All devices that accomplish work must have a power source. For hydraulic systems, the hydraulic power source is a pump. A pump acts in the same manner as an electric motor. As an electric motor changes electric energy into mechanical energy, a pump changes mechanical energy into hydraulic energy, which is the energy used in a hydraulic system. All hydraulic systems have a pump, and although there are many different types of pumps, they all accomplish the goal of moving hydraulic fluid to where it is needed to operate equipment.

OBJECTIVES

• Describe the basic steps for creating fluid flow that are common to all hydraulic pumps.

• Describe how hydraulic pumps are rated and distinguish the different ratings.

• Distinguish between the different types of hydraulic pumps that are used in hydraulic systems.

• Describe the specific actions that the different types of hydraulic pumps use to create fluid flow and pressure.

INTRODUCTION

All devices that accomplish work must have a power source. For hydraulic systems, the hydraulic power source is a pump. A pump acts in the same manner as an electric motor. As an electric motor changes electric energy into mechanical energy, a pump changes mechanical energy into hydraulic energy, which is the energy used in a hydraulic system. All hydraulic systems have a pump, and although there are many different types of pumps, they all accomplish the goal of moving hydraulic fluid to where it is needed to operate equipment.
HYDRAULIC PUMPS

A hydraulic pump is a mechanical device that changes mechanical energy into hydraulic energy (fluid flow). Hydraulic pumps create flow by increasing the volume of fluid at their inlet and decreasing the volume of fluid at their outlet. The resistance to fluid flow in the pathway and the load on the system create pressure in the system. The greater the load or system resistances, the higher the pressure in the system.

Hydraulic pumps are used in all hydraulic systems and are classified by the type of pumping mechanisms used. The main categories of pumps are positive-displacement and dynamic pumps. See Figure 4-1. Although categorized as a type of hydraulic pump, dynamic pumps are rarely used for hydraulic applications because they cannot create flow against the pressures found in hydraulic systems.

Hydraulic Pump Ratings

Hydraulic pump ratings are assigned by the pump manufacturer and are the main factors in determining pump use. The most common pump ratings include displacement, gallons per minute, pressure, and volumetric efficiency.

All the information needed to service or replace a pump can be found on the pump nameplate. Nameplates are generally affixed to hydraulic pumps to identify the different pump ratings. In addition to pump ratings, the nameplate also identifies the pump manufacturer’s name, the pump serial number, pump type, and/or the pump model number.

Nameplates are typically made from stainless steel and affixed to the pump in an easy-to-read location. The pump’s nameplate can sometimes break off, so it is important to keep the information in another location in case the pump fails.

Note: Not all hydraulic pumps have nameplates. Relevant pump information can also be obtained through the documents provided by the manufacturer with the pump’s original packaging. Such information must never be discarded but saved for future reference.

Figure 4-1. The two main types of hydraulic pumps are positive-displacement pumps and dynamic pumps.
**Displacement.** Displacement is the volume of hydraulic fluid moved during each revolution of a pump’s shaft. Displacement is rated in cubic inches per revolution of the pump shaft and is calculated by applying the following formula:

\[ D = \text{rpm} \times P, \]

where
\[ D = \text{displacement (in cu in. shaft revolution)} \]
\[ \text{rpm} = \text{revolutions per minute of prime mover} \]
\[ P = \text{pump shaft revolutions (in cu in.)} \]

**Example:** What is the displacement of a pump with revolutions of 1.94 cu in. that has a prime mover with revolutions of 1120 rpm?

\[ D = \text{rpm} \times P, \]
\[ D = 1120 \times 1.94 \]
\[ D = 2173 \text{ cu in./min} \]

A prime mover is a device that supplies rotating mechanical energy to a fluid power system. The two main types of prime movers used in fluid power systems are electric motors and internal combustion engines. See Figure 4-2.

**Gallons Per Minute.** When used in fluid power systems, gallons per minute is the number of gallons of fluid that a pump can force into the system every minute. Gallons per minute (gpm) is a measure of fluid flow that is used to measure small volumes of intermittently flowing fluids such as pump discharges. See Figure 4-3.

Gallons per minute in a pump is typically measured with a flow meter attached to the hydraulic system, but can be calculated if certain variables are known. Gpm in a pump is calculated by applying the following formula:

\[ \text{gpm} = \frac{\text{displacement} \times \text{rpm}}{231} \]

where
\[ \text{gpm} = \text{gallons per minute} \]
\[ \text{displacement} = \text{cubic inches of flow per revolution} \]
\[ \text{rpm} = \text{revolutions per minute} \]
\[ 231 = \text{constant (cu in. in one gal)} \]
Pressure Ratings. **Pressure rating** is the highest amount of pressure at which a pump can create flow against. A pump must be specified with a higher pressure rating than the fluid power system’s maximum pressure requirement. If a pump’s maximum pressure is not properly rated for the application it is used for, the pump will experience premature wear and breakdown.

**Volumetric Efficiency.** **Volumetric efficiency** is the relationship between actual and theoretical fluid flow, or pump gpm. See Figure 4-4. All pumps have internal leakage (slippage). As pressure requirements in a fluid power system increase, the efficiency of the pump decreases. The higher the pump efficiency, the less internal losses there will be inside the pump and less energy will be lost. Volumetric efficiency is calculated by applying the following formula:

\[
Eff_V = \left( \frac{P_o}{P_{ro}} \right) \times 100
\]

where

- \( Eff_V \) = volumetric efficiency (in %)
- \( P_o \) = actual pump output (in gpm)
- \( P_{ro} \) = rated pump output (in gpm)

**Example:** What is the pump efficiency of a pump rated for 20 gpm that has actual output of 19 gpm?

\[
Eff_V = \left( \frac{19}{20} \right) \times 100
\]

\[
Eff_V = 0.95 \times 100
\]

\[
Eff_V = 95\%
\]

**Positive-Displacement Pumps**

A **positive-displacement pump** is a pump that has a positive seal between its inlet and outlet and moves a specific volume of hydraulic oil with each revolution of the shaft. Positive-displacement pumps are the only type of pump used in hydraulic systems and equipment. Typical applications for positive-displacement pumps include creating hydraulic flow for hydraulic press equipment, agricultural equipment, construction equipment, flight navigation systems, and robotic systems. See Figure 4-5.

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**TERMS**

| **Gallons per minute (gpm)** | is a measure of fluid flow that is used to measure small volumes of intermittently flowing fluids such as pump discharges. |
| **Pressure rating** | is the highest amount of pressure at which a pump can create flow against. |
| **Volumetric efficiency** | is the relationship between actual and theoretical fluid flow, or pump gpm. |
| **A positive-displacement pump** | is a pump that has a positive seal between its inlet and outlet and moves a specific volume of hydraulic oil with each revolution of the shaft. |
All positive-displacement pumps can operate under a wide range of pressures, have high-pressure capability, can operate in a wide range of environments, and can be small to large in size. Positive-displacement pumps are typically categorized as fixed or variable.

**Fixed-Displacement Pumps.** A fixed-displacement pump is a positive-displacement pump where the fluid flow rate (gpm) cannot be changed. Fixed-displacement pumps are rated by fluid flow, pressure rating, volumetric displacement per rotation, maximum pressure rating, minimum and maximum operating speeds, overall efficiency, noise level, mounting options, maximum input power (horsepower and kilowatts), torque range, and fluid cleanliness requirements. Hydraulic fixed-displacement pumps cannot vary the amount of fluid flow that they produce during operation without changing the speed at which they operate.

A second method used to change the amount of fluid flow produced by the pump is to change the pump’s internal components. Typical applications for fixed-displacement pumps include hydraulic systems that do not require variation in system pressure, such as mobile hydraulic equipment. See Figure 4-6.

**Figure 4-5.** A typical application for a positive-displacement pump includes the fluid power systems on a hydraulic production press.

**Figure 4-6.** Fixed-displacement pumps are available in various sizes with different displacement ratings.
Variable-Displacement Pumps. A variable-displacement pump is a positive-displacement pump that can have its flow rate (gpm) changed. The variable amount of hydraulic fluid that the pump moves is dictated by the demand of the fluid power system it is installed in. A variable-displacement pump varies the amount of hydraulic fluid with movable internal components while the rpm of the prime mover remains fixed.

Like fixed-displacement pumps, variable-displacement pumps are rated by maximum pressure rating, minimum and maximum operating speeds, overall efficiency, noise level, mounting options, maximum input power (horsepower and kilowatts), torque range, and fluid cleanliness requirements. However, unlike fixed-displacement pumps, variable-displacement pumps are also rated in maximum volumetric displacement per rotation and minimum and maximum pressure compensated ranges. Excessive pressure may cause the pump housing to rupture or the pump seals to burst. For maximum safety, the hydraulic pump selected for a fluid power system must be rated to withstand pressures that are higher than the highest anticipated pressure in the system. This prevents damage and possible failure if an overpressure condition occurs. Typical applications for variable-displacement pumps include systems that operate with varied system fluid flow, such as industrial robotic systems. See Figure 4-7.

Figure 4-7. Typical applications for variable-displacement pumps include systems that operate with varied system fluid flow, such as industrial robots.
Positive-Displacement Pump Operation

All positive-displacement pumps operate similarly to create fluid flow. Therefore, the principles of positive-displacement pump operation can be applied directly to the different types of positive-displacement pumps encountered in the field. All hydraulic positive-displacement pumps have similar parts such as a shaft, pump housing, inlet port, and outlet port. See Figure 4-8. A positive-displacement pump operates in four basic steps:

1. The pump creates a vacuum by increasing the volume at its inlet, which is connected to the reservoir. Vacuum is created in a confined space that has less pressure than atmospheric pressure. The vacuum in a pump is created when the pump rotates and an increased volume is created at its inlet. The pressure in the tank is at atmospheric pressure, which is higher than the vacuum created at the inlet. Atmospheric pressure forces the fluid to flow from the tank into the inlet of the pump.

2. Once the fluid enters the pump through the inlet, the pump traps the fluid through a sealing method. A seal is an airproof and/or fluidproof joint between two members. The fluid travels through the pump, in decreasing volume, towards the outlet side of the pump.

3. Once the trapped fluid moves toward the outlet side of the pump, the sealed chamber opens and releases the fluid into the pump outlet.

4. The sealed chamber then closes, preventing fluid in the outlet side of the pump from slipping to the inlet side of the pump. At the same time, more fluid is forced out of the outlet and into the hydraulic equipment.

TECH FACT

Positive displacement, as it relates to hydraulic pumps, means that regardless of the load or speed involved with a hydraulic system, the pump will always displace the same amount of fluid per shaft revolution.

Figure 4-8. All positive-displacement pumps follow the same basic operational steps to create fluid flow.
HYDRAULIC PUMP TYPES

Hydraulic pump types include gear, vane, and piston pumps. All hydraulic pumps create fluid flow by following four basic steps, with some differences according to pump type. For example, a gear pump uses meshing gears to create fluid flow, while a piston pump uses the extension and retraction of multiple pistons.

Gear Pumps

A gear pump is a hydraulic pump that consists of gears that mesh together in various manners to create fluid flow. Gear pumps may be external, lobe, internal, or gerotor pumps. The teeth on the meshing gears create a vacuum at the inlet and then push the fluid to the outlet by using a decreasing volume. See Figure 4-9. Gear pumps are ideal for equipment that operates in dirty environments, such as mobile hydraulic construction equipment, because a small amount of dirt in the system will not affect the overall performance of the pump.

TERMS

A seal is an airproof and/or fluidproof joint between two members.

A gear pump is a hydraulic pump that consists of gears that mesh together in various manners to create fluid flow.

An external gear pump is a gear pump that consists of two externally toothed gears that form a seal within the pump housing.
All gear pumps are fixed-displacement pumps. The most practical method used to change the flow of a gear pump is to replace its meshing gears with those of a different size. Each gear pump has specific applications, and each has advantages and disadvantages. Advantages of using gear pumps are that they are inexpensive, work well in dirty environments, are easier to repair than other pumps, can be used with a wide range of hydraulic fluid viscosities, are less sensitive to pump cavitation, have low noise levels, and have an output that is more predictable because it is linear with the speed of the prime mover.

Disadvantages include that they are not as efficient as other types of pumps, have fixed clearance ends, and can only accomplish volume control by changing the pump gears or changing the speed of the prime mover. Gear pumps can be found in low volume transfer applications such as hydraulic aerial lifts, log splitters, dump trucks, trailers, earthmovers, trucks, buses, and machine tool equipment.

**External Gear Pumps.** An external gear pump is a gear pump that consists of two externally toothed gears that form a seal within the pump housing. External gear pumps have two equal-sized gears, the drive gear and driven gear, which rotate to cause fluid to flow into the system. See Figure 4-10. External gear pumps operate in four basic steps:

1. As the drive gear rotates, it turns the driven gear. This causes both gears to move away from the inlet. This movement creates a vacuum on the inlet side of the pump as the gear teeth pull apart. The atmospheric pressure then pushes the fluid from the reservoir into the inlet.
2. As both gears rotate away from the inlet, the gear teeth move closer to the pump housing internal wall. This traps the fluid and forces it between the gear teeth and the internal wall toward the discharge.
3. As the gear teeth reach the outlet, they pull away from the internal wall. The fluid is then released. As the gear teeth start moving toward each other again, all fluid is forced out of the pump by decreasing volume.
4. As the gear teeth mesh back together, they form a seal that does not allow most of the fluid to flow back into the inlet. More fluid moves into the outlet area each time fluid is forced out of the gear teeth. This forces the fluid through the outlet port and into the hydraulic system.

**Lobe Pumps.** A lobe pump is a positive-displacement pump that has two external-driven, intermeshing, lobe-shaped gears. A lobe pump operates similar to an external gear pump. See Figure 4-11. The main advantage of having two driven lobes is that the two lobes do not have to make contact with each other, thereby reducing the amount of operational noise and wear on the pump. A lobe pump requires timing gears to drive the lobe-shaped driven gears.

Although lobe pumps can be used in hydraulic applications, they are typically used in pneumatic applications or to move products such as slurries, pastes, and solids. Lobe pumps are commonly used in industries such as pulp and paper processing chemical refining, food and beverage processing, pharmaceutical production, and biotechnology. Lobe pumps operate in four basic steps:

1. As the lobes unmesh, they create a vacuum by increasing the volume on the inlet side of the pump.
2. The fluid flows into the pump housing and is trapped by the lobes as they rotate.
3. The fluid travels around the interior of the pump housing in the gaps between the lobes and starts to leave the trapped areas.
4. The meshing of the lobes forces the fluid through the outlet into the system.

**TERMS**

- A lobe pump is a positive-displacement pump that has two external-driven, intermeshing, lobe-shaped gears.
- An internal gear pump is a gear pump that consists of a small external drive gear mounted inside a large internal spur gear, also called a ring gear.
- A crescent seal is a crescent-moon-shaped seal between the gears and between the inlet and outlet sides of an internal gear pump.

**TECH FACT**

Common external gear pump applications include pumping acids, fuels, and lube oils; metering chemical additives and polymers; mixing and blending chemicals; transferring low-volume fluid; and operating industrial and mobile hydraulic equipment, such as log splitters.
Figure 4-10. An external gear pump consists of meshing gears that form a seal with the pump housing and operates similar to the four basic steps of a positive-displacement pump.

Figure 4-11. A lobe pump has two external driven gears and operates similar to an external gear pump.
**Internal Gear Pumps.** An internal gear pump is a gear pump that consists of a small external drive gear mounted inside a large internal spur gear, (ring gear). The two gears rotate in the same direction. See Figure 4-12. A crescent seal separates the low- and high-pressure areas of the pump. A crescent seal is a crescent-moon-shaped seal between the gears and between the inlet and outlet sides of an internal gear pump. Hydraulic fluid is trapped as the gears rotate and is discharged through the pump outlet.

Internal gear pumps can pump fluids with a wide range of viscosity and can operate at temperatures up to 750°F. Because there are only two moving parts, internal gear pumps are reliable and easy to maintain. Internal gear pumps are typically used in industrial production facilities. Internal gear pumps operate in three basic steps:

1. As the motor turns the external toothed gear, the gear teeth unmesh, creating an increasing volume. Atmospheric pressure then pushes the fluid from the reservoir into the inlet of the pump.

2. The fluid becomes trapped in the cavities of the unmeshed gears. As the gears rotate, the crescent seal separates the internal gear and the external gear. The fluid continues to move as the two gears continue to rotate.

3. As the two gears reach the end of the crescent seal, the gears begin to mesh again, decreasing the volume. The decrease in volume forces the fluid out of the cavities between the teeth and causes the fluid to flow through the outlet side of the pump and into the hydraulic system.

**TECH FACT**

In addition to hydraulic oil, internal gear pumps are used to pump fuel oil, lube oil, resins, polymers, alcohols, solvents, asphalt, bitumen, tar, polyurethane foam, products, paint, inks, pigments, soaps, surfactants, and glycol.

Figure 4-12. An internal gear pump consists of a small external drive gear mounted inside a large internal gear.
Gerotor Pumps. A gerotor pump is a gear pump that has an inner rotor that meshes with the gear teeth of an outer rotor. The inner rotor has one less gear tooth than the outer rotor and both rotors rotate in the same direction. Gerotor pump operation is similar to internal gear pump operation without the crescent seal. See Figure 4-13.

Gerotor pumps are used for low-to moderate-pressure hydraulic applications of less than 1000 psi, such as trash compactors, hydraulic lifts, and hydraulic elevators. Because gerotor pumps are susceptible to problems with dirt, they can only be used in applications that have clean oil. Due to these considerations, gerotor pumps are used in clean, low-pressure industrial and commercial applications. Gerotor pumps operate in three basic steps:

1. Fluid enters the inlet port between the inner rotor and outer rotor.
2. Fluid travels through the pump between the teeth of the two rotors.
3. The inner rotor and outer rotor teeth mesh to form a seal between the inlet and outlet ports, forcing the fluid through the outlet port.

Gear Pump Assembly

Gear pumps can sometimes be repaired in the field. For a technician to accomplish this, they must have an understanding of how the pump is assembled. Gear pump assemblies consist of major parts (a frame, gears, housing, and a shaft) and minor parts (O-rings, backup rings, and seals) that may need to be repaired, replaced, or refurbished. Many gear pump manufacturers supply step-by-step procedures for the assembly and disassembly of their pumps. This allows a technician to repair a gear pump in the field, rather than removing it from the hydraulic equipment and sending it out for repair. Gear pump manufacturers also supply part numbers and/or descriptions for every part that may need to be replaced. See Figure 4-14.

For example, the two gears in a gear pump can be replaced by applying the following procedure:

1. Remove the pump from its motor coupling by removing the bolts.
2. Remove all bolts from the front of the pump that hold the pump assembly together.
3. Disassemble pump.
   a. Detach the front plate assembly from the pump.
   b. Remove the two gears from the body housing.
   c. Detach the body housing from the back plate assembly.
4. Place all parts in a straight line in the exact order that they were disassembled.
5. Inspect all seals that connect the three main sections together.
   a. If the seals are good, proceed to step 6.
   b. If the seals are worn or damaged, replace them.
6. Inspect the ball bearings for wear and lubrication. Replace or regrease as required.
7. Replace the two gears with new gears in the order that they have been laid out.
8. Reassemble the gear pump by working backwards from step 7.

**Vane Pumps**

A *vane pump* is a hydraulic pump that creates a vacuum by rotating a rotor inside a cam ring while trapping fluid between vanes that expand and retract from the rotor while moving the fluid toward the output. See Figure 4-15. There are a number of different types of vane pumps including unbalanced vane pumps; variable-displacement, pressure-compensated vane pumps; and balanced vane pumps.

**Figure 4-15.** A vane pump contains vanes in an offset rotor and rotates the rotor to produce the flow of hydraulic fluid.
Each type of vane pump follows four basic operational steps. However, all vane pumps have similar parts such as the shaft, cam ring, vanes, rotor, inlet port, outlet port, and pump body.

Vane pumps are known for their dry priming capability, ease of maintenance, and good suction characteristics over the life of the pump. Because of a smoother, nonpulsing flow rate, vane pumps run quietly and efficiently. Vane pumps can operate at temperatures ranging from –25°F to 500°F. Vane pumps extend their vanes through centrifugal force or through a mechanical means such as a spring.

**Unbalanced Vane Pumps.** An unbalanced vane pump is a fixed- or variable-displacement hydraulic pump in which the pumping action occurs in the chambers on one side of the rotor and shaft. Unbalanced vane pumps have the simplest design of the various types of vane pumps.

An unbalanced vane pump is typically used in low-pressure applications. **See Figure 4-16.** A high pressure differential between the inlet and outlet of the pump creates a load on the rotor that is attached to the shaft. Larger bearings and shafts must be used because of this extra load, which limits the size of unbalanced vane pumps. Unbalanced vane pumps operate in four basic steps:

1. The offset rotor rotates with vanes contacting the cam ring, creating a vacuum at the inlet of the pump. As the rotor rotates, the vanes extend outward by centrifugal force, creating a confined space for the fluid. The shape of the inlet allows the pump to pull more fluid into the confined space.

2. As the fluid becomes trapped between the vanes and the cam ring, it is forced toward the outlet of the pump.

3. As the trapped fluid gets closer to the outlet side of the pump, it is released from its confined space. The outlet is also shaped to allow more fluid to move through the pump. At this point, the vanes are forced back into the rotor by the cam ring, making a smaller confined space for the fluid.

4. As the fluid is forced out of the confined space, the rotor and the cam ring provide a leakproof seal that does not allow the fluid to slip back to the inlet. At the same time, more fluid is forced out of the pump, forcing fluid into the system.

![Figure 4-16. Unbalanced vane pumps operate similar to the four basic steps of a positive-displacement pump.](image)
**Variable-Displacement, Pressure-Compensated Vane Pumps.** A variable-displacement, pressure-compensated vane pump is a pump that automatically adjusts the amount of volume it displaces per rotation by centering the rotor when the pressure in the system starts to build. See Figure 4-17. A variable-displacement, pressure-compensated vane pump operates by adjusting a cam ring to allow the volume per revolution to change according to system pressure. This type of pump protects itself against excessive pressure by reducing power consumption as the flow rate decreases. When pressure reaches a certain value, the compensator spring force equals the hydraulic piston force. As pressure continues to increase, the compensator spring is compressed until concentricity on the compensator ring is achieved. Maximum pressure is then achieved. At this point, the pump is protected because it produces no more flow, resulting in no power loss and no fluid heating. A thrust block is used to ensure smooth movement and correct placement of the cam ring.

Variable-displacement, pressure-compensated vane pumps are the most commonly used vane pumps and have ease of maintenance over the life of the pump. Setting the maximum fluid flow of a variable-displacement, pressure-compensated vane pump is performed using the following procedure:

1. Connect the outlet side of the pump directly to a pressure gauge.
2. Turn the pump ON and record the pressure when the pump rotor becomes centered.
3. Use the pressure adjustment screw to set the desired fluid flow.

Figure 4-17. A variable-displacement, pressure-compensated vane pump is a pump that automatically adjusts the amount of volume it displaces per rotation by centering the rotor when the pressure in the system starts to build.
Balanced Vane Pump. A balanced vane pump is a pump that consists of a cam ring, rotor, vanes, and a port plate with opposing inlet and outlet ports. See Figure 4-18. This creates a balanced load on the pump bearings and seals. The two inlets and two outlets are set 180° apart from each other. This helps to prolong the life of the shaft bearings and allows the pump to run at higher speeds and at higher pressure ratings than an unbalanced vane pump. A balanced vane pump also has an elliptical cam ring.

A cartridge assembly is a cartridge located in a vane pump that houses the vanes, rotor, and cam ring, which are all placed between two end plates. See Figure 4-19. A cartridge assembly allows a technician to service the pump quickly because it allows for replacement of the entire assembly when the internal parts need to be replaced. Additionally, changing the size of the cartridge assembly can change the displacement of the pump.

Vane Pump Assembly

Like gear pumps, many types of vane pumps can be repaired in the field. Vane pump assemblies are more complicated than gear pump assemblies and require more time to repair. Many manufacturers provide detailed assembly and disassembly instructions for vane pumps that make it possible to repair, replace, or refurbish any part of a vane pump. It is also common for vane pump assemblies to have rebuild kits that can be ordered and kept onsite for quicker repair time. Usually specific assembly and disassembly instructions are used because vane pumps may have a cartridge that holds the vanes. See Figure 4-20.
For example, a cam ring in a vane pump is replaced by applying the following procedure:
1. Remove the pump from its foot bracket by removing the bolts.
2. Remove four bolts from the back of the pump.
3. Disassemble the pump into three sections.
   a. One section is the back housing with O-rings.
   b. Another section is the cartridge assembly.
   c. The third section is the front housing with the shaft.
4. Place all parts in a straight line in the exact order that they were disassembled.
5. Inspect all the seals that connect the three main sections together.
   a. If the seals are good, go to step 6.
   b. If the seals are worn or damaged, replace them.
6. Inspect the ball bearings for wear and lubrication. Replace or regrease as required.
7. Remove two screws holding the vane cartridge together.
8. Place all parts from the vane cartridge in a straight line in the exact order that they were disassembled.
9. Remove the cam ring and the rotor, making sure that the vanes do not fall out of the rotor.
10. Remove all vanes from the rotor and inspect for premature wear.
11. Replace the damaged cam ring with a new cam ring.
12. Reassemble the vane pump by working backwards from step 11.

**Piston Pumps**

A piston pump is a hydraulic pump in which fluid flow is produced by reciprocating pistons. Piston pumps are either fixed or variable displacement. They use a rotating internal piston assembly to create a vacuum as the pistons pull away from the inlet. The piston assembly then forces fluid out when the pistons are pushed toward the outlet.

A bent-axis piston pump is the most durable type of hydraulic pump and can operate at pressures of up to 10,000 psi. Piston pumps are typically used in applications such as small loaders. Types of piston pumps include axial, variable-displacement, bent-axis, and radial piston pumps.

**TECH FACT**

To achieve a uniform volumetric flow rate of hydraulic fluid, hydraulic piston machines, such as piston pumps, are designed with an odd number of pistons. For example, many hydraulic piston pumps are designed to house seven or nine pistons.
Axial Piston Pumps. An axial piston pump is a piston pump that consists of pistons in a rotating piston block parallel to the drive shaft. Axial piston pumps create smooth fluid flow for piston pumps. See Figure 4-21. Axial piston pumps consist of a number of pistons, a piston block, piston shoes, a swash plate, and a drive shaft. A swash plate is an angled plate in contact with the piston heads that moves the pistons in the cylinders of a pump. A variable-displacement piston pump is a piston pump in which the angle of the swash plate can be varied.

TERMS

An axial piston pump is a piston pump that consists of pistons in a rotating piston block parallel to the drive shaft. A swash plate is an angled plate in contact with the piston heads that moves the pistons in the cylinders of a pump. A variable-displacement piston pump is a piston pump in which the angle of the swash plate can be varied.

Axial Piston Pump Operation. Axial piston pumps consist of a number of pistons, a piston block, piston shoes, a swash plate, and a shaft and operate with four basic steps:

1. As the drive shaft rotates, the piston block rotates in the same direction. This pulls a piston from the number of pistons out and creates suction. The piston is pulled because it is attached to the swash plate and the swash plate is in a fixed, slanted position. The farther back the piston moves, the more volume of fluid it will move. The length of the piston is the main determinant to the amount of gpm a pump can produce.

2. As the piston moves through the first half of the pump, it pulls more fluid every degree it turns, trapping more fluid in the piston barrel.

3. When the piston reaches the halfway point of a cycle (180°), the piston pushes fluid out of the piston barrel. As the shaft continues to rotate, more fluid is forced out of the piston barrel.

4. As the piston completes a 360° cycle, all fluid is pushed out of the piston barrel, creating a leakproof seal that will not allow the oil to reenter the inlet. At the same time, the next piston forces fluid out of its barrel, which forces fluid flow in the hydraulic system.

Figure 4-21. Axial piston pumps consist of a number of pistons, a piston block, piston shoes, a swash plate, and a shaft and operate with four basic steps.
Variable-Displacement Piston Pumps. A variable-displacement piston pump is a piston pump in which the angle of the swash plate can be varied. See Figure 4-22. Variable-displacement piston pumps have a simple design. They are also reliable and durable. Variable-displacement piston pumps include applications where a large amount of varied pressure is required such as backhoes, hydraulic cranes, heavy-duty presses, and balers. They are also used in applications where heat buildup can affect pump performance.

A variable-displacement piston pump works under the same principles as an axial piston pump with the exception of the variability of the angle of the swash plate. When the angle of the swash plate is varied, it changes the distance of how far back a piston pulls. This causes the piston to allow more or less fluid into its barrel, varying the amount of gpm that the pump produces.

TECH FACT

The pistons in an axial piston pump reciprocate parallel to the centerline of the drive shaft of the piston block. Rotary shaft motion is converted into axial reciprocating motion. Most axial piston pumps contain multiple pistons and use check valves or port plates to direct fluid flow from the inlet port to the outlet port.

Figure 4-22. A variable-displacement piston pump has a swash plate at an angle that can be varied, thereby varying the amount of fluid flow (gpm).
The most common method to vary the angle of a swash plate is through internal pilot pressure. As the pressure in the fluid power system begins to reach the set pressure of the pump, pressure from the internal pilot lines begins to push on the pilot valve attached to the swash plate.

Maximum pilot pressure is set with a setscrew that adjusts a control spring. As the swash plate begins to move, the distance the pistons pull back into the barrel changes. When the swash plate is vertical, there is no fluid flow produced by the pump. However, the prime mover still rotates at the same rpm, which saves energy because there is no load on the motor and there is no energy being wasted as heat from fluid moving through the pressure relief valve.

**Bent-Axis Piston Pumps.** A bent-axis piston pump is a piston pump in which the pistons and cylinders are at an angle to the drive shaft and thrust plate. See Figure 4-23. Bent-axis piston pumps operate similarly to axial piston pumps, but rather than the swash plate being at an angle (offset), the pistons and piston block are at an angle (offset). The angle at which the pistons and piston block are offset determines the amount of fluid that each piston can take in. Thus, the angle at which the pistons and piston block are set determines the amount of fluid flow.

Bent-axis piston pumps can be either fixed or variable. Fixed bent-axis piston pumps work by rotation from the prime mover that the angled piston is attached to. As they rotate, the pistons extend and retract, creating fluid flow. Variable bent-axis piston pumps work by adjusting the angle at which the pistons and the piston block sit. Typical applications for bent-axis piston pumps include mobile and industrial equipment where a high-pressure rating is required and space is limited.

**Radial Piston Pumps.** A radial piston pump is a piston pump that consists of a cylinder barrel, pistons with shoes, a ring, and a valve block located perpendicular to the pump shaft. See Figure 4-24. Radial piston pumps are high-pressure hydraulic pumps, capable of operating at 10,000 psi. Radial piston pumps are used because of the design of their pistons and barrel, which allow for a short stroke. Typical applications for radial piston pumps include equipment that uses a heavy fluid for low fluid flow and high pressure, such as plastics injection molding machines or die-casting machines for metals.

Radial piston pumps are classified as cam or rotating piston pumps. In a cam pump, a rotating internal cam moves the pistons in cylinders. The cam is shaped to push the pistons out during one half of the cam rotation and allow the pistons to retract during the other half. There are also variable pressure-compensated radial piston pumps.

A variable pressure-compensated radial piston pump works similar to a variable axial model by adjusting the stroke of the pistons to adjust the amount of fluid flow as pressure increases. The amount of fluid flow is adjusted by centering the cam ring and controlling the distance that the pistons extend and retract. In a rotating piston pump, pistons are housed in a rotating piston block that is offset inside the pump housing and rotates around a fixed shaft. Fluid enters the pump inlet as the pistons extend and is discharged from the pump outlet as the pistons retract.
Radial piston pumps operate on the same basic principles as axial piston pumps but are built with the pistons lying flat and facing inward toward the shaft. The inlet and outlet are located close to the shaft, and the piston block is off-center inside the cam ring. As the shaft rotates, the pistons extend and retract to complete the four basic operational steps of positive-displacement pumps.

**Cavitation.** Cavitation is a localized gaseous condition within a stream of fluid, which occurs when pressure is reduced to vapor pressure. Implosion is an inward bursting. See Figure 4-25. Pseudocavitation is artificial cavitation caused by air being allowed into the pump suction line. Pseudocavitation is caused by low reservoir fluid, contaminated fluid, or leaking pump suction lines. Pseudocavitation is indicated by a loud noise for an extended period of time.

Not allowing air to dissolve in hydraulic fluid helps prevent pump cavitation. Air can be removed most effectively when fluid is in the tank. It takes time for air to separate from fluid, so the path from the tank return line to the pump inlet must be as long as possible and with as little turbulence present as possible.

**TERMS**

| Cavitation | Cavitation is a localized gaseous condition within a stream of fluid, which occurs when pressure is reduced to vapor pressure. |
| Implosion  | Implosion is an inward bursting. |
| Pseudocavitation | Pseudocavitation is artificial cavitation caused by air being allowed into the pump suction line. |

**Figure 4-24.** Radial piston pumps consist of reciprocating pistons in cylinders and can be classified as cam or rotating piston pumps.

**Figure 4-25.** Cavitation occurs as gas bubbles expand in a vacuum and implode when entering a pressurized area.

Pseudocavitation occurs when the inlet port of a pump is restricted. An indication of pump cavitation is a high shrieking sound or a sound similar to loose marbles or ball bearings in the pump. Pseudocavitation is normally created when the suction line is damaged, plugged, or collapsed. Pseudocavitation may also be caused by an increase in pump rpm that requires more fluid than the system piping allows, fluids with an increased viscosity due to lower ambient temperatures, or an increase in the viscosity of a fluid in a system when the system has a long suction line.
With cavitation, as the pump pulls against a fluid that does not flow, a greater vacuum is created. Any microscopic air or gas within the fluid expands. Expanded bubbles on the inlet side collapse rapidly on the outlet side of the pump. The small but tremendous implosions can cause extensive damage to pump parts. Theoretically, an air bubble exposed to a 5000 psi cavitation may create an implosion pressure of 75,000 psi and travel at a speed of 600 fps to 4000 fps.

Double and Triple Pumps

Although rare in modern hydraulic equipment, hydraulic pumps are available with double and triple pump styles. These pump styles have two or three pumping units inside a single pump housing on the same shaft. The pumping units may or may not be the same size. The advantage of these systems is that one prime mover is used to rotate two or three pumps at the same time. Double and triple pumps can provide greater flow by connecting the pumps in series or they can supply two or three different hydraulic systems using only one prime mover. Each pump requires its own relief valve. Only one pump unit needs to be installed when using double or triple pumps, which simplifies the installation process. Pumps that are connected together can deliver greater volumes of hydraulic fluid and produce higher pressures than a single pump.

In addition to high cost, the main disadvantage of using double or triple pumps is that if one of the pump units breaks down, the entire hydraulic system must be shutdown while the pump is repaired. Double and triple pumps are used in mobile and industrial applications such as hydraulic log splitters, shear presses, underground well drilling machines, and trash compactors. For example, a small pump can provide hydraulic fluid to a piece of equipment while the larger pump can unload fluid to the reservoir. The most common types of double and triple pumps are gear and vane pumps. See Figure 4-26.
Hydraulic Pump Schematic Symbols

Hydraulic pump schematic symbols are used to determine general information about the pump used in a system. See Figure 4-27. While hydraulic pump schematic symbols do not provide direct information on pump type, such as piston, gear, or vane, they do provide information on whether the pump is unidirectional or bidirectional by using arrows. These symbols also provide information on whether the pump is fixed or variable.

Figure 4-27. Hydraulic pump schematic symbols are used to determine general information about the type of pump used in a system.

Quick Quiz®

Refer to CD-ROM for the Quick Quiz® questions related to chapter content.
MULTIPLE CHOICE

1. Fixed-displacement pumps are rated by fluid flow and ___.
   A. electrical requirements
   B. housing size
   C. pressure rating
   D. speed

2. Hydraulic pump types include gear, vane, and ___ pumps.
   A. centrifugal
   B. gerotor
   C. lobe
   D. piston

3. ___ is a localized gaseous condition within a stream of fluid that occurs when pressure is reduced to vapor pressure.
   A. Cavitation
   B. Implosion
   C. Pseudocavitation
   D. all of the above

4. A lobe pump requires ___ to drive the lobe-shaped driven gears.
   A. lobe gears
   B. pistons
   C. timing belts
   D. timing gears

5. ___ is the volume of hydraulic fluid moved during each revolution of the shaft of a pump.
   A. Displacement
   B. Gallons per minute
   C. Revolutions per minute
   D. Volumetric efficiency

6. A ___ pump has an inner rotor that meshes with the gear teeth of an outer rotor.
   A. gerotor
   B. lobe
   C. piston
   D. vane

7. A variable-displacement pump varies the amount of hydraulic fluid with movable internal components while the ___ of the prime mover remains fixed.
   A. displacement
   B. gpm
   C. rpm
   D. volumetric efficiency
8. Bent-axis piston pumps are different from axial piston pumps because their ___ are at an angle (offset).
   A. pistons and piston block
   B. swash plates
   C. pistons, piston block, and swash plate
   D. none of the above

9. A(n) ___ plate is an angled plate used to extend and retract the pistons in an axial piston pump.
   A. axial
   B. cylinder barrel
   C. piston
   D. swash

10. The main categories of hydraulic pumps are dynamic and ___ pumps.
    A. fixed
    B. nonpositive-displacement
    C. positive-displacement
    D. variable

11. The most common method to vary the angle of a swash plate is through ___.
    A. internal pilot pressure
    B. the speed of the prime mover
    C. the rotating vanes
    D. the cartridge assembly

12. A ___ is part of a vane pump and houses the vanes, rotor, and cam ring, which are all placed between two end plates.
    A. cam ring
    B. cartridge assembly
    C. cartridge fitting
    D. slotted rotor

13. Gear pumps may be external, internal, lobe, or ___.
    A. centrifugal
    B. gerotor
    C. piston
    D. vane

14. ___ is the highest amount of pressure at which a pump can create fluid flow.
    A. Displacement
    B. Gallons per minute
    C. Pressure rating
    D. Volumetric efficiency

15. A(n) ___ vane pump allows adjustment of the flow rate of the pump.
    A. axial
    B. balanced
    C. variable-displacement
    D. variable-displacement, pressure-compensated
COMPLETION

1. A(n) ___ is an airproof and/or fluidproof joint between two members.

2. Vane pump types include unbalanced, balanced, and ___.

3. A(n) ___ is a crescent-moon-shaped seal between the gears and between the inlet and outlet sides of an internal gear pump.

4. A(n) ___ pump has pistons in a rotating cylinder block parallel to the drive shaft.

5. A(n) ___ piston pump has pistons and cylinders that are at an angle to the drive shaft and thrust plate.

6. A(n) ___ allows a technician to replace an entire assembly in a vane pump when the internal parts need to be replaced.

7. ___ is the relationship between actual and theoretical fluid flow.

8. Pseudocavitation is caused by ___ being allowed into the suction line.

9. ___ are generally affixed to a pump to identify the different pump ratings.

10. A(n) ___ vane pump is a fixed- or variable-displacement hydraulic pump in which the pumping action occurs in the chambers on one side of the rotor and shaft.

11. A(n) ___-displacement piston pump can have the angle of its swash plate varied.

12. A(n) ___ pump uses gears that mesh together in various manners in a close-fitting housing to create fluid flow.

13. A(n) ___-displacement pump cannot have its fluid flow (gpm) changed.

14. ___ pumps are known for their dry priming capability, ease of maintenance, and good suction characteristics over the life of the pump.

15. A(n) ___ consists of a cam ring, rotor, vanes, and a port plate with opposing inlet and outlet ports set 180˚ apart from each other.

16. ___ is the volume of hydraulic fluid moved during each revolution of the shaft of a pump.

17. A(n) ___ is a mechanical device that changes mechanical energy into hydraulic energy (fluid flow).

18. A(n) ___ piston pump has pistons located perpendicular to the pump shaft.

19. Pseudocavitation occurs when the ___ port of a pump is restricted.

20. A(n) ___ pump has a positive seal between its inlet and outlet and moves a specific volume of hydraulic fluid with each revolution of the shaft.
1. Although lobe pumps can be used in pneumatic applications, they are typically used in hydraulic applications to move products such as slurries, pastes, and solids.

2. Hydraulic fixed-displacement pumps cannot vary the amount of fluid flow that they produce during operation without changing the speed at which they operate.

3. External gear pumps have two different size gears.

4. A balanced vane pump has an elliptical cam ring.

5. Displacement is the fluid flow that a pump can produce.

6. Axial piston pumps create smooth fluid flow for piston pumps.

7. Changing the angle of the swash plate in a variable-displacement piston pump does not affect the distance of how far back a piston pulls.

8. Gear pumps operate through the extension and retraction of multiple pistons.

9. All bent-axis piston pumps are variable.

10. Dynamic pumps include gear, vane, and piston pumps.

11. Pseudocavitation can be caused by low reservoir fluid.

12. Gear pumps have the highest level of loudness while in operation.

13. Hydraulic pump schematic symbols provide direct information on pump type.

14. Vane pumps are typically used in applications that require the movement of high-viscosity fluids.

15. A radial piston pump consists of pistons located parallel to the pump shaft.

16. Radial piston pumps can be classified as cam or rotating piston pumps.

17. All hydraulic pumps have nameplates affixed to them.

18. The length of the piston is the main determinant to the amount of gpm that an axial piston pump can produce.

19. Gear pumps are ideal for equipment that operates in dirty environments.

20. A bent-axis piston pump can operate at pressures above 10,000 psi.

21. The rotor of a variable-displacement, pressure-compensated, vane pump is centered with a crescent seal.

22. All gear pumps are fixed-displacement pumps.

23. Unbalanced vane pumps have the simplest design of the various types of vane pumps.

24. Gerotor pumps are used for high-pressure applications of greater than 1000 psi.

25. Positive-displacement pumps are typically classified as fixed or variable.
MATCHING

Cartridge Assemblies

1. Back end plate
2. Cam ring
3. Front end plate
4. Slotted rotor
5. Vane

Schematic Symbols

1. Hydraulic pump—bidirectional flow—fixed-displacement
2. Hydraulic pump—bidirectional flow with case drain—variable-displacement
3. Electric motor
4. Double-acting cylinder
5. Hydraulic pump, unidirectional flow
6. Internal combustion engine
7. Hydraulic pump—unidirectional flow—fixed-displacement
8. Hydraulic pump—unidirectional flow with case drain—variable-displacement
9. Hydraulic pump—unidirectional flow with case drain—variable-displacement, pressure compensated
**Gear Pumps**

1. External
2. Gerotor
3. Internal
4. Lobe

**Balanced Vane Pumps**

1. Elliptical cam ring
2. Port plate
3. Port plate inlet port
4. Port plate outlet port
5. Pump housing inlet port
6. Pump housing outlet port
7. Rotor
8. Vane

**SHORT ANSWER**

1. List and describe the four main pump ratings.
Activity 4-1: Pump Identification Information

A technician must be able to use a pump nameplate to identify the specific information of different pump parts. The hydraulic pump on a mobile hydraulic system has failed. The company that manufactured the pump no longer exists, but the original operator’s manual is available.

1. List the pump description required for ordering a replacement pump for the existing pump GE-PP-F-CC-07-KY-A2-T.
Activity 4-2: Vane Pump Repair

A vane pump used in a hydraulic press has failed. The rotor has been damaged from contaminated hydraulic fluid and must be replaced.

I. Using the parts assembly diagram, list the steps required to disassemble the pump and replace the damaged rotor.
Activity 4-3: Vane Pump Cartridge Analysis

Below is a chart for two vane pump cartridges commonly used in industrial applications. Both vane pumps were tested to see how much fluid flow each produced at specific pressures under standard conditions. The standard conditions for both vane pump cartridges are 150 Saybolt Universal Seconds (SUS) hydraulic fluid at 120°F.

Use the Vane Pump Cartridge Analysis chart and information from the chapter to answer the following questions:

1. If the pump with cartridge A installed is operating at 1000 psi and the prime mover is rotating at 1200 rpm, what should a flow meter read if installed within 6′ of the pump discharge?

2. If the pump with cartridge A installed is operating at 2300 psi and the prime mover is turning at 1700 rpm, what should a flow meter read if installed within 6′ of the pump discharge?

3. If the pump with cartridge B installed is operating at 2000 psi and the prime mover is rotating at 1100 rpm, what should a flow meter read if installed within 6′ of the pump discharge?

4. If the pump with cartridge B installed is operating at 3000 psi and the prime mover is rotating at 1400 rpm, what should a flow meter read if installed within 6′ of the pump discharge?

5. If the pump with cartridge A installed is operating at 1000 psi, the prime mover is rotating at 1700 rpm, and the flow meter reads 13.5 gpm, what is the volumetric efficiency of the pump?

6. The pump with cartridge A installed is operating at 2300 psi, the prime mover is rotating at 1600 rpm, and the cartridge is 2.01 cu in. Place a mark on the chart where that should be represented.
**Activity 4-4: Pump Analysis**

Refer to Hydraulic System to answer the following questions.

1. The pump displacement in Hydraulic System is rated at 2.56 cu. in. and is rotating at 1200 rpm. If flow meter FM1 shows a reading of 12.25 gpm, what is the pump efficiency of the pump to FM1?

2. The pump displacement in Hydraulic System is rated at 1.34 cu. in. and is rotating at 1000 rpm. If flow meter FM2 shows a reading 5.2 gpm what is the pump efficiency of the pump to FM2?

3. The pump displacement in Hydraulic System is rated at 1.34 cu. in. and is rotating at 1000 rpm. If flow meter FM3 shows a reading 4.2 gpm what is the pump efficiency of the pump to FM3?

4. What is the difference in pump efficiency between FM2 and FM3?

5. List at least two possible reasons for the difference in flow from FM2 and FM3.
6. The technician responsible for inspecting Hydraulic System notices that the pump efficiency is down 12% at each flow meter. List at least five possible reasons for lower pump efficiency. Note: Assume that the system could possibly be damaged.
Activity 4-5: Pump Flow Rate

A hydraulic press needs to have the flow rate of its pump adjusted from 0.45 gpm to 4.98 gpm. Review the schematic diagram from Hydraulic Press System.

1. Use FluidSIM® to build the same schematic diagram to have a flow rate of 0.45 gpm from the pump and observe the system operation.

2. Use FluidSIM® to build the same schematic diagram to have a flow rate of 4.98 gpm from the pump and observe the system operation.

3. What was the outcome of changing the flow rate of the pump?

4. List two different methods for changing the flow rate of a pump.