breaker labeled "Starter, Primer, and Induction Vibrator." *[Figure 5-7]* When the engine selector switch is in position for the engine start, closing the starter energizes the starter relay located in the engine nacelle area. Energizing the starter relay completes the power circuit to the starter motor. The current necessary for this heavy load is taken directly from the master bus through the starter bus cable.

All starting systems have operating time limits because of the high energy used during cranking or rotation of the engine. These limits are referred to as starter limits and must be observed or overheating and damage of the starter occurs. After energizing the starter for 1 minute, it should be allowed to cool for at least 1 minute. After a second or subsequent cranking period of 1 minute, it should cool for 5 minutes.

Direct Cranking Electric Starting System for Small Aircraft

Most small, reciprocating engine aircraft employ a direct cranking electric starting system. Some of these systems are automatically engaged starting systems, while others are manually engaged.

Manually engaged starting systems used on many older, small aircraft employ a manually operated overrunning clutch drive pinion to transmit power from an electric starter motor to a crankshaft starter drive gear. *[Figure 5-8]* A knob or handle on the instrument panel is connected by a flexible control to a lever on the starter. This lever shifts the starter drive pinion into the engaged position and closes the starter switch contacts when the starter knob or handle is pulled. The starter lever is attached to a return spring that returns the lever and the flexible control to the off position. When the engine starts, the overrunning action of the clutch protects the starter drive pinion until the shift lever can be released to disengage the pinion. For the typical unit, there is a specified length of travel for the starter gear pinion. *[Figure 5-8]* It is important that the starter lever move the starter pinion gear this proper distance before the adjustable lever stud contacts the starter switch.

The automatic, or remote solenoid engaged, starting systems employ an electric starter mounted on an engine adapter. A starter solenoid is activated by either a push button or turning the ignition key on the instrument panel. When the solenoid is activated, its contacts close, and electrical energy energizes the starter motor. Initial rotation of the starter motor engages the starter through an overrunning clutch in the starter adapter, which incorporates worm reduction gears.

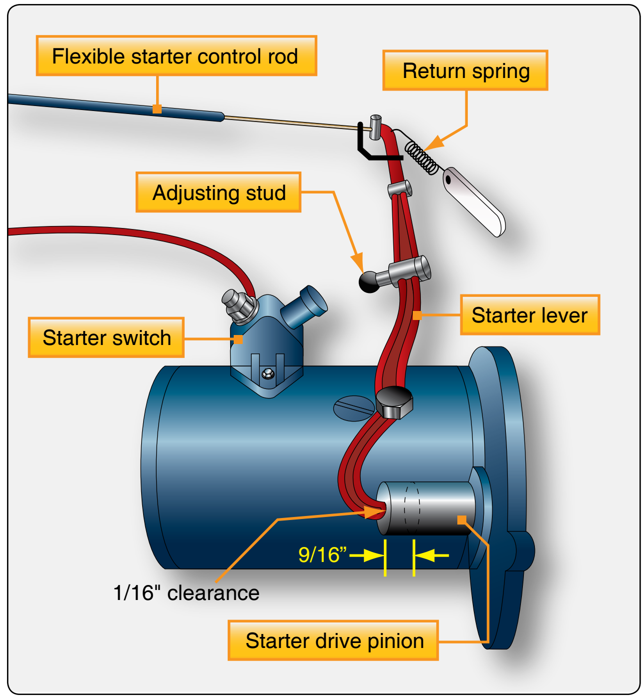

Figure 5-8. *Starter level controls and adjustment.*

Some engines incorporate an automatic starting system that employs an electric starter motor mounted on a right angle drive adapter. As the starter motor is electrically energized, the adapter worm shaft and gear engage the starter shaft gear by means of a spring and clutch assembly. The shaft gear, in turn, rotates the crankshaft. When the engine begins to turn on its own power, the clutch spring disengages from the shaft gear. The starter adapter uses a worm drive gear shaft and worm gear to transfer torque from the starter motor to the clutch assembly. *[Figure 5-9]* As the worm gear rotates the worm wheel and clutch spring, the clutch spring is tightened around the drum of the starter shaft gear. As the shaft gear turns, torque is transmitted directly to the crankshaft gear.

Other engines use a starter that drives a ring gear mounted to the propeller hub. *[Figure 5-10]* It uses an electric motor and a drive gear that engages as the motor is energized and spins the gear, which moves out and engages the ring gear on the propeller hub cranking the engine for start. *[Figure 5-11]* As the engine starts, the starter drive gear is spun back by the engine turning, which disengages the drive gear. *[Figure 5-12]* The starter motors on small aircraft also have operational limits with cool down times that should be observed.

Reciprocating Engine Starting System Maintenance Practices

Most starting system maintenance practices include replacing the starter motor brushes and brush springs, cleaning dirty commutators, and turning down burned or out-of-round

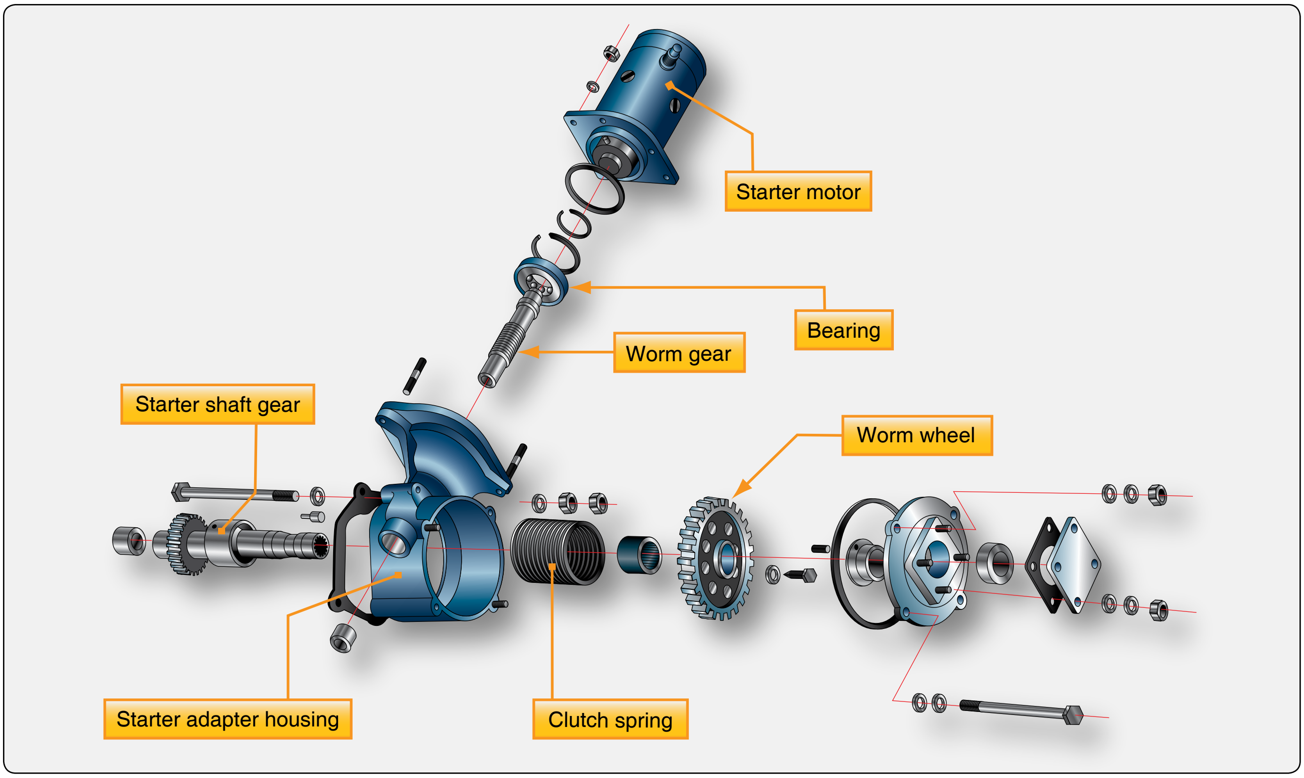

Figure 5-9. *Starter adapter.*

Figure 5-10. *Starter ring gear mounted on the propeller hub.*

starter commutators. As a rule, starter brushes should be replaced when worn down to approximately one-half the original length. Brush spring tension should be sufficient to give brushes a good firm contact with the commutator. Brush leads should be unbroken and lead terminal screws tight.

A glazed or dirty starter commutator can be cleaned by holding a strip of double-0 sandpaper or a brush seating stone against the commutator as it is turned. The sandpaper or stone should be moved back and forth across the commutator to avoid wearing a groove. Emery paper or carborundum should never be used for this purpose because of their possible shorting action.

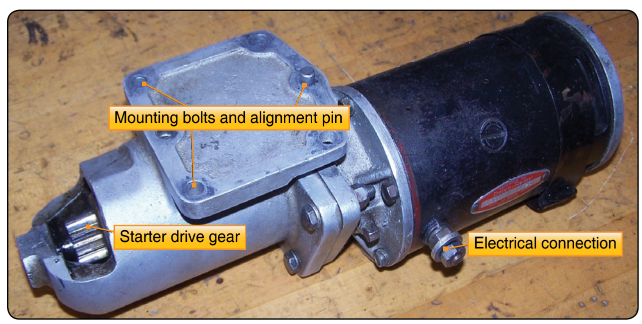

Figure 5-11. *Starter drive gear mounting holes and electrical connector.*

Roughness, out-of-roundness, or high-mica conditions are reasons for turning down the commutator. In the case of a high-mica condition, the mica should be undercut after the turning operation is accomplished. Refer to FAA-H-8083-30, Aviation Maintenance Technician—General for a review of high-mica commutators in motors.

The drive gear should be checked for wear along with the ring gear. The electrical connections should be checked for looseness and corrosion. Also, check the security of the mounting of the housing of the starter.

Troubleshooting Small Aircraft Starting Systems

The troubleshooting procedures listed in *Figure 5-13* are typical of those used to isolate malfunctions in small aircraft starting systems.

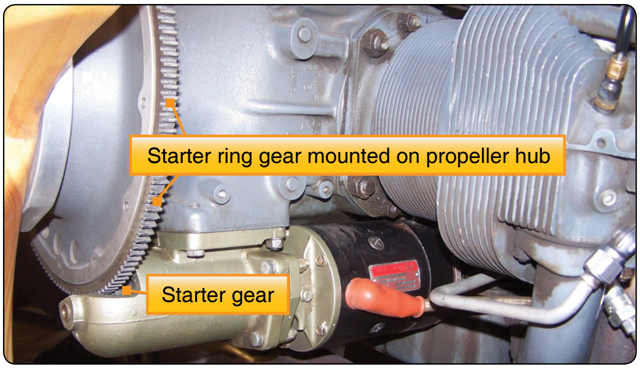

Figure 5-12. *Engine starter mounted on the engine.*

Gas Turbine Engine Starters

Gas turbine engines are started by rotating the high-pressure compressor. On dual-spool, axial flow engines, the high-pressure compressor and N1 turbine system is only rotated by the starter. To start a gas turbine engine, it is necessary to accelerate the compressor to provide sufficient air to support combustion in the combustion section, or burners. Once ignition and fuel have been introduced and the lite-off has occurred, the starter must continue to assist the engine until the engine reaches a self-sustaining speed. The torque supplied by the starter must be in excess of the torque required to overcome compressor inertia and the friction loads of the engine's compressor.

Figure 5-14 illustrates a typical starting sequence for a gas turbine engine, regardless of the type of starter employed. As soon as the starter has accelerated the compressor sufficiently to establish airflow through the engine, the ignition is turned on followed by the fuel. The exact sequence of the starting procedure is important since there must be sufficient airflow through the engine to support combustion before the air-fuel mixture is ignited. At low engine cranking speeds, the fuel flow rate is not sufficient to enable the engine to accelerate; for this reason, the starter continues to crank the engine until after self-accelerating speed has been attained. If assistance from the starter were cut off below the self-accelerating speed, the engine would either fail to accelerate to idle speed or might even decelerate because it could not produce sufficient energy to sustain rotation or to accelerate during the initial phase of the starting cycle. The starter must continue to assist the engine considerably above the self-accelerating speed to avoid a delay in the starting cycle, which would result in a hot or hung false start or a combination of both. At the proper points in the sequence, the starter and ignition

Small Aircraft Troubleshooting Procedures

	Probable Cause	Isolation Procedure	Remedy
Starter will not operate	• Defective master switch or circuit. • Defective starter switch or switch circuit. • Starter lever does not activate switch. • Defective starter.	• Check master circuit. • Check switch circuit continuity. • Check starter lever adjustment. • Check through items above. If another cause is not apparent, starter is defective.	• Repair circuit. • Replace switch or wires. • Adjust starter lever in accordance with manufacturer's instructions. • Remove and repair or replace starter.
Starter motor runs but does not turn crankshaft	• Starter lever adjusted to activate switch without engaging pinion with crankshaft gear. • Defective overrunning clutch or drive. • Damaged starter pinion gear or crankshaft gear.	• Check starter lever adjustment. • Remove starter and check starter drive and overrunning clutch. • Remove and check pinion gear and crankshaft gear.	• Adjust starter lever in accordance with manufacturer's instructions. • Replace defective parts. • Replace defective parts.
Starter drags	• Low battery. • Starter switch or relay contacts burned or dirty. • Defective starter.	• Check battery. • Check contacts. • Check starter brushes, brush spring tension for solder thrown on brush cover.	• Charge or replace battery. • Replace with serviceable unit. • Repair or replace starter.
Starter excessively noisy	• Dirty, worn commutator. • Worn starter pinion. • Worn or broken teeth on crankshaft gears.	• Clean and check visually. • Remove and examine pinion. • Remove starter and turn over engine by hand to examine crankshaft gear.	• Turn down commutator. • Replace starter drive. • Replace crankshaft gear.

Figure 5-13. *Small aircraft troubleshooting procedures.*

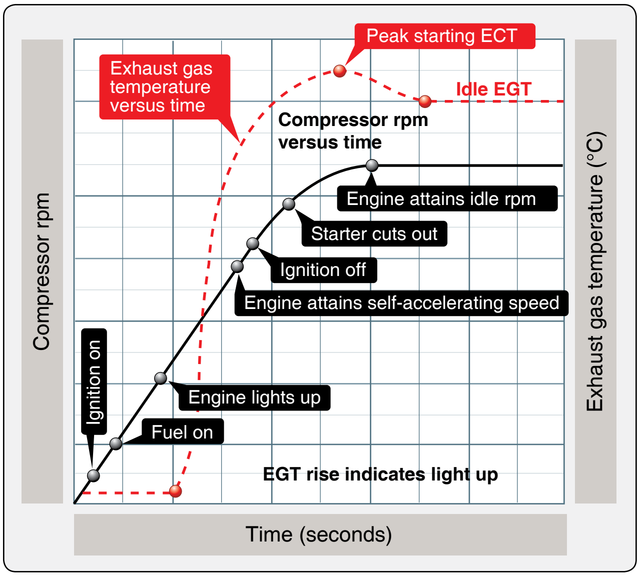

Figure 5-14. *Typical gas turbine engine starting sequence.*

are automatically cut off. The basic types of starters that are in current use for gas turbine engines are direct current (DC) electric motor, starter/generators, and the air turbine type of starters.

Many types of turbine starters have included several different methods for turning the engine for starting. Several methods have been used but most of these have given way to electric or air turbine starters. An air impingement starting system, which is sometimes used on small engines, consists of jets of compressed air piped to the inside of the compressor or turbine case so that the jet air blast is directed onto the compressor or turbine rotor blades, causing them to rotate.

A typical cartridge/pneumatic turbine engine starter may be operated as an ordinary air turbine starter from a ground-operated air supply or an engine cross-bleed source. It may also be operated as a cartridge starter. *[Figure 5-15]* To accomplish a cartridge start, a cartridge is first placed in the breech cap. The breech is then closed on the breech chamber by means of the breech handle and then rotated a partial turn to engage the lugs between the two breech sections. The cartridge is ignited by applying voltage through the connector at the end of the breech handle. Upon ignition, the cartridge begins to generate gas. The gas is forced out of the breech to the hot gas nozzles that are directed toward the buckets on the turbine rotor, and rotation is produced via the overboard exhaust collector. Before reaching the nozzle, the hot gas passes an outlet leading to the relief valve. This valve directs hot gas to the turbine, bypassing the hot gas nozzle, as the pressure rises above the preset maximum. Thus, the pressure of the gas within the hot gas circuit is maintained at the optimum level.

The air-fuel combustion starter was used to start gas turbine

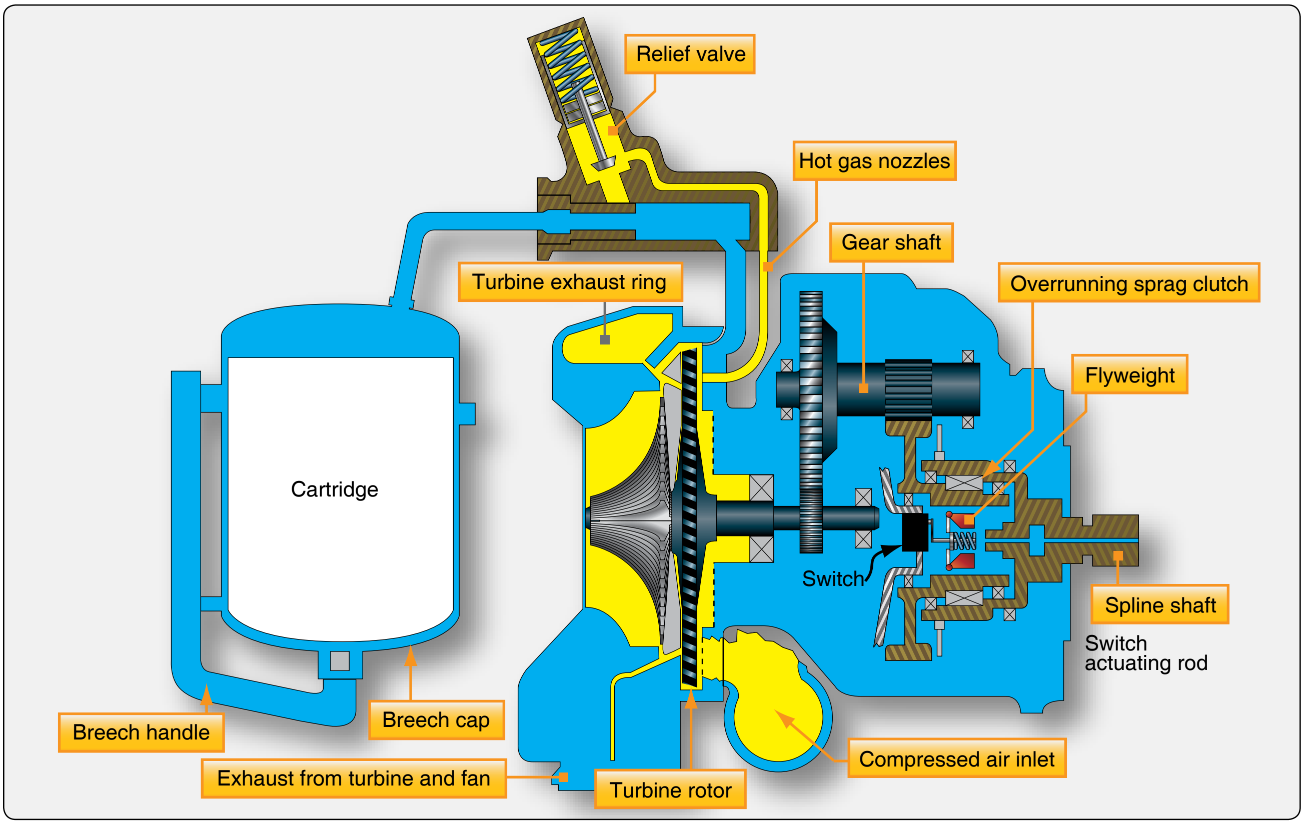

Figure 5-15. *Cartridge/pneumatic starter schematic.*

engines by using the combustion energy of jet A fuel and compressed air. The starter consists of a turbine-driven power unit and auxiliary fuel, air, and ignition systems. Operation of this type starter is, in most installations, fully automatic; actuation of a single switch causes the starter to fire and accelerate the engine from rest to starter cutoff speed.

Hydraulic pumps and motors have also been used for some smaller engines. Many of these systems are not often used on modern commercial aircraft because of the high power demands required to turn the large turbofan engines during the starting cycle on transport aircraft.

Electric Starting Systems & Starter Generator Starting System

Electric starting systems for gas turbine aircraft are of two general types: direct cranking electrical systems and starter generator systems. Direct cranking electric starting systems are used mostly on small turbine engines, such as Auxiliary Power Units (APUs), and some small turboshaft engines. Many gas turbine aircraft are equipped with starter generator systems. Starter generator starting systems are also similar to direct cranking electrical systems except that after functioning as a starter, they contain a second series of windings that allow it to switch to a generator after the engine has reached a self-sustaining speed. This saves weight and space on the engine.

The starter generator is permanently engaged with the engine shaft through the necessary drive gears, while the direct cranking starter must employ some means of disengaging the starter from the shaft after the engine has started. The starter generator unit is basically a shunt generator with an additional heavy series winding. *[Figure 5-16]* This series winding is electrically connected to produce a strong field and a resulting high torque for starting. Starter generator units are desirable from an economic standpoint, since one unit performs the functions of both starter and generator. Additionally, the total weight of starting system components is reduced and fewer spare parts are required.

The starter generator internal circuit has four field windings: a series field (C field), a shunt field, a compensating field, and an interpole or commutating winding. *[Figure 5-17]* During starting, the C field, compensating, and commutating windings are used. The unit is similar to a direct cranking starter since all of the windings used during starting are in series with the source. While acting as a starter, the unit makes no practical use of its shunt field. A source of 24 volts and 1,500 peak amperes is usually required for starting.

When operating as a generator, the shunt, compensating, and commutating windings are used. The C field is used

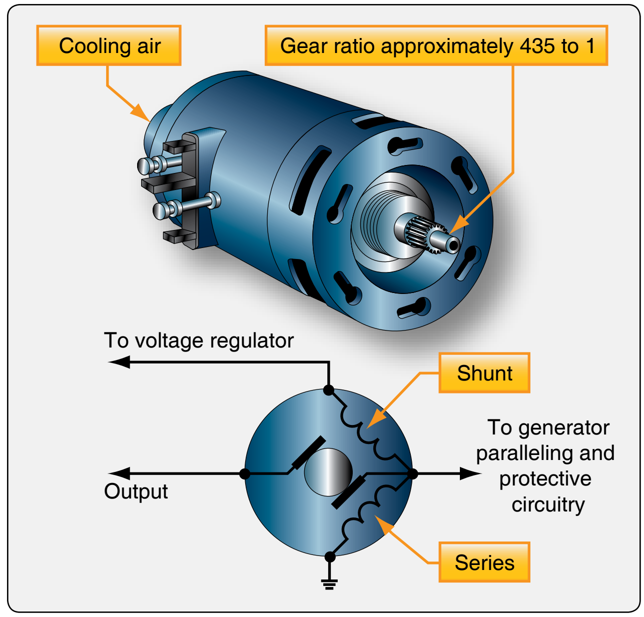

Figure 5-16. *Typical starter generator.*

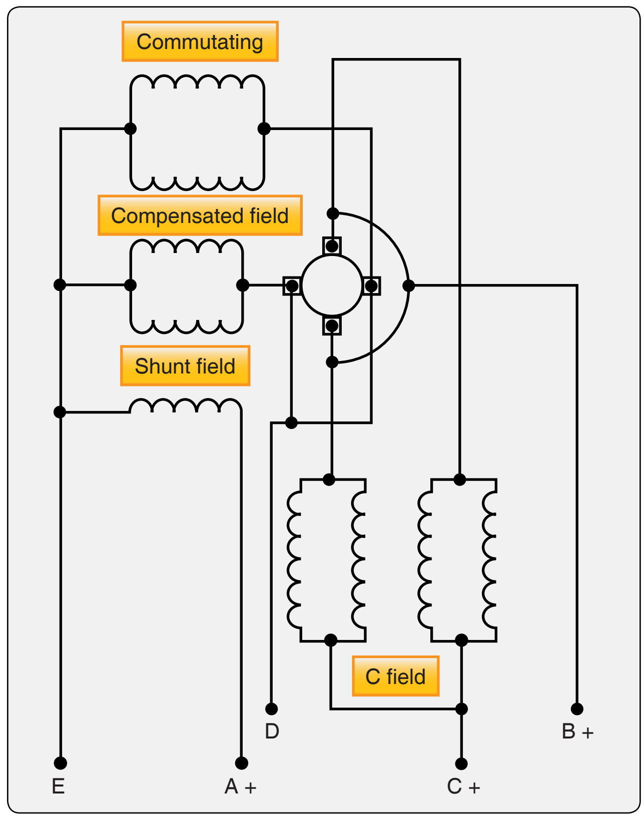

Figure 5-17. *Starter generator internal circuit.*

only for starting purposes. The shunt field is connected in the conventional voltage control circuit for the generator. Compensating and commutating or interpole windings provide almost sparkless commutation from no load to full load. *Figure 5-18* illustrates the external circuit of a starter generator with an undercurrent controller. This unit controls the starter generator when it is used as a starter. Its purpose is

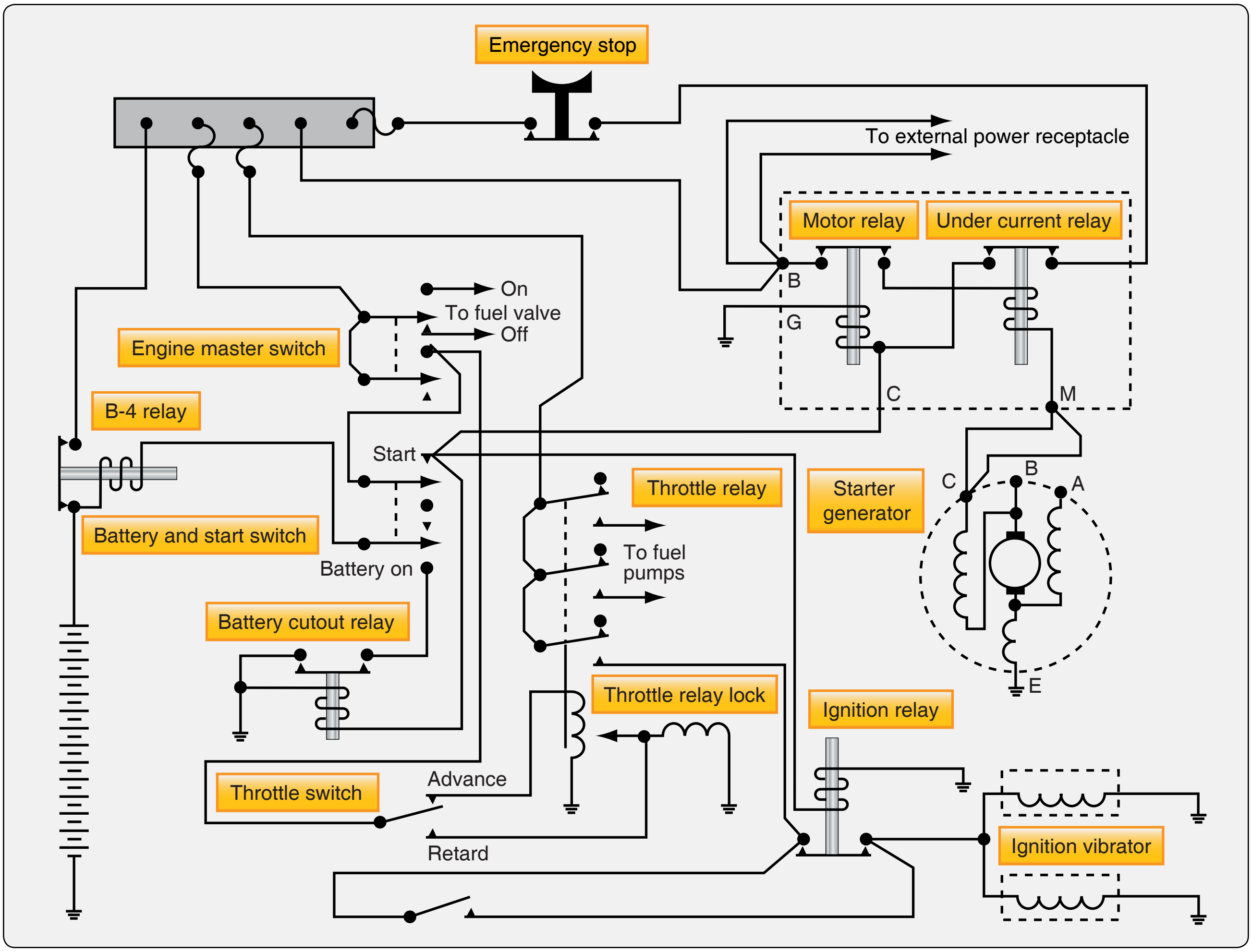

Figure 5-18. *Starter generator circuit.*

to assure positive action of the starter and to keep it operating until the engine is rotating fast enough to sustain combustion. The control block of the undercurrent controller contains two relays. One is the motor relay that controls the input to the starter; the other, the undercurrent relay, controls the operation of the motor relay.

The sequence of operation for the starting system is discussed in the following paragraphs. *[Figure 5-18]* To start an engine equipped with an undercurrent relay, it is first necessary to close the engine master switch. This completes the circuit from the aircraft's bus to the start switch, to the fuel valves, and to the throttle relay. Energizing the throttle relay starts the fuel pumps and completing the fuel valve circuit gives the necessary fuel pressure for starting the engine. As the battery and start switch is turned on, three relays close: the motor relay, ignition relay, and battery cutout relay. The motor relay closes the circuit from the power source to the starter motor; the ignition relay closes the circuit to the ignition units; the battery cutout relay disconnects the battery. Opening the battery circuit is necessary because the heavy drain of the starter motor would damage the battery. Closing the motor relay allows a very high current to flow to the motor. Since this current flows through the coil of the undercurrent relay, it closes. Closing the undercurrent relay completes a circuit from the positive bus to the motor relay coil, ignition relay coil, and battery cutout relay coil. The start switch is allowed to return to its normal off position, and all units continue to operate.

As the motor builds up speed, the current draw of the motor begins to decrease. As it decreases to less than 200 amps, the undercurrent relay opens. This action breaks the circuit from the positive bus to the coils of the motor, ignition, and battery cutout relays. The de-energizing of these relay coils halts the start operation.

After these procedures are completed, the engine should be operating efficiently, and ignition should be self-sustaining. If, however, the engine fails to reach sufficient speed to halt the starter operation, the stop switch may be used to break the circuit from the positive bus to the main contacts of the undercurrent relay.

Troubleshooting a Starter Generator Starting System

The procedures listed in *Figure 5-19* are typical of those used to repair malfunctions in a starter generator starting system similar to the system described in this section. These procedures are presented as a guide only. The appropriate manufacturer's instructions and approved maintenance directives should always be consulted for the aircraft involved.

Air Turbine Starters

Air turbine starters are designed to provide high starting torque from a small, lightweight source. The typical air turbine starter weighs from one-fourth to one-half as much as an electric starter capable of starting the same engine. It is capable of developing considerable more torque than the electric starter.

The typical air turbine starter consists of an axial flow turbine that turns a drive coupling through a reduction gear train and a starter clutch mechanism. The air to operate an air turbine starter is supplied from either a ground-operated air cart, the APU, or a cross-bleed start from an engine already operating. *[Figure 5-20]* Only one source of around 30–50 pounds per square inch (psi) is used at a time to start the engines. The pressure in the ducts must be high enough to provide for a complete start with a normal limit minimum of about 30 psi. When starting engines with an air turbine starter, always check the duct pressure prior to the start attempt.

Figure 5-21 is a cutaway view of an air turbine starter. The starter is operated by introducing air of sufficient volume and pressure into the starter inlet. The air passes into the starter turbine housing where it is directed against the rotor blades by the nozzle vanes causing the turbine rotor to turn. As the rotor turns, it drives the reduction gear train and clutch arrangement, which includes the rotor pinion, planet gears and carrier, sprag clutch assembly, output shaft assembly, and drive coupling. The sprag clutch assembly engages automatically as soon as the rotor starts to turn but disengages as soon as the drive coupling turns more rapidly than the rotor side. When the starter reaches this overrun speed, the action of the sprag clutch allows the gear train to coast to a halt. The output shaft assembly and drive coupling continue to turn as long as the engine is running. A rotor switch actuator, mounted in the turbine rotor hub, is set to open the turbine switch when

Starter Generator Starting System Troubleshooting Procedures		
Probable Cause	**Isolation Procedure**	**Remedy**
Engine does not rotate during start attempt		
• Low supply voltage to the starter. • Power switch is defective. • Ignition switch in throttle quadrant. • Start-lockout relay is defective. • Battery series relay is defective. • Starter relay is defective. • Defective starter. • Start lock-in relay defective. • Starter drive shaft in component drive gearbox is sheared.	• Check voltage of the battery or external power source. • Check switch for continuity. • Check switch for continuity. • Check position of generator control switch. • With start circuit energized, check for 48 volts DC across series relay coil. • With start circuit energized, check for 48 volts DC across starter relay coil. • With start circuit energized, check for proper voltage at the starter. • With start circuit energized, check for 28 volts DC across the relay coil. • Listen for sounds of starter rotation during an attempted start. If the starter rotates but the engine does not, the drive shaft is sheared.	• Adjust voltage of the external power source or charge batteries. • Replace switch. • Replace switch. • Place switch in OFF position. • Replace relay if no voltage is present. • Replace relay if no voltage is present. • Replace the starter if voltage is present. • Replace relay if voltage is not present. • Replace the engine.
Engine starts but does not accelerate to idle		
• Insufficient starter voltage.	• Check starter terminal voltage.	• Use larger capacity ground power unit or charge batteries.
Engine fails to start when throttle is placed in idle		
• Defective ignition system.	• Turn on system and listen for spark-igniter operation.	• Clean or replace spark igniters, or replace exciters or leads to igniters.

Figure 5-19. *Starter generator starting system troubleshooting procedures.*

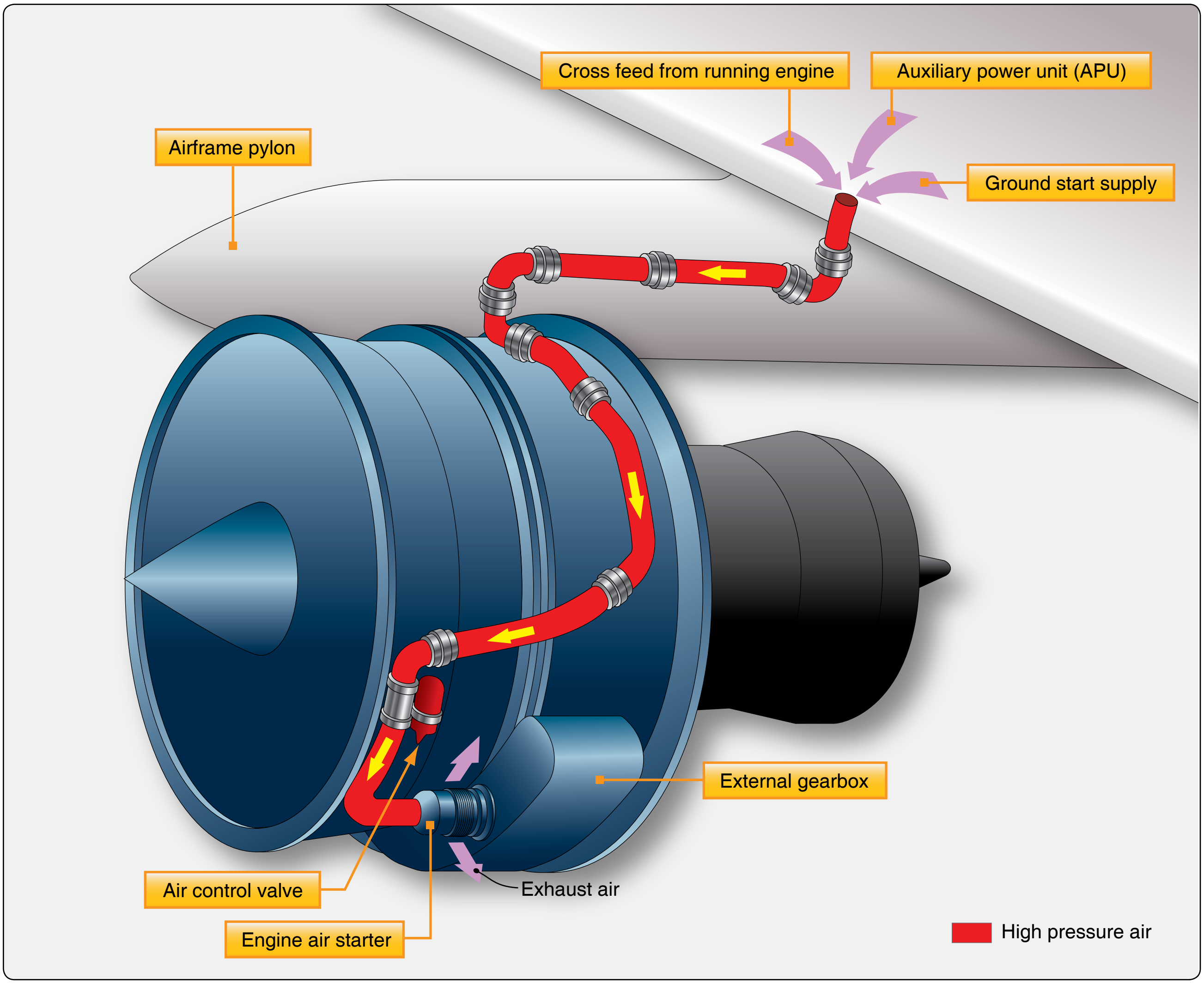

Figure 5-20. *Air turbine starters are supplied by ground cart, APU, or another operating onboard engine.*

the starter reaches cutout speed. Opening the turbine switch interrupts an electrical signal to the start valve. This closes the valve and shuts off the air supply to the starter.

The turbine housing contains the turbine rotor, the rotor switch actuator, and the nozzle components that direct the inlet air against the rotor blades. The turbine housing incorporates a turbine rotor containment ring designed to dissipate the energy of blade fragments and direct their discharge at low energy through the exhaust duct in the event of rotor failure due to excessive turbine overspeed.

The transmission housing contains the reduction gears, the clutch components, and the drive coupling. The transmission housing also provides a reservoir for the lubricating oil. *[Figure 5-22]* Normal maintenance for air turbine starters includes checking the oil level, inspecting the magnetic chip detector for metal particles, and checking for leaks. Oil can be added to the transmission housing sump through a port in the starter. This port is closed by a vent plug containing a ball valve that allows the sump to be vented to the atmosphere during normal flight. The housing also incorporates a sight gauge that is used to check the oil quantity. A magnetic drain plug in the transmission drain opening attracts any ferrous particles that may be in the oil. The starter uses turbine oil, the same as the engine, but this oil does not circulate through the engine.

The ring gear housing, which is internal, contains the rotor assembly. The switch housing contains the turbine switch and bracket assembly. To facilitate starter installation and removal, a mounting adapter is bolted to the mounting pad on the engine. Quick-detach clamps join the starter to the mounting adapter and inlet duct. *[Figure 5-22]* Thus, the starter is easily removed for maintenance or overhaul by disconnecting the electrical line, loosening the clamps, and carefully disengaging the drive coupling from the engine starter drive as the starter is withdrawn.

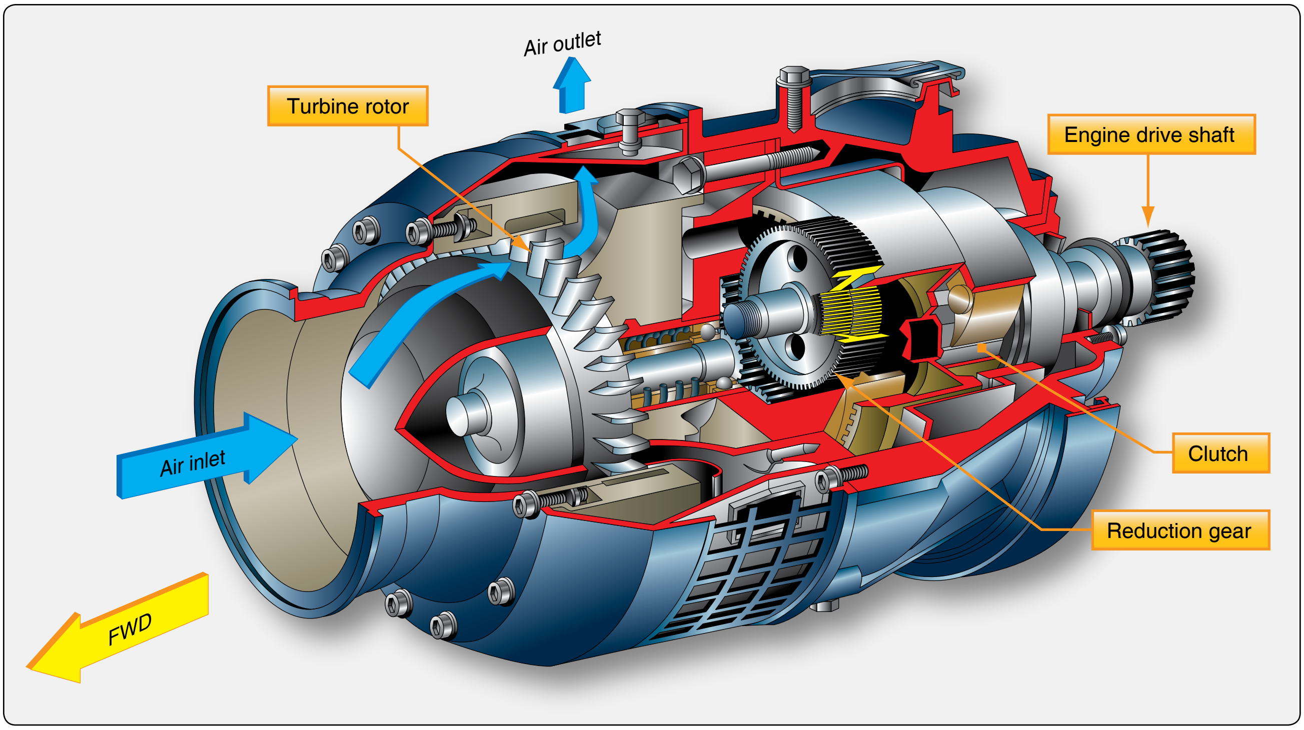

Figure 5-21. *Cutaway view of an air turbine starter.*

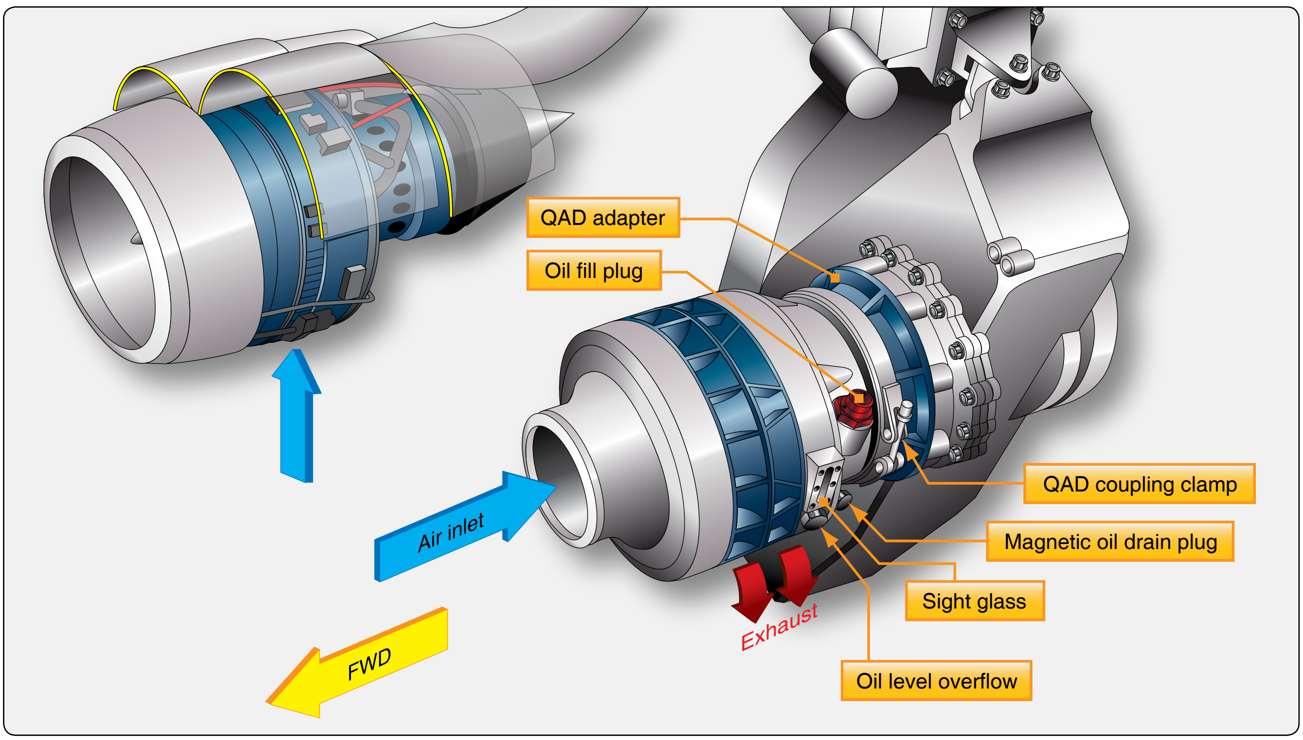

Figure 5-22. *Air turbine starter.*

The air path is directed through a combination pressure-regulating and shutoff valve, or bleed valve, that controls all duct pressure flowing to the starter inlet ducting. This valve regulates the pressure of the starter operating air and shuts off the air supply to the engine when selected off. Downstream from the bleed valve is the start valve, which is used to control air flow into the starter. *[Figure 5-23]*

The pressure-regulating and shutoff valve consists of two subassemblies: pressure-regulating valve and pressure-

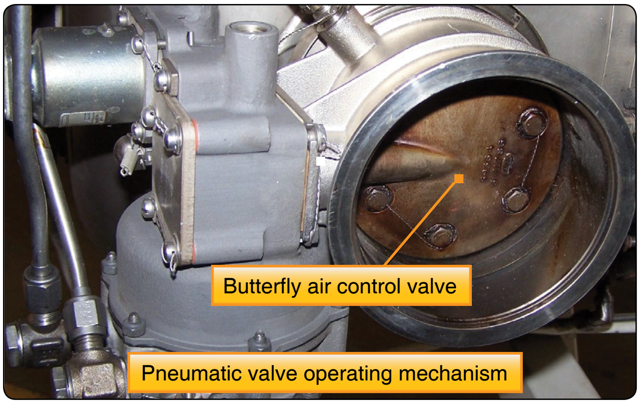

Figure 5-23. *Regulating and shutoff bleed valve.*

regulating valve control. *[Figure 5-24]* The regulating valve assembly consists of a valve housing containing a butterfly-type valve. *[Figure 5-24]* The shaft of the butterfly valve is connected through a cam arrangement to a servo piston. When the piston is actuated, its motion on the cam causes rotation of the butterfly valve. The slope of the cam track is designed to provide small initial travel and high initial torque when the starter is actuated. The cam track slope also provides more stable action by increasing the opening time of the valve.

The control assembly is mounted on the regulating valve housing and consists of a control housing in which a solenoid is used to stop the action of the control crank in the off position. *[Figure 5-24]* The control crank links a pilot valve that meters pressure to the servo piston, with the bellows connected by an air line to the pressure-sensing port on the starter.

Turning on the starter switch energizes the regulating valve solenoid. The solenoid retracts and allows the control crank to rotate to the open position. The control crank is rotated by the control rod spring moving the control rod against the closed end of the bellows. Since the regulating valve is closed and downstream pressure is negligible, the bellows can be fully extended by the bellows spring.

As the control crank rotates to the open position, it causes the pilot valve rod to open the pilot valve, allowing upstream air, which is supplied to the pilot valve through a suitable filter and a restriction in the housing, to flow into the servo piston chamber. The drain side of the pilot valve, which bleeds the servo chamber to the atmosphere, is now closed by the pilot valve rod and the servo piston moves inboard. *[Figure 5-24]* This linear motion of the servo piston is translated to rotary motion of the valve shaft by the rotating cam, thus opening the regulating valve. As the valve opens, downstream pressure increases. This pressure is bled back to the bellows through the pressure-sensing line and compresses the bellows. This action moves the control rod, thereby turning the control crank, and moving the pilot valve rod gradually away from the servo chamber to vent to the atmosphere. *[Figure 5-24]* When downstream (regulated) pressure reaches a preset value, the amount of air flowing into the servo through the restriction equals the amount of air being bled to the atmosphere through the servo bleed; the system is in a state of equilibrium.

When the bleed valve and the start valve are open, the regulated air passing through the inlet housing of the starter

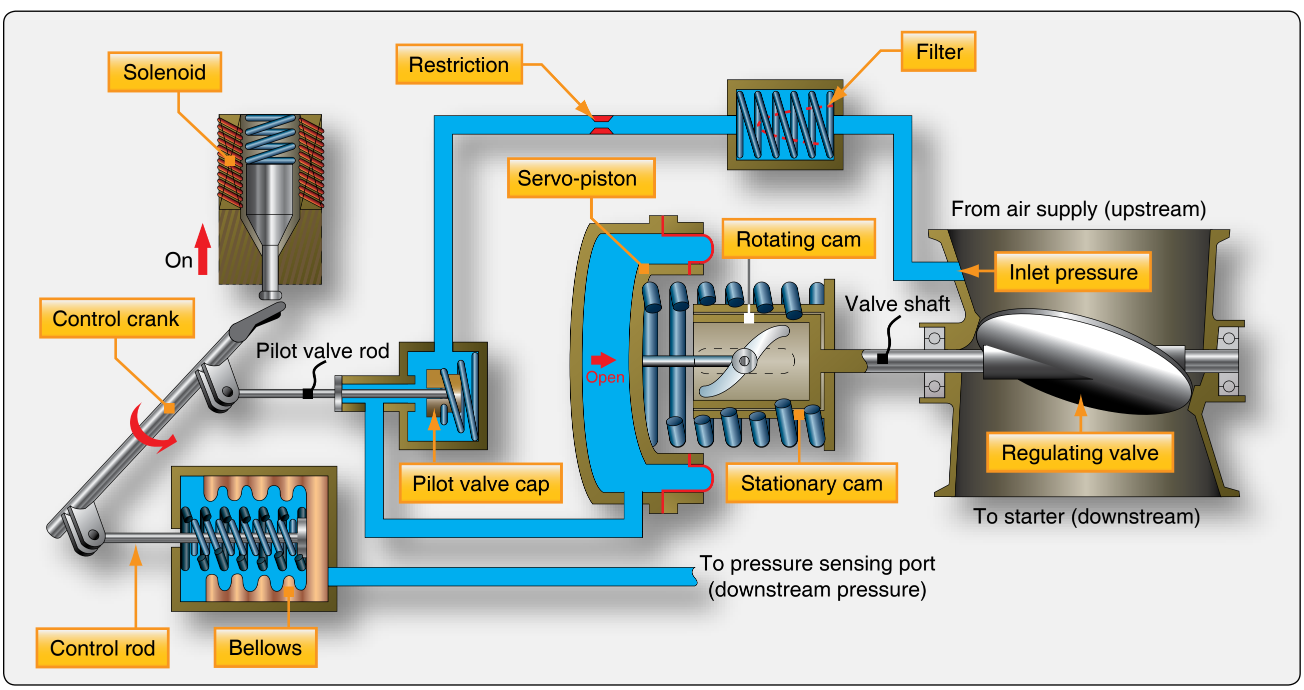

Figure 5-24. *Pressure-regulating and shutoff valve in on position.*

impinges on the turbine causing it to turn. As the turbine turns, the gear train is activated and the inboard clutch gear, which is threaded onto a helical screw, moves forward as it rotates; its jaw teeth engage those of the outboard clutch gear to drive the output shaft of the starter. The clutch is an overrunning type to facilitate positive engagement and minimize chatter. When starter cut-out speed is reached, the start valve is closed. When the air to the starter is terminated, the outboard clutch gear, driven by the engine, begins to turn faster than the inboard clutch gear; the inboard clutch gear, actuated by the return spring, disengages the outboard clutch gear allowing the rotor to coast to a halt. The outboard clutch shaft continues to turn with the engine.

Air Turbine Starter Troubleshooting Guide

The troubleshooting procedures listed in *Figure 5-25* are applicable to air turbine starting systems equipped with a combination pressure-regulating and shutoff valve. These procedures should be used as a guide only and are not intended to replace the manufacturer's instructions.

Air Turbine Starter System Troubleshooting Procedures

Trouble	Probable Cause	Remedy
• Starter does not operate (no rotation).	• No air supply. • Electrical open in cutout switch. • Sheared starter drive coupling. • Internal starter discrepancy.	• Check air supply. • Check switch continuity. If no continuity, remove starter and adjust or replace switch. • Remove starter and replace drive coupling. • Remove and replace starter.
• Starter will not accelerate to normal cutoff speed.	• Low starter air supply. • Starter cutout switch set improperly. • Valve pressure regulated too low. • Internal starter malfunction.	• Check air source pressure. • Adjust rotor switch actuator. • Replace valve. • Remove and replace starter.
• Starter will not cut off.	• Low air supply. • Rotor switch actuator set too high. • Starter cutout switch shorted.	• Check air supply. • Adjust switch actuator assembly. • Replace switch and bracket assembly.
• External oil leakage.	• Oil level too high. • Loose vent, oil filler, or magnetic plugs. • Loose clamp band assembly.	• Drain oil and re-service properly. • Tighten magnetic plug to proper torque. • Tighten vent and oil filler plugs as necessary and lock wire. Tighten clamp band assembly to higher torque.
• Starter runs, but engine does not turn over.	• Sheared drive coupling.	• Remove starter and replace the drive coupling. If couplings persist in breaking in unusually short periods of time, remove and replace starter.
• Starter inlet will not line up with supply ducting.	• Improper installation of starter on engine, or improper indexing of turbine housing on starter.	• Check installation and/or indexing for conformance with manufacturer's installation instructions and the proper index position of the turbine housing specified for the aircraft.
• Metallic particles on magnetic drain plug.	• Small fuzzy particles indicate normal wear. • Particles coarser than fuzzy (chips, slivers, etc.) indicate internal difficulty.	• No remedial action required. • Remove and replace starter.
• Broken nozzle vanes.	• Large foreign particles in air supply.	• Remove and replace starter and check air supply filter.
• Oil leakage from vent plug assembly.	• Improper starter installation position.	• Check installed position for levelness of oil plugs and correct as required in accordance with manufacturer's installation instructions.
• Oil leakage at drive coupling.	• Leaking rear seal assembly.	• Remove and replace starter.

Figure 5-25. *Air turbine starter system troubleshooting procedures.*