7.0 DIESEL ENGINE STARTING SYSTEMS

This chapter presents the requirements for starting a diesel engine for an EDG in a nuclear plant and the equipment and systems required to accomplish it.

Learning Objectives

As a result of this lesson, you will be able to:

1. Describe the requirements for starting an Emergency Diesel Generator in a nuclear plant application.

2. Identify the components and describe the operation of a direct air injection, com-pressed air diesel engine starting system.

3. Identify the components and describe the operation of an air motor type, com-pressed air diesel engine starting system.

4. Identify the components and describe the operation of a typical starting air supply system used in a nuclear plant application.

5. Identify the components and describe the operation of an electric diesel engine starting system for a nuclear application diesel engine.

7.1 Technical Specification Starting Requirements

In accordance with the applicable regulatory requirements, emergency diesel generators specified for use as emergency onsite power supplies at commercial nuclear facilities must be capable of achieving a minimum voltage and frequency upon initiation of a "start" signal. Both conditions must be achieved within an acceptable time frame that meets the plant's Technical Specifications.

Typical specifications involve the engine starting from keepwarm conditions and accelerating to a minimum, self-sustaining rotational speed (RPM). Simultaneously, the generator must establish the required voltage and frequency all within the time limits specified. An example of a set of typical EDG specifications is given below:

- 60 Hz ± 1.2 Hz

- Rated Voltage (4000 ± 320 volts)

- ≤ 10 seconds

7.2 Starting Characteristics

By reviewing the operational characteristics of the diesel engine, we can gain a better understanding of what is required of the starting system.

7.2.1 Admission of Air

A fresh charge of air must enter the cylinder during the intake event to provide the oxygen required to support combustion of the fuel. This is accomplished by either of two ways. For a 4-stroke cycle engine, this is accomplished by the downward motion of the piston during the intake stroke. For a 2-stroke cycle engine, the pumping action of the engine-driven blower (positive displacement or centrifugal) delivers the air charge to the cylinders.

7.2.2 Compression of Air Charge

Once the cylinder has been charged with fresh air, the rapid upward or inward movement of the piston compresses the air charge, increasing its temperature to a point higher than that required to ignite the fuel.

7.2.3 Injection of Fuel

With the piston near to top or inner most point of its stroke, fuel is injected into the heated air charge where combustion occurs and power is delivered to the crankshaft. As the cylinders begin to fire, the engine achieves self-sustained operation.

For the three activities listed to occur, the engine crankshaft must be rotated by an external source of power. The engine starting system stores energy either as compressed air in the system's air receivers or as chemical energy in the designated storage batteries. Upon initiation of a start signal, the stored energy is converted into the mechanical energy needed to rotate the engine components.

7.2.4 Compression Characteristics

Charging the cylinder with air and injecting the fuel at the proper time are basic functions of crankshaft rotation. Crankshaft rotation also causes the air charge to be compressed; however, the rotation alone does not ensure the air charge will reach the temperature needed to ignite the fuel injected into the cylinder.

The actual temperature achieved is a function of the compression pressure minus any pressure lost past the piston rings and valves and any heat lost to the incoming air charge or relatively cool internal components of the engine. Assuming the engine is mechanically sound, the compression, and therefore ignition temperature, becomes a function of the engine compression ratio, valve or port timing, and cranking speed.

The single most important element in attaining the compression pressure, and therefore the air charge temperature required for ignition of the fuel, is the cranking or rotational speed of the engine during the starting sequence. Figure 7-1 depicts a typical relationship between the cranking speed (RPM) and the compression pressure (PSIG) achieved for a high speed diesel engine. Several factors contribute to this relationship:

- The more rapid the rate of compression is, the higher the pressure and temperature of the air charge.
- Rapid compression allows less time for pressure to be lost past the piston rings and valves.
- At higher cranking speeds, less time is available for the heat of compression to be lost from the engine cylinders.

7.3 Starting System Capability

In addition to the engine start criteria listed in section 7.2, the EDG starting system must have a capacity and redundancy commensurate with the safety function of the unit.

7.3.1 System Capacity

Each starting system must have an energy storage capacity sufficient to support a specific number of start attempts prior to reaching a low energy level (e.g. low air pressure, low battery voltage). For example, a starting air system may be required to perform two consecutive start attempts before reaching a specified low pressure of 150 psig.

The generic nuclear application starting air system also provides control air for diesel engine controls and instrumentation during standby and during operation. The control air portion of the Starting Air System will be discussed in Chapter 10, "Emergency Diesel Generator Control and Monitoring."

7.3.2 System Redundancy

To preclude a single failure, which could prevent the engine from starting, each unit is required to be equipped with two parallel, non-connected redundant starting systems. Each system must be capable of starting the EDG in the event of a failure in the other system.

In some specifications, the requirement was to attempt to start the engine on one system and then go to the second (redundant) system if the engine failed to start. This philosophy wastes time and probably results in a failed start in that the unit would not be up to rated speed in the required time.

All of the systems furnished to date use both systems simultaneously (in tandem) such that if one system failed, the other system would automatically start the unit with only an extended time probable, but not a failure to start.

7.3.3 Energy Storage System

The energy required for starting the EDG is stored as compressed air in designated air receivers or as chemical energy stored in a battery bank. In either system, a minimum energy level must be maintained at all times for the unit to be considered operable.

With the compressed air systems, the receivers must be kept above a minimum pressure. This is accomplished by air compressors which automatically recharge the system when the low pressure limit is reached. For electric powered systems, the batteries are maintained at a voltage above the minimum electrical storage capacity by the battery charging systems. The electric system will be discussed in greater detail later in this chapter.

7.4 Starting Air Systems

There are two types of compressed air starting systems used in nuclear plant applications: the direct air injection system shown in Figure 7-2A and the air motor system shown in Figure 7-2B. In both systems, air is stored under pressure in air receiver tanks. Quick opening solenoid-operated air admission valves prevent air from reaching the engine until actuated by an engine start signal.

7.4.1 Direct Air Injection Systems

This system is also often referred to as the 'air over piston' or the 'cylinder air start' system.

With the direct air injection system (Figure 7-2A), air under pressure is applied to the inlet of the Starting Air Admission Valve and to the Starting Air Solenoid Valve. With no start signal present, both valves remain closed. Upon receiving a "start" signal, the Solenoid Valve opens, directing air to the Air Admission Valve pilot section, causing the main valve to open.

Downstream of the Air Admission Valve, the air flow is split. The major portion of the air is passed to the Starting Air Header. A small portion of the air is also directed to the Starting Air Distributor. Air from the Starting Air Header enters each of the Starting Air Check Valves. Starting Air Check Valves, where used, are mounted in each of the engine cylinder heads. For the Fairbanks-Morse Opposed Piston engine, the starting air check valves mount through the wall of the cylinder liner. The design of these valves is such that they will remain closed until acted upon by a pilot signal from the Starting Air Distributor.

The Starting Air Distributor, driven by the engines camshaft or accessory drive gear train, provides a pilot air signal in proper sequence to each of the Starting Air Check Valves. At the appropriate time, usually a few degrees past Top Dead Center (TDC), the pilot air signal is applied to each Starting Air Check Valve, causing it to open. Starting air, under pressure, is admitted directly into the engine cylinder. This air pressure rapidly pushes each piston downward in succession. As each piston is later moving upward, the air charge is compressed in preparation for injection of the fuel.

As the engine achieves self-sustained operational speed, a signal from the control system shuts off the starting air supply. This is usually controlled by a speed sensing device monitoring the engine speed (RPM). The Solenoid Valve then closes, allowing the Air Admission Valve to close. Air then vents from the Starting Air Distributor and Starting Air Header. This allows the spring-loaded Starting Air Check Valves to close and returns the engine starting air system to the standby mode.

7.4.1.1 Starting Air Admission Valves

Figure 7-3 shows a typical pilot-operated, poppet type Starting Admission Valve. The Solenoid Valve is generally mounded directly to the Admission Valve. In other applications, the Solenoid Valve may be mounted remotely to the Admission Valve and connected by pipe or tubing.

In the standby mode, the spring-loaded valve poppet is held in the closed position by the force of the spring. Air from the air receiver enters the valve as shown. The design of the valve poppet is such that the air pressure acting against the poppet is balanced by the equal areas of the valve poppet. The force of the spring is sufficient to keep the valve closed. A portion of the air entering the valve (pilot air) is directed to the inlet of the Solenoid Valve. In standby, the Solenoid Valve is also closed (not energized).

When a "start" signal is generated, it is applied to the Solenoid Valve. This signal energizes the solenoid coil. The magnetic field created lifts the valve plunger, opening the valve. Pilot air is then directed through the signal port (orifice) to the top of the pilot piston (part of the valve poppet). The force of the air pressure applied to the pilot piston exceeds the force of the spring holding the poppet in the closed position. This differential force causes the valve poppet to move downward, opening the valve. Air from the air receiver passes freely through the valve and on to the Starting Air Header and Starting Air Distributor.

Loss of a "start" signal closes the Solenoid Valve, which vents air from the pilot piston. Spring force causes the valve poppet to close returning to a standby mode.

7.4.1.2 Starting Air Distributor

Since the Starting Air Check Valves must open at a specific time relative to the position of the piston in the cylinder, a Starting Air Distributor is needed and provided. The Starting Air Distributor, which is timed from the engine camshaft(s) or other portion of the engine gear train, directs a pilot signal to each Start Air Check Valve, when the piston is slightly after top dead center and maintains that signal until the movement of the piston reaches approximately 120° after top dead center. A typical Start Air Distributor is shown in Figure 7-4.

The Starting Air Distributor consists of a series of spool valve assemblies, one for each Starting Air Check Valve. One assembly for each cylinder is mounted in a common housing. The timing cam, timed to the engine, causes each spool valve to direct pilot air pressure to or vent the pressure from each of the Starting Air Check Valves. Operation of the spool valve assemblies is shown in Figures 7-5 through 7-7.

With the starting air admission valve closed, no air is applied to the Starting Air Distributor. With no air pressure present, the distributor spool valves are held in the off cam or vent position by the force of the spring as shown in Figure 7-5. This prevents the spool valve from contacting the timing cam during normal engine operation or standby.

When a 'start' signal is generated, the air admission valve opens supplying high pressure starting air to the internal passages of the distributor housing. This air pressure forces the spool valves downward into contact with the timing cam as shown in Figure 7-6. In the high cam position, the spool valve is held in the vent position, and no pilot air signal is applies to the associated Starting Air Check Valve.

Rotation of the timing cam will eventually align the low portion of the cam with the spool valve as shown in Figure 7-7. The pressure of the starting air from the internal passages of the distributor housing will keep the spool valve in contact with the timing cam. The spool valve moves downward blocking the vent port and connecting the Starting Air Check Valve port. Starting air pressure is then applied to the pilot piston of the associated Start Air Check Valve, opening the valve and allowing starting air to enter the engine cylinder. When the timing cam has moved beyond a spool valve position, the spool valve is returned to the vent position and the air signal is removed from the Starting Air Check Valve.

With cessation of the 'start' signal, the Air Admission Valve closes allowing the air to vent from the Starting Air Distributor internal passages. This loss of air pressure allows the force of the spring to lift the spool valves off the timing cam. All of the spool valves will be returned to the off/vent position, and the starting process will be terminated.

7.4.1.3 Starting Air Check Valves

In the start mode, air from the Starting Air Header is delivered to each of the Starting Air Check Valves mounted in the engine cylinder heads. In the Fairbanks-Morse Opposed Piston engine, the Starting Air Check Valves mount through the wall of the cylinder liner adjacent to the fuel injection nozzle. A typical Starting Air Check Valve is shown in Figures 7-8 and 7-9.

The air start check valve assembly includes a poppet type valve which is located in a precision bore cast body or housing. A spring applied to the upper end of the valve keeps the valve in the closed position. The design of the valve including the balance piston is such that the starting air entering the valve body is balanced. Starting air pressure acting against the valve is balanced by the air pressure acting against the equal area of the balance piston. The force of the spring is sufficient to hold the valve in the closed position. A pilot inside the piston cap rests against the tip of the valve.

Initiation of a ‘start’ signal opens the Air Admission Valve allowing air to enter the housing as shown. The balanced design of the valve maintains it in the closed position until a pilot air signal is applied to the pilot piston.

As mentioned previously, air from the Starting Air Admission Valve is directed to the Starting Air Distributor as well as the Starting Air Header. The Starting Air Distributor is timed to direct a pilot signal to the Starting Air Check Valve, when the piston for the cylinder involved is just past top dead center. The force supplied by the pilot air signal, which is applied to the pilot piston, overcomes the spring force holding the valve closed. This opens the Starting Air Check Valve allowing starting air to enter the engine cylinder.

The pressure of the starting air entering the engine cylinder is applied to the top of the engine’s piston forcing the piston downward and causing rotation of the crankshaft. This rotation subsequently causes upward motion of other engine pistons. As each engine piston moves upward on the compression stroke, the air in that cylinder is compressed to achieve the temperature required for ignition. Rotation of the crankshaft also causes rotation of the timing cam for the Starting Air Distributor (see Figure 7-4). As the engine’s piston nears the bottom of its stroke, the Starting Air Distributor closes the associated valve port and vents the pilot air signal from the Starting Air Check Valve. This allows the spring to return the valve to the closed position. As this occurs, other Starting Air Check Valves are receiving the pilot signal which results in a continuous rotation of the engine until engine start is achieved or the start signal ceases.

The Starting Air Check Valves have to remain closed during normal engine operation. If a Starting Air Check Valve should not close or should leak, the combustion gases from the cylinder will leak out of the Starting Air Check Valve, and it will become extremely hot and may further seize. It is important to occasionally check the Starting Air Check Valves and the associated Starting Air Supply Header to determine that none of the valves are leaking.

7.4.2 Starting Air Motor System

In the air motor system, shown in Figure 7-2B, engine rotation is accomplished by a rotary vane or piston type air motor which engages with a ring gear mounted to the periphery of the engine flywheel. During a start sequence, the drive mechanism of the starting air motor engages with the flywheel ring gear. Air entering the starting air motor then causes rotation of the engine crankshaft. Upon completion of the start sequence, the air is shut off and vented allowing the starting air motor to disengage from the flywheel gear.

7.4.2.1 Starting Air Admission Valve

The Starting Air Admission Valve used with the air motor system is similar to that used in the direct injection system. Notice in Figure 7-2B that the solenoid valve is not connected directly to the Air Admission Valve but feeds the pilot signal through the drive mechanism of the Starting Air Motor. With this configuration, the Starting Air Motor drive fully engages with the flywheel ring gear prior to achieving rotation of the Starting Air Motor.

7.4.2.2 Vane Type Air Motors

A typical vane type Starting Air Motor is shown in Figure 7-10. It consists of a rotor mounted off center within a cylindrical housing. A set of sliding vanes radiate outward from the rotor to make contact with the bore of the housing. As air enters the inlet of the housing, the pressure is applied to the sliding vanes as shown, causing the rotor to rotate. Air continues to enter as the volume between the rotor and housing increases.

The pressure differential between the air inlet and the exhaust (atmospheric pressure) creates the torque necessary for the rotor to rotate. As the starting air reaches the exhaust port, it is exhausted to the atmosphere as pressurized air continues to enter the inlet.

The power and rotary motion of the rotor is transmitted through shafts and in some applications, through gears to the starter drive gear which is engaged with the flywheel ring gear. The subsequent rotation of the engine flywheel and crankshaft is used to generate the engine start.

7.4.2.3 Start Drive Gear - Bendix

As the starting air motor in required only intermittently, a drive mechanism is provided which will engage and disengage the starter from the flywheel ring gear as needed. A starter drive gear, often referred to as a Bendix, is shown in Figure 7-11.

The starter drive mechanism that is shown mounts either directly to the rotor shaft or to an output shaft via a set of reduction gears. Where used, the reduction gears allow the rotor to rotate at a high RPM while increasing the overall output torque. A drive gear is provided which will mesh with the teeth of the ring gear on the flywheel. When the starting motor is not required to rotate the crankshaft, the drive gear assembly is spring loaded in the disengaged position. A drive piston is provided to engage the drive gear with the flywheel ring gear during the 'start' sequence.

To prevent over-speeding of the starting air motor as the engine begins to fire, an overrunning clutch is incorporated between the drive gear and the rotor shaft. This clutch mechanism engages the rotor shaft with the drive gear when the starting motor is driving the engine flywheel. As the engine RPM increases, the speed of the drive gear is greater than that of the rotor shaft. At this point, the clutch mechanism releases the drive gear from the rotor shaft. The drive gear can continue to rotate with the engine flywheel without transmitting that high speed to the starting motor rotor assembly.

7.4.2.4 Starting Motor Operation

When a 'start' signal is received, the solenoid valve opens (see Figure 7-2B) directing air pressure to the drive piston port in the starter housing as shown in Figure 7-11. This air pressure moves the drive piston causing the starter drive gear to engage with the engine flywheel ring gear. This piston movement also opens an outlet port which directs pilot air pressure to the pilot port of the starting air admission valve causing it to open.

With the air admission valve open, full starting air pressure is directed to the inlet of the starting air motor causing it to rotate, driving the flywheel ring gear and rotating the engine crankshaft. When the 'start' signal is turned off by the control system, the solenoid valve closes blocking air flow to the starter drive piston, which disengages the drive gear and blocks the air flow to the air admission valve. Loss of the pilot signal to the pilot piston of the air admission valve allows the valve to close, returning the start system to the standby mode.

7.4.3 Supplemental Components

In order to meet the "fast start" requirements of diesel engines in nuclear applications, it is necessary to move the fuel racks to the full fuel position as soon as possible. The following two devices are employed to work with the starting air system to bypass the governor and give the cylinders full fuel during the start sequence.

7.4.3.1 Governor Boost Cylinder

A governor boost cylinder, as shown in Figure 7-12, is mounted to the side and below the level of the governor housing. It is hydraulically connected to both the governor oil sump and to the governor power piston housing.

The boost cylinder is simply a pneumatic-hydraulic cylinder with a spring loaded piston. As the force of the spring moves the piston down, oil is drawn from the governor oil sump through the inlet check valve to fill the volume above the piston. The volume below the piston is connected to the starting air header.

When a 'start' signal is generated, air under pressure from the starting air header or supply pipe to the air start motor enters below the piston forcing it upward sharply. This discharges the oil above the piston past the outlet check valve to the governor power piston. This increased oil pressure quickly moves the fuel control linkage to the full fuel position ensuring a rapid engine start and acceleration.

The oil supplied by the boost cylinder bleeds off through the internal passages of the governor as the governor takes over operation of the fuel control linkage. The outlet check valve prevents governor oil pressure from entering the boost cylinder. Closure of the starting air admission valve drops air pressure from the boost cylinder and the spring again moves the piston downward, refilling the space above the piston with oil from the governor oil sump.

On the actuators used with the electronic governing systems (to be discussed in Chapter 8), the boost oil does not actually lift the power piston but charges portions of the hydraulic circuit with oil which allows the governor to take control earlier than would be the case without the boost oil.

7.4.3.2 Shuttle Valve

When only one boost cylinder is used, a shuttle valve is installed to maintain the redundancy and separation required by nuclear specifications.

Under normal conditions, the shuttle valve takes a center position directing air from both headers to the underside of the boost cylinder piston. However, should a failure of one of the redundant systems occur, the air pressure from the operational side causes the shuttle valve to shift blocking off the failed side and directing air from the operational side to the boost cylinder.

7.4.3.3 Other Fuel Rack Boost Systems

Some engines such as the Colt Pielstick engine line include fuel rack boost cylinders and shuttle valves that are part of the engine fuel rack control system. These units do not use the governor boost cylinder system as described above.

7.4.4 Starting Air Supply System

Regardless of the type of starting air system used, sufficient air pressure and volume must be available at all times to ensure engine start capability. The air to support engine starting is automatically maintained in ASME Class 3 air receivers located near the engine. It is the starting air supply system which maintains the air pressure and volume in these receivers. A typical starting air supply system is shown in Figure 7-13. Starting air piping is ASME Class 3 and designed for seismic loading.

7.4.4.1 Air Receivers

Compressed air receivers are cylindrical pressure vessels whose design and construction is governed by the requirements of the ASME Boiler and Pressure Vessel Code, Construction of Unfired Pressure Vessels. The generic plant air receivers are designed to conform to the requirements of ASME Code, Section III for Class 3 components.

Their specific size (volume) is a function of the size of the engine they are required to start and the number and duration of start attempts specified by the FSAR. The generic FSAR requirement is to have air storage capability to provide two (2) consecutive diesel engine starts. The two

(2) start capability is required to assure that the engine can help mitigate the consequences of design basis events (e.g. LOCA). A number of the later plants specified capacity for five (5) start attempts, a starting attempt generally taking more air than a successful start. **NOTE:** If either starting air receiver is inoperable on one diesel, then the diesel is inoperable.

7.4.4.2 Air Compressors

Starting air compressors are normally of the reciprocating (piston) type. They are usually multiple-stage, multi-cylinder types with cylinders configured in a “V” or “W”. They may be either air cooled or water cooled.

Compressor capacity is based upon the amount of time required to recharge the receiver from a specified (cut-in) pressure to the desired operational pressure. Compressor capacity may be determined using the following formula:

$$D = \frac{(V * P_2) - (V * P_1)}{15 * T}$$

Where:

D = Compressor capacity, cubic feet of free air per minute

V = Volume of the Receiver, cubic feet

P1 = Cut-in Pressure, absolute (PSIA)

P2 = Desired operating pressure, absolute (PSIA)

T = Recharging time, in minutes

The generic starting air compressors are designed to deliver 40 SCFM at 250 psig. They require Class 1E power and are indirectly tested by diesel start tests.

If two compressors are inoperable on one diesel, then the diesel is inoperable.

In some specifications, the air compressors were sized such that the tanks had to be charged from atmospheric pressure to high cut-out pressure within 30 minutes.

7.4.4.3 Pressure Switches

Operation of the compressor is controlled by a pressure switch located on the air receiver. Set at a specified "cut-in" pressure, the switch starts the compressor when the pressure becomes lower than the set pressure and allows the compressor to run until the receiver is at or slightly above the desire operating pressure. As the air pressure reaches the operating pressure, the pressure switch opens the circuit, stopping (unloading) the compressor.

7.4.4.4. Pressure Relief Valves

To protect the system from over-pressurization, pressure relief valves are installed near the discharge of the compressor and on the starting air receiver. The safety valve near the compressor discharge is normally set at 115% of the rated operating pressure. The safety valve installed on the air receiver is normally set at 110% of rated pressure.

7.4.4.5 Aftercoolers

As air is compressed, its temperature increases substantially. This reduces the density of the air being discharged from the compressor. To compensate for this condition, aftercoolers are installed downstream of the compressors. Either air cooled or water cooled, these aftercoolers cool the air to100^{o}F prior to its entering the air dryer. Air-cooled units often use force draft fans to increase their cooling capacity.

7.4.4.6 Air Dryers

Air taken from the atmosphere contains a certain amount of moisture (humidity). Air-operated equipment including starting air motors and various valves may become damaged or degraded if exposed to excess moisture in the compressed air. Moisture may be carried by the air into the air receivers. This moisture may condense and collect in the receiver causing localized corrosion. This corrosion could lead to weakening of the receiver and failure of the components. Moisture carried by the air past the receiver into the system can damage the starting air system components and/or restrict air flow through small orifices and passages.

Air dryers usually use a combination of desiccant and temperature reduction (refrigerants) to remove unwanted moisture from the compressed air. As the air passes through the desiccant tower, the pellets of desiccant absorb and hold the moisture. Periodically, heated air is passed backwards through the desiccant tower to dry out the desiccant pellets preparing them for further use.

The combination of these two methods removes most of the moisture from the compressed air prior to its reaching the receiver. This protects both the receivers and the air-operated components of the system.

7.4.5 Control Air

Control air, supplied from the engine starting air system, utilizes an air filter pressure- reducing valve and volume control tank. In a generic system, control air aligns a pilot valve to pressurize engine run/shutdown cylinders and position engine fuel racks during starting. Control air continues to pressurize the run/shutdown cylinders to support EDG operation. Solenoid valves control the air flow during start and run sequences. The solenoids are powered from a Class 1E DC power supply. If the control air solenoid valves are inoperable, then the EDG is inoperable.

7.5 Electric Starting Systems

Electric starting systems utilize direct current (DC) motors which engage with a ring gear on the engine flywheel as with the starting air motor system. A set of batteries are installed to provide the necessary electric energy needed to operate the motors.

7.5.1 Electric Starting Motor

A typical electric starting motor is shown in Figure 7-14. The main structural components of the assembly are the field frame, lever housing, and nose housing. Field windings, anchored to the field frame, produce a strong magnetic field when energized. The armature with its commutator forms the rotary component of the motor. The starter drive mechanism or Bendix including an overrunning clutch similar to the one used on the vane type air motor is mounted to the armature shaft and is enclosed by the nose housing.

A solenoid switch, mounted to the field frame, serves two functions. First, it provides a means for positive engagement of the drive gear with the flywheel ring gear. Secondly, it acts as a switch to make the connection between the batteries and the field windings and motor brush assembly.

Initiation of a ‘start’ signal electrically connects the solenoid switch to the batteries. Energizing the windings of the solenoid switch creates a magnetic field which pulls the plunge into the core of the switch. That causes the shift lever to pivot forcing the drive gear to mesh with the flywheel ring gear. As the plunger makes contact with the switch rod, the contact plate is forced against the motor contacts. This then makes the electrical connection between the batteries and the field windings and armature. Once the field windings are energized, the motor begins to rotate the engine crankshaft starting the engine.

Loss of the ‘start’ signal de-energizes the solenoid switch allowing the spring force to disengage the drive gear from the flywheel ring gear. The solenoid switch also breaks the circuit between the batteries and field windings and armature. At this point, the motor is disengaged and de-energized.

7.5.2 Batteries

Starting system batteries are of the lead acid type. Each cell of the battery produces about two volts. In series, starting system batteries produce 24 or more volts depending on the design specifications of the licensee.

Battery chargers constantly monitor and maintain the batteries in a fully charged condition. Periodic inspection and testing of the batteries is required to ensure that the batteries are kept fully charged and that they have the capacity (rate of chemical energy conversion) to provide the power necessary for an engine start.

It is recommended that a separate set of batteries be supplied for engine starting. The station battery (typically 125VDC) should not be used for engine starting, as running down that set of batteries would preclude the engine running.

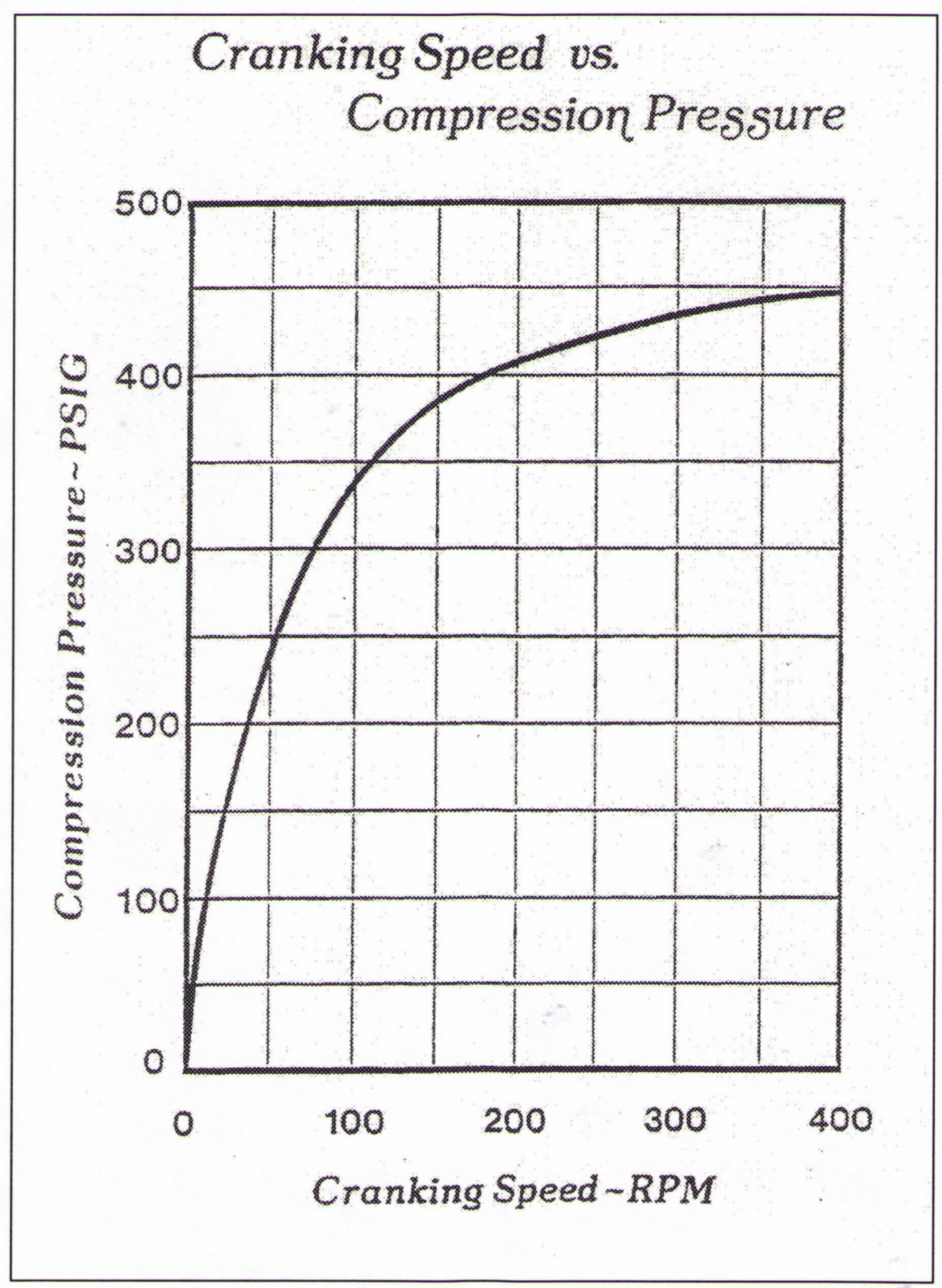

Figure 7-1 Cranking Speed vs Compression Pressure

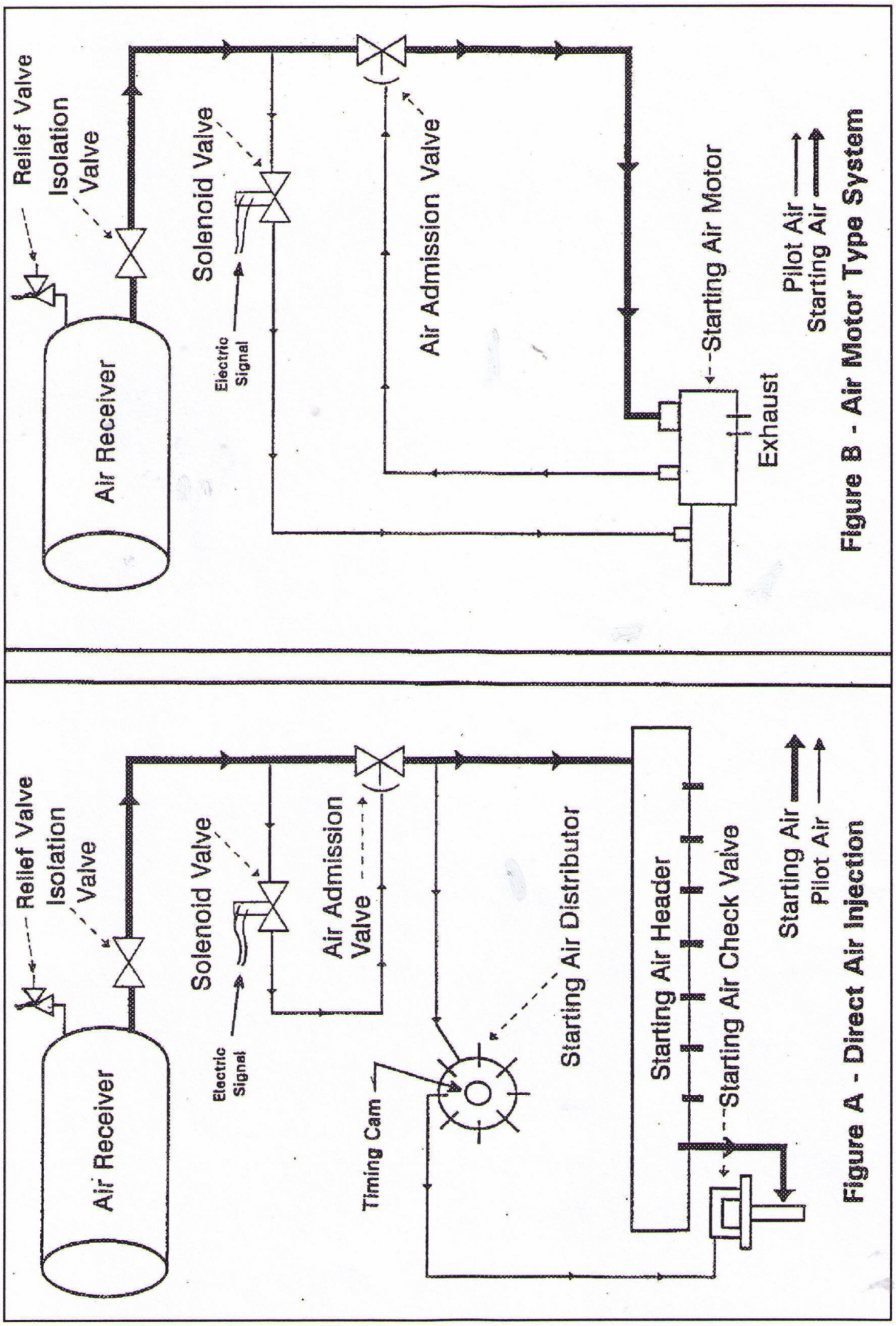

Figure 7-2 Starting Air System

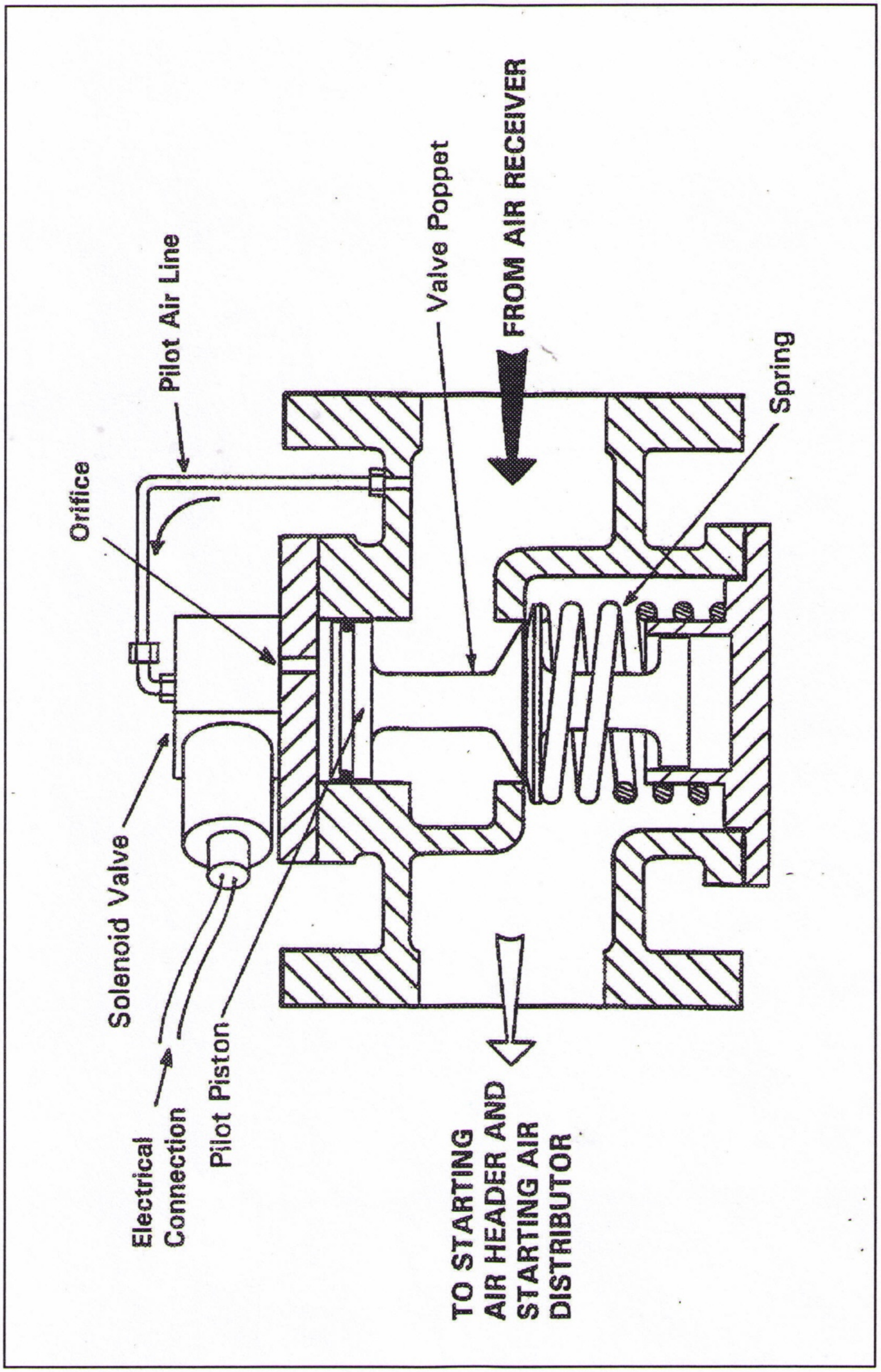

Figure 7-3 Starting Air Valve (Solenoid Activated)

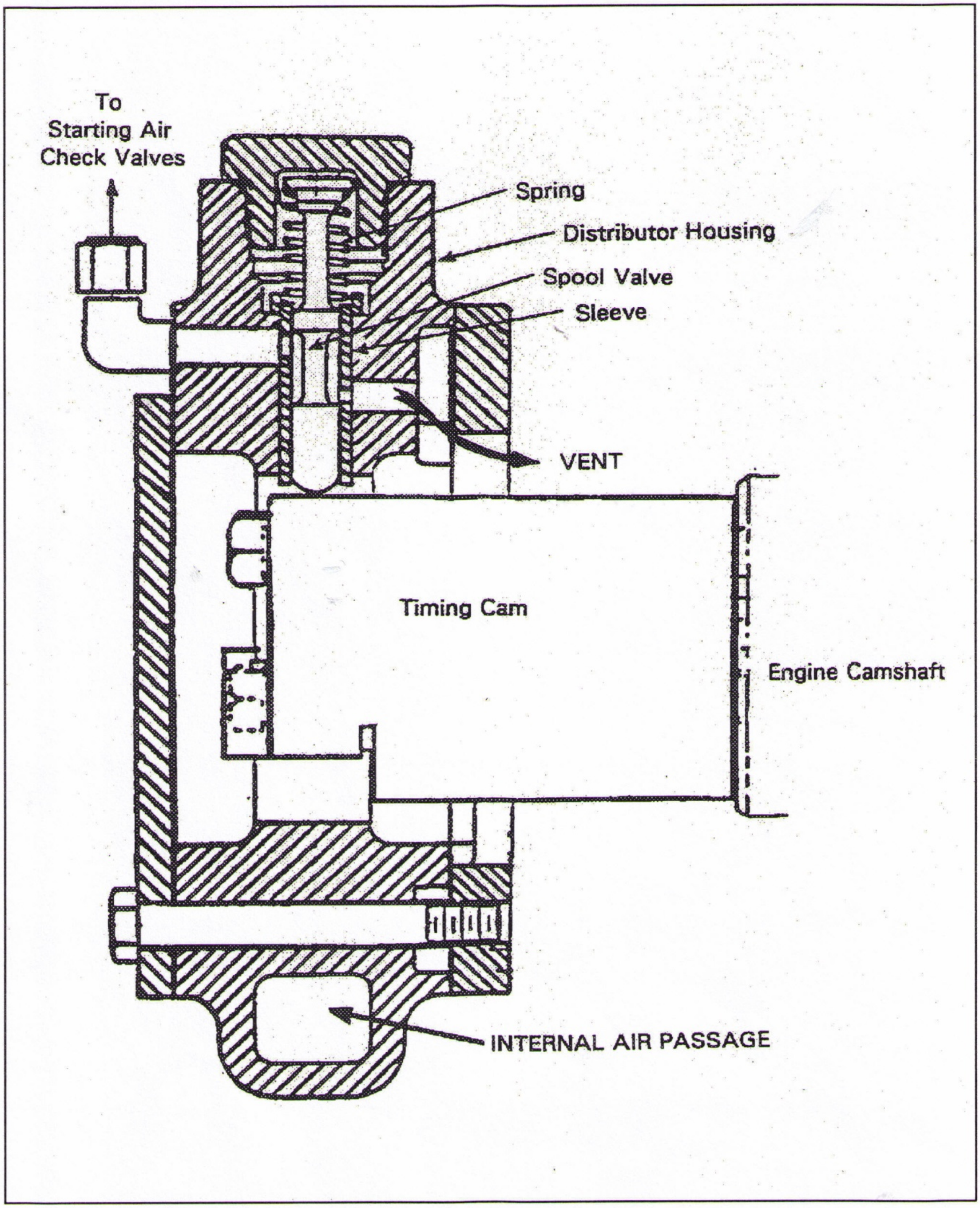

Figure 7-4 Starting Air Distributor (FM OP Engine)

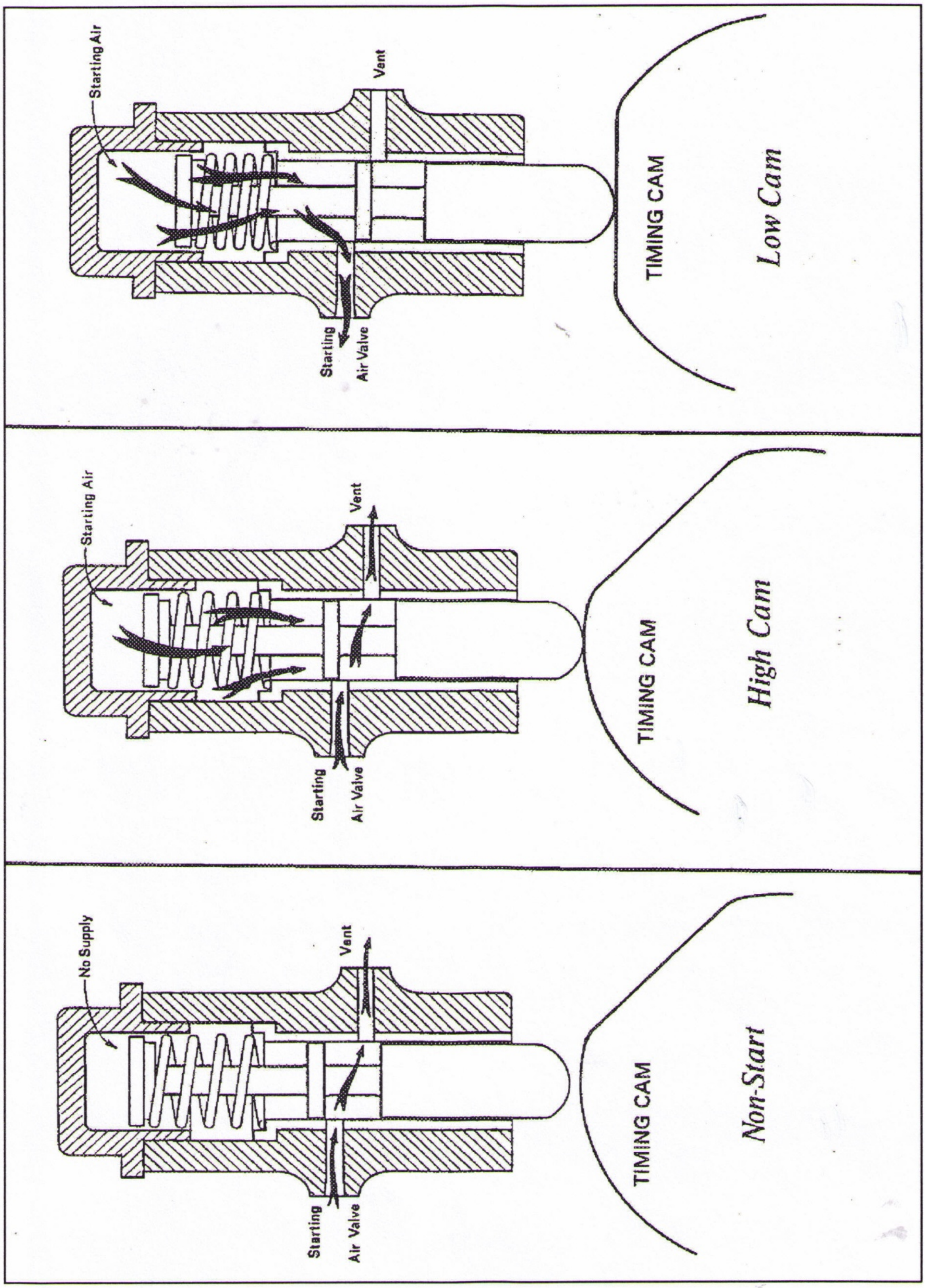

Figure 7-5 Spool Valve Off Cam

7-6 Spool Valve High Cam

7-7 Spool Valve Low Cam

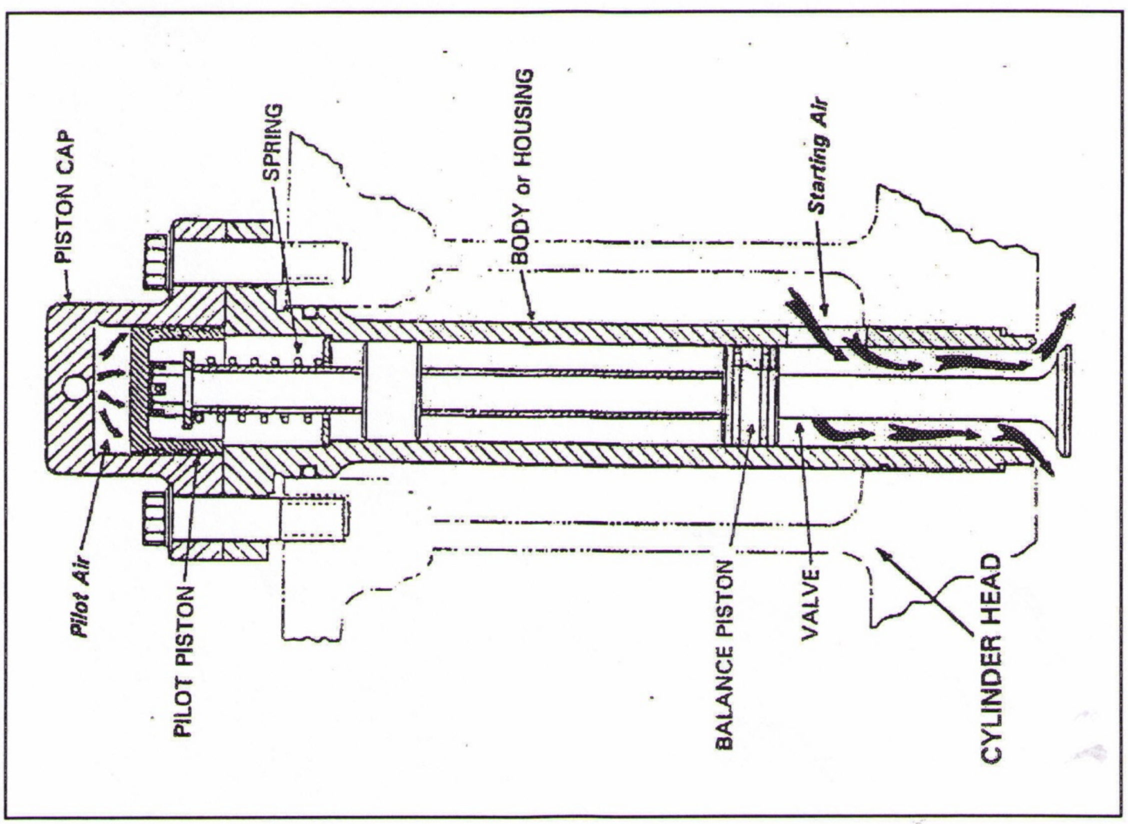

Figure 7-8 Starting Air Check Valve - Open

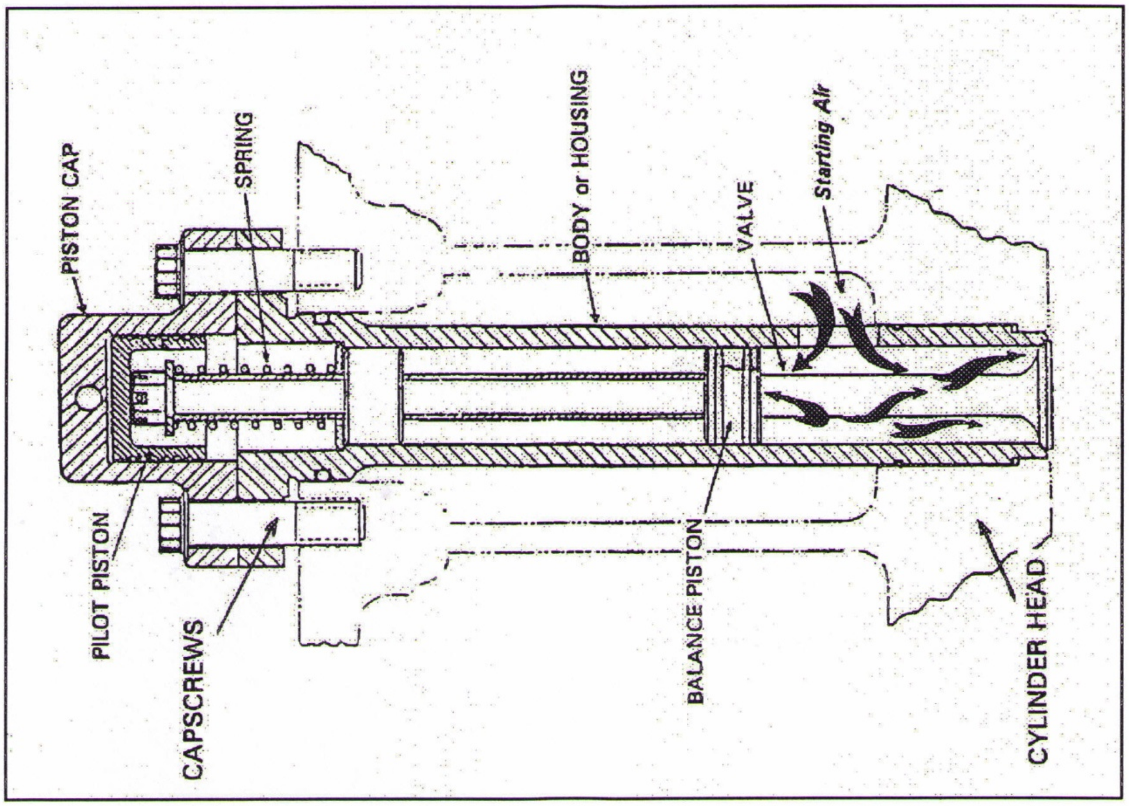

Figure 7-9 Starting Air Check Valve - Closed

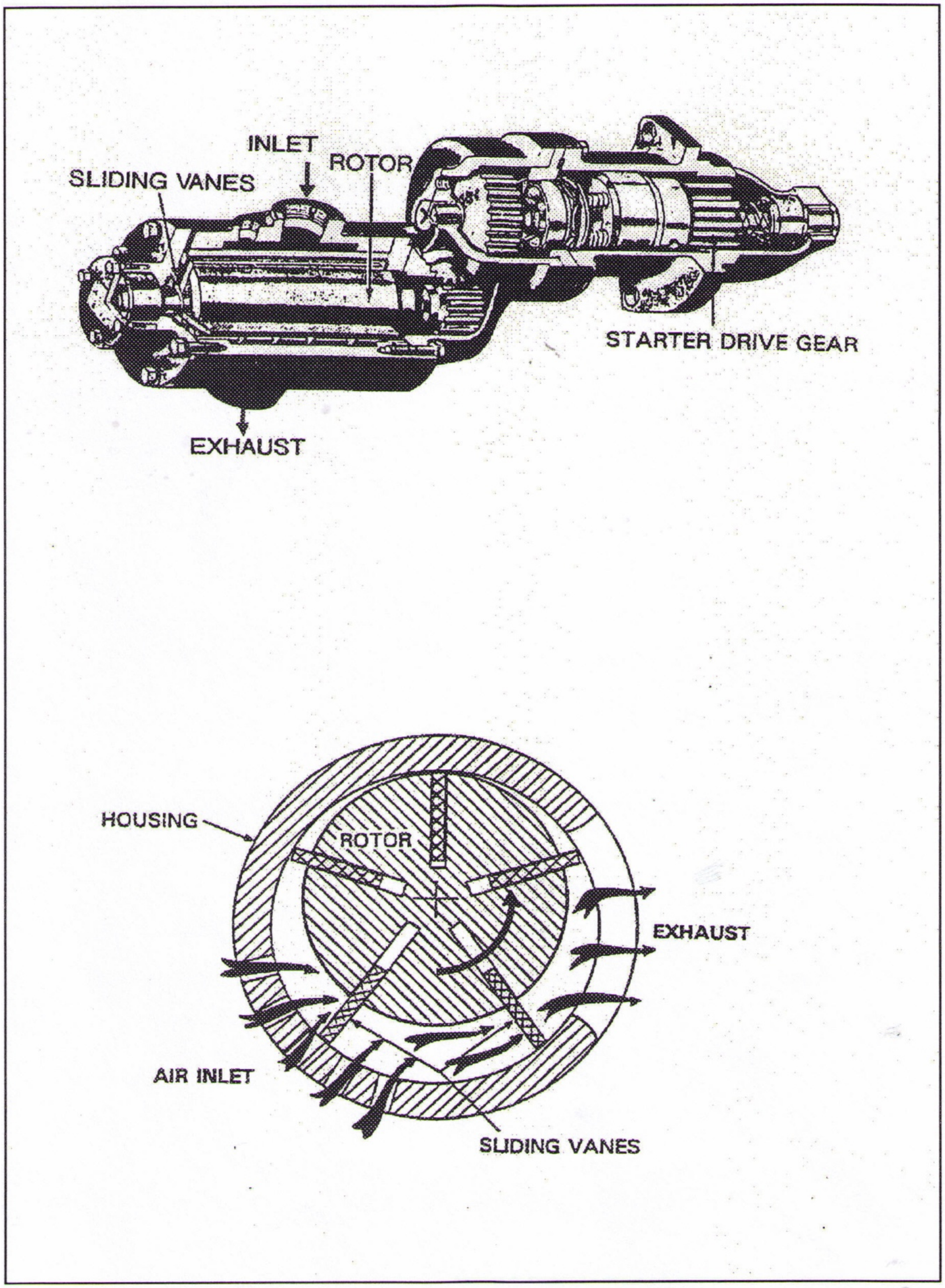

Figure 7-10 Vane Type Starting Air Motor

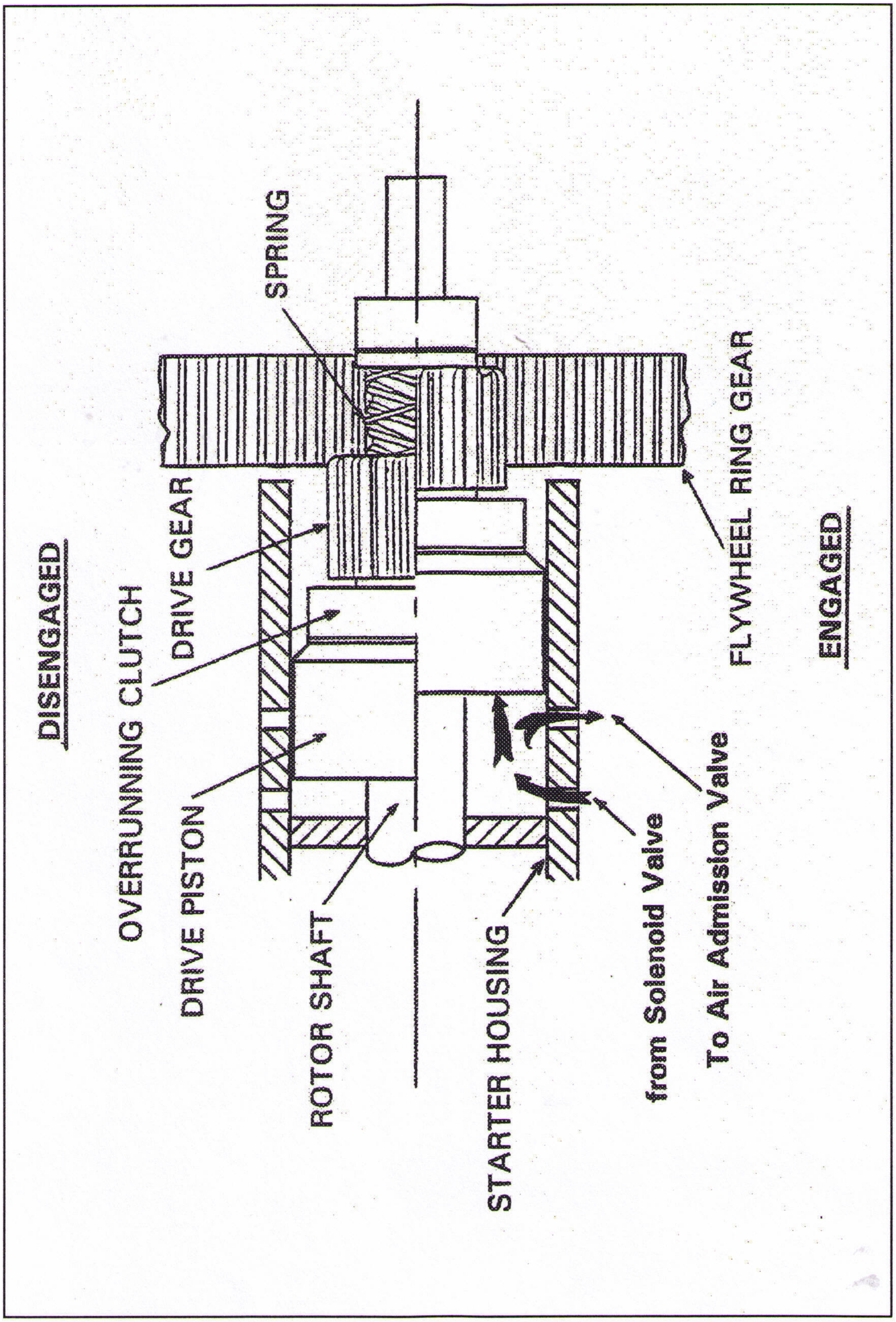

Figure 7-11 Bendix Drive Assembly

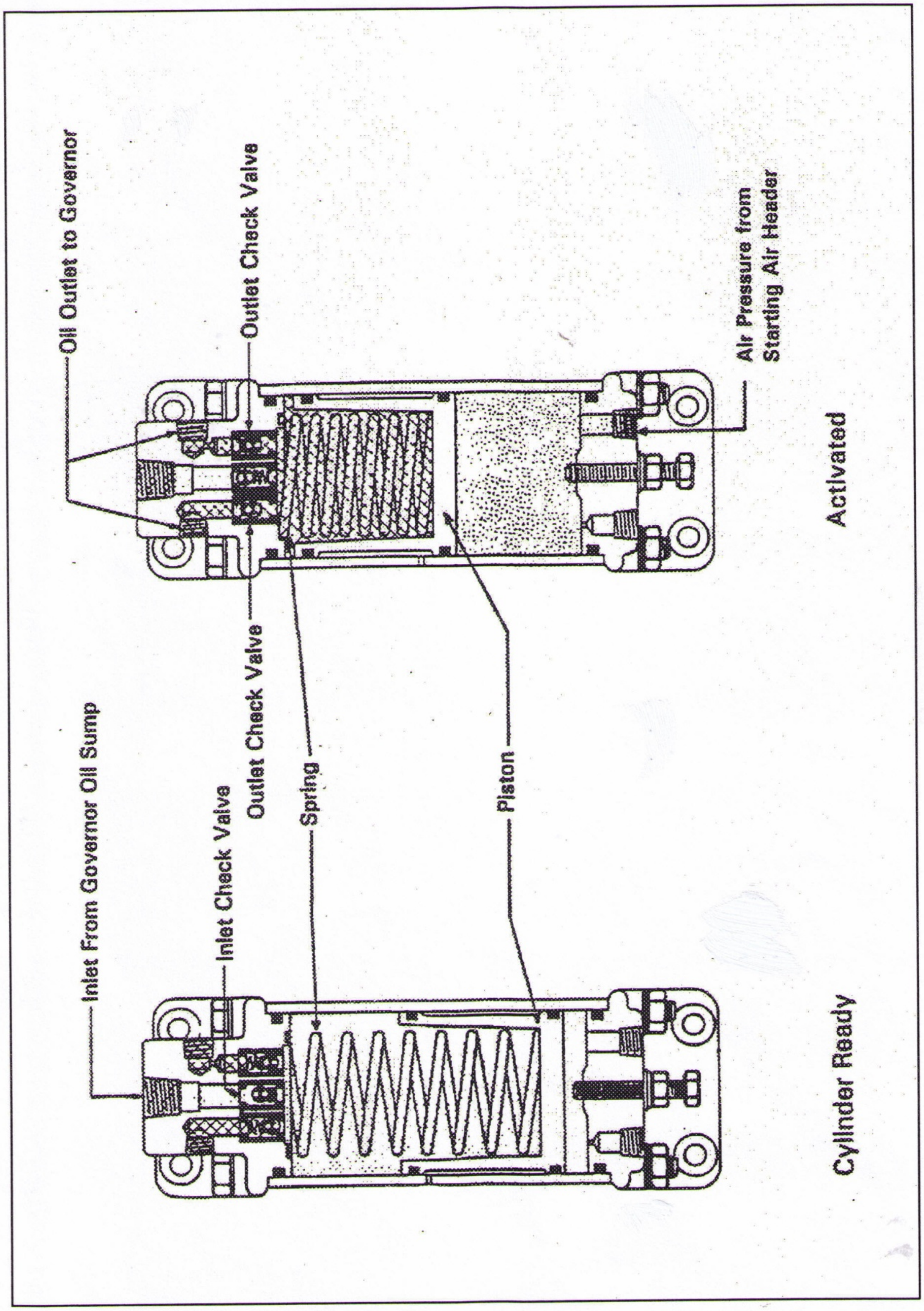

Figure 7-12 Governor Boost Cylinder (Woodward Governor Co.)

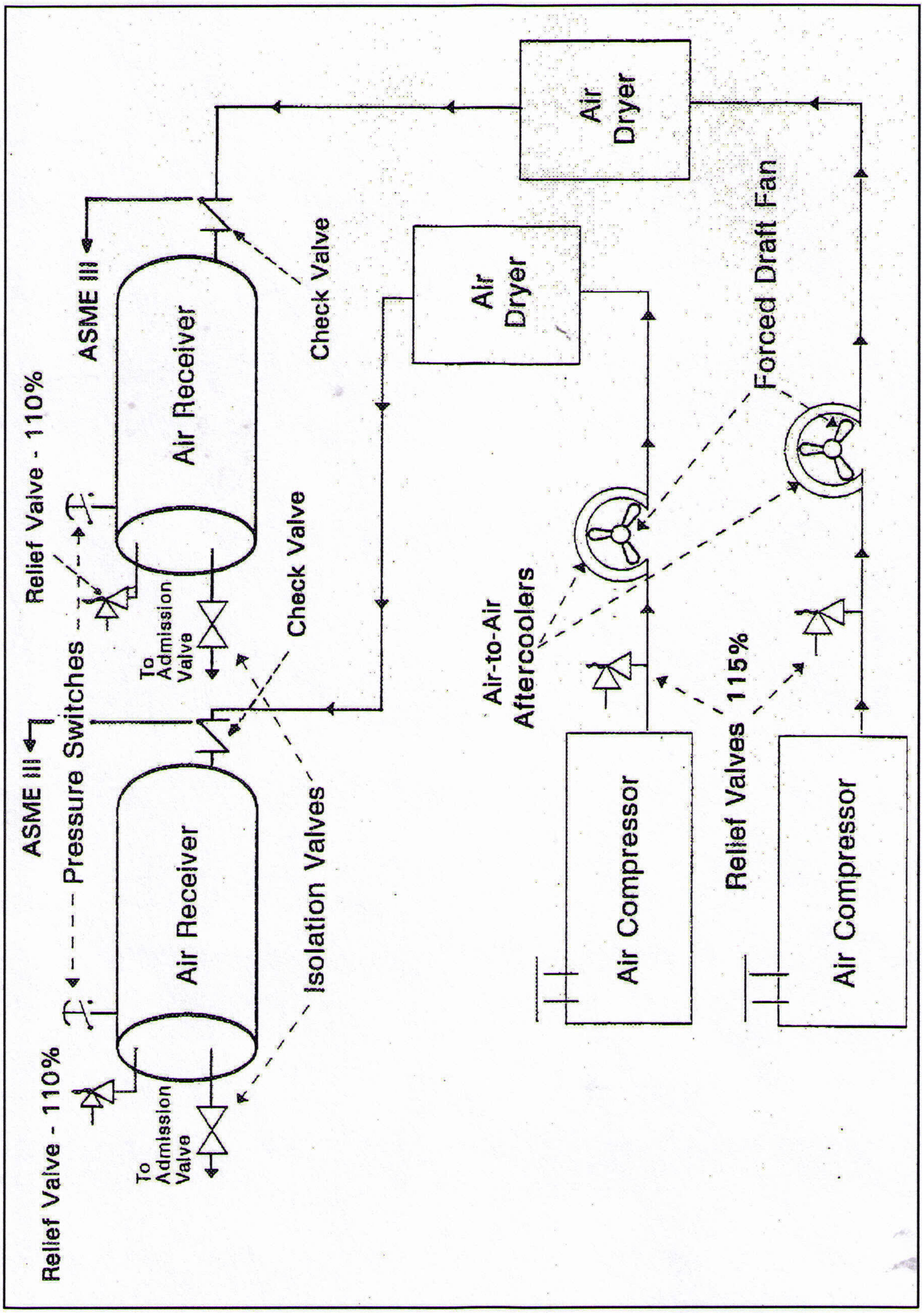

Figure 7-13 Starting Air Supple System

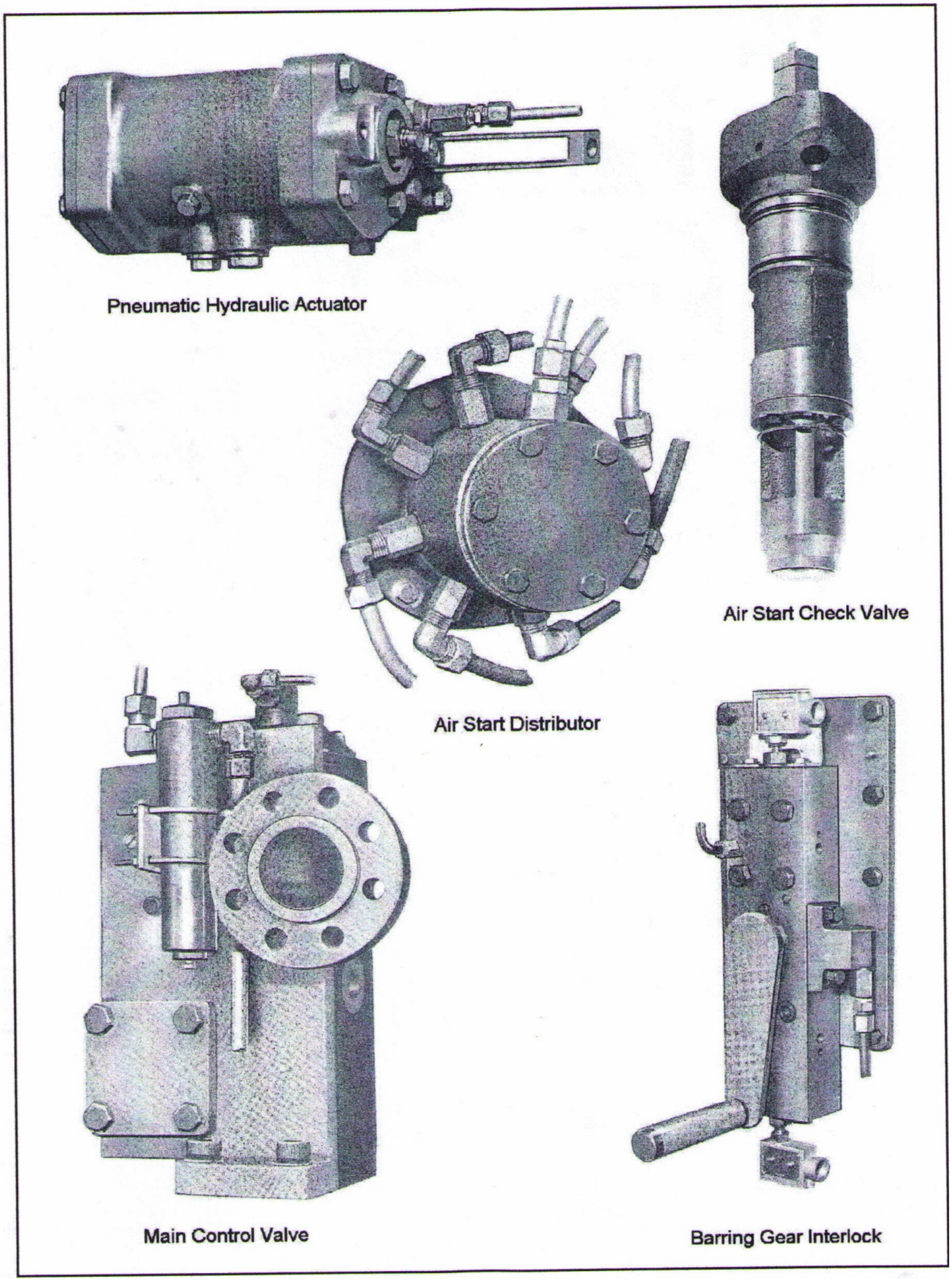

Figure 7-14 Typical Components Direct Air-Over-Piston Starting System

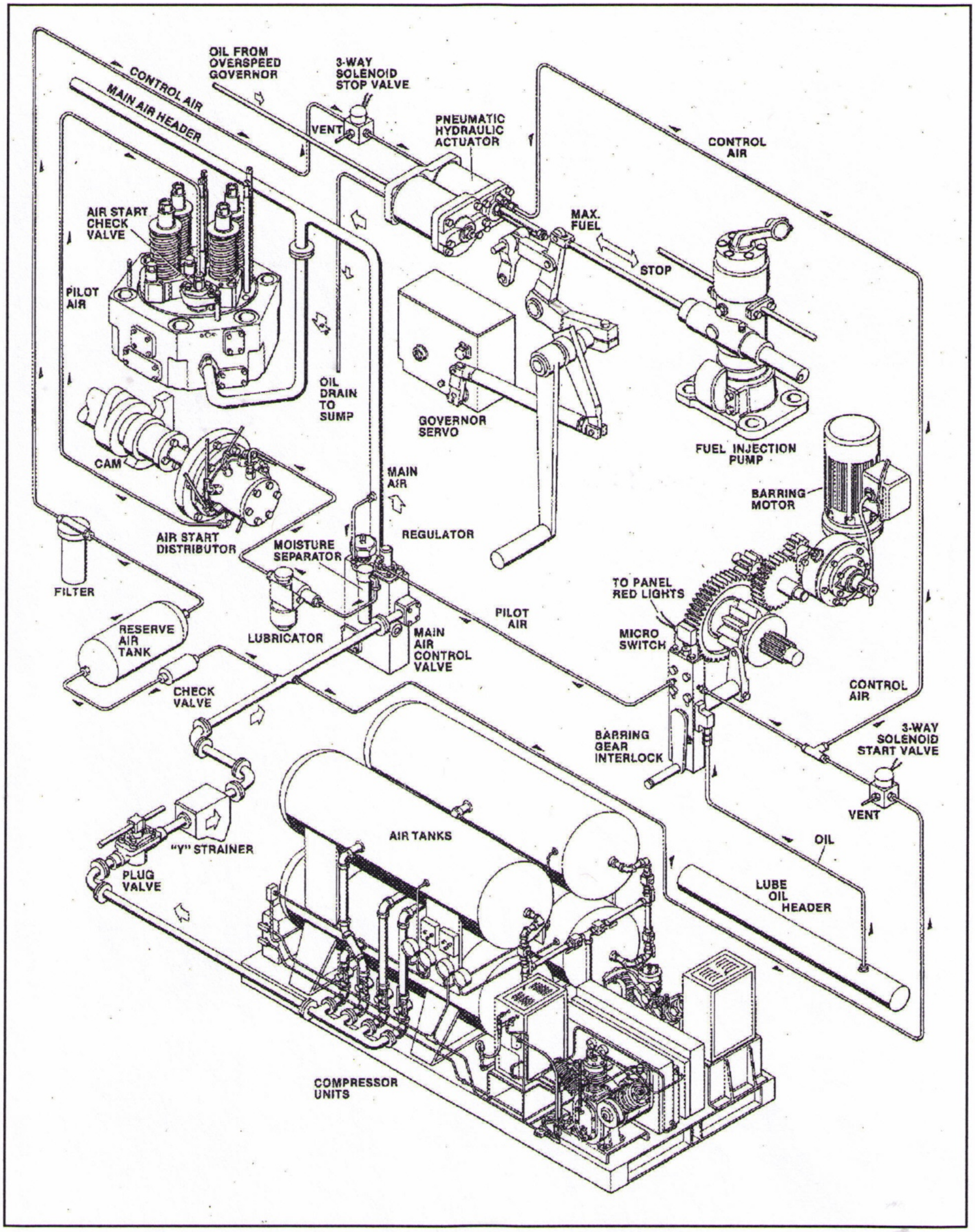

Figure 7-15 Typical Direct Air-Over-Piston Starting System

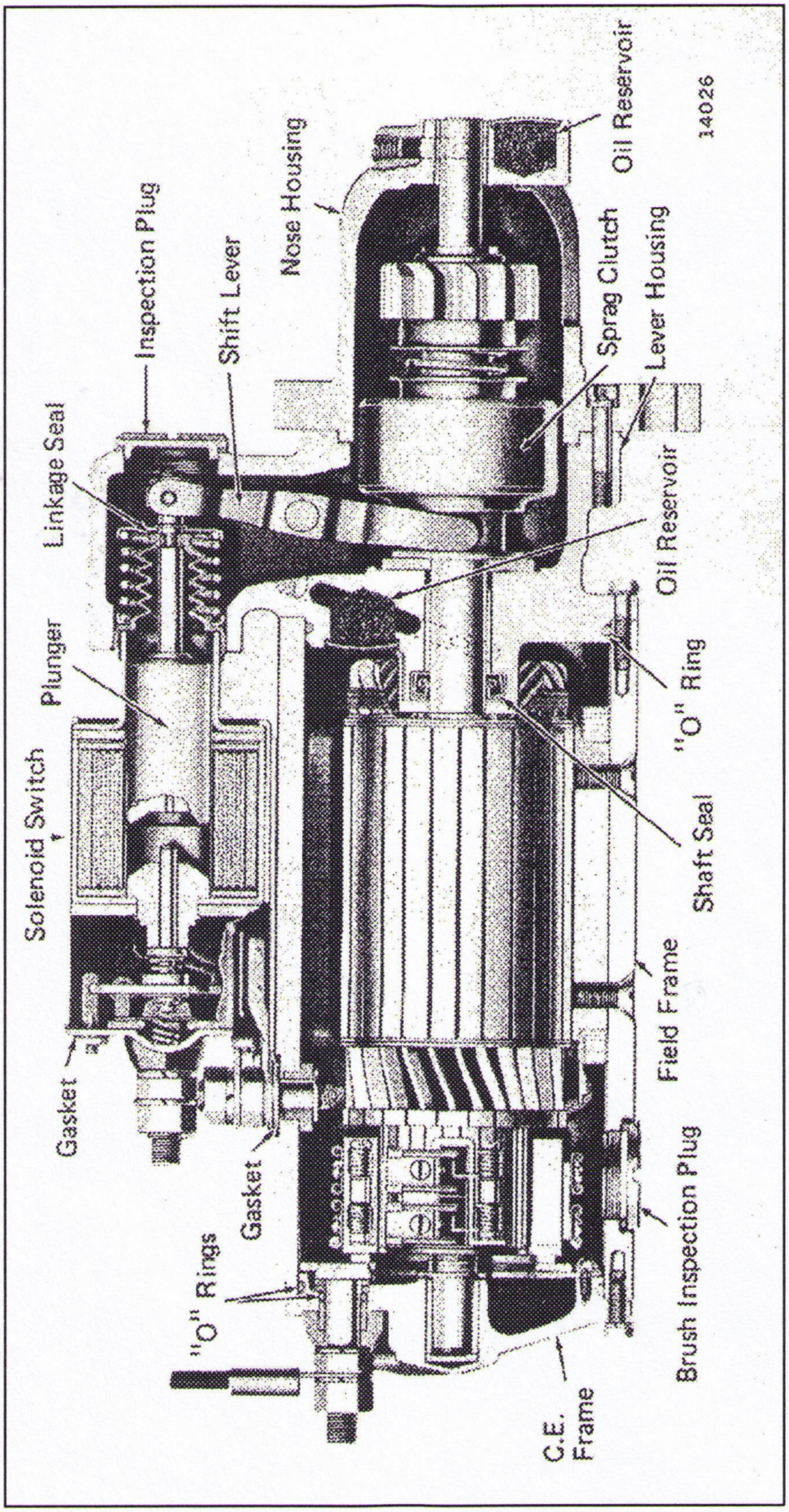

Figure 7-16 Electric Starting Motor System (with Bendix)

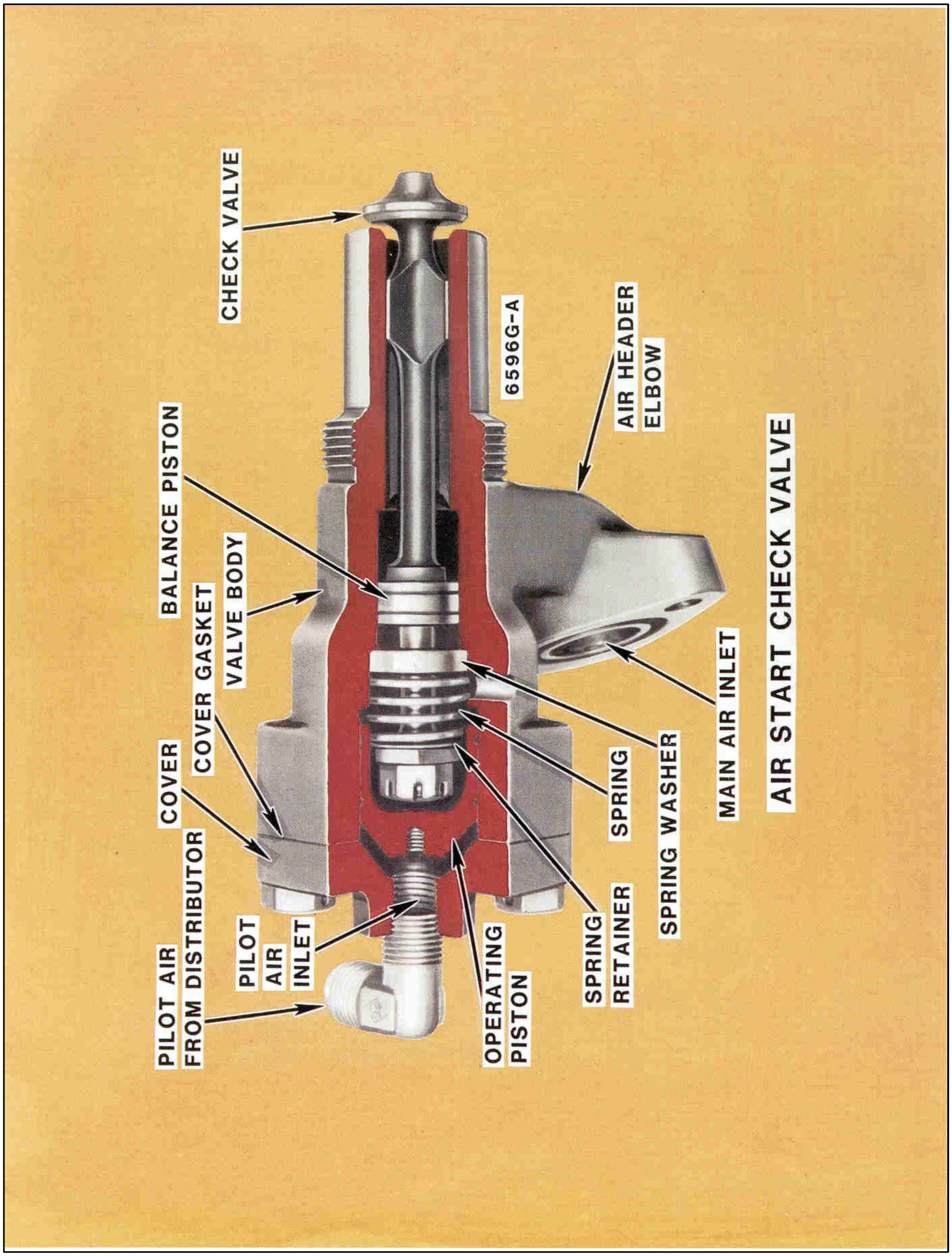

Figure 7-17 Air Start Check Valve

HANDS-ON SESSION 9

9.0 DIRECT AIR INJECTION SYSTEM

Purpose

The purpose of this session is to complement Chapters 3 and 7.

Learning Objectives

Upon completion of this lesson you will be able to understand:

- How the direct air-over-piston starting system operates including its components and their location on the engine.

9.1 Air Start System and Its Components

Utilizing the cutaway OP and ALCO engines, the instructor will conduct a hands-on walkaround presentation to identify the location of the air starting system and its components. Starting air will be traced from its input to the air admits in valve and to all of its output locations including:

- The main starting air header and its flow to each air cylinder start cheek
- The starting air distributor with its lines to the pilot valve on each cylinder's air start check valve
- The line to governor boost cylinder

The instructor will discuss each application of starting air to these components and show cutaways of the components.

- Multi-port air admission valve
- Air-start check valve
- Starting distributor
- Governor boost cylinder

9.1.1 Air Start Distributor

The air start distributor consists of a number of valve assemblies, usually one for each cylinder of the engine. There is a cam, driven by the engine at engine speed. This cam has a flat which is located such that for a particular cylinder, the flat allows the valve for that cylinder to open at a point just past top dead center (or inner dead center) for that cylinder on its power stroke.

When the valve in the air start distributor opens, its causes the air start check valve on that cylinder to also open, thus allowing starting air to enter the engine cylinder at a considerable pressure. The air between the pistons forces the pistons apart. This force drives the connecting rods power the crankshafts, which causes them to rotate. Reference Figures 7-4 through 7-7.

In the air start distributor on the Opposed Piston engine, air is admitted to the distributor when the engine start signal causes the air start solenoid valve to open. The air pressure inside the air start distributor causes the individual cylinder valves to push in against the cam surface. When there is no air pressure present, springs in each valve cause the valves to be forced outward, away from the cam. Thus, when there is no air pressure, there is no contact between the valves and the cam and no wear on the parts.

When the cam rotates to the point that the flat is located at an individual valve, the valve moves further toward the cam. Ports in the housing are opened to allow pilot air pressure to be transmitted to the air start check valves in the associated cylinder. The pilot air opens air start check valve which admits air from the starting air manifold header into the cylinder. When the cam continues to turn, the flat passes that valve and the valve is rammed to the closed position venting the air signal from the cylinder air check valve and shutting off the air into that cylinder. This happens to each cylinder in the firing order sequence of the engine until the engine is started. When the engine reaches a self-sustaining speed of about 125 to 150 rpm, a speed sensing mechanism shuts off starting air to the distributor and header.

The instructor will demonstrate the operation of the air start distributor by applying air pressure to the inlet fitting and then will demonstrate the operation of the individual cylinder valves by turning the cam.

The air start distributor on some early models of engines was mounted on the front of the upper crankshaft as shown on Figure 2-37. The display model has this configuration. On all 12-cylinder and later model engines, the air start distributor is mounted on the opposite control side of the engine (opposite the governor) on the front end or the engine.

One air start check valve for each cylinder is mounted at the center of the cylinder liner on the opposite control side (OCS). See Figure 7-17. There is an air header that connects to each air start check valve and supplies starting air pressure, usually at about 250 psig, to the valves. As each air start distributor valve is opened by the air start distributor, air pressure from the distributor causes the individual air start check valve to open in sequence.

When the air start pressure/supply is on, indicating the engine is to be started, pressure enters the air start check valve from the starting air header. The valve is of the balanced pressure design, and this header pressure will not cause the valve to open on its own. The spring ensures that the valve will not open from the header pressure. A pilot piston is operated by the air start distributor air pressure, which causes the pilot piston to overcome the spring pressure and allow the air start check valve to open.

The instructor will show a sectioned air start check valve and will also demonstrate the operation of the air start check valve by applying pressure to the pilot piston.

It is very important that the air start check valve seal tightly when it is closed because the valve is subject to the pressure and temperature existent in the cylinder during normal operation. If the air start check valve were to leak, it would allow pressure and heat to build up in the air start header, which is not made to operate at such conditions. During normal operation of the engine, it is a good idea to occasionally feel the air start check valves. If they are hot, then they may be leaking and they should be removed from the engine and replaced or rebuilt.