Lesson 3: Hydraulic Pumps and Motors

Basic Hydraulic Systems

- Hydraulic Tank
- Hydraulic Fluids
- **Hydraulic Pumps and Motors**
- Pressure Control Valves
- Directional Control Valves
- Flow Control Valves
- Cylinders

Fig. 3.3.0

Introduction

Pumps and motors are similar in construction but different in operational characteristics. Therefore, most of the material in this lesson will concentrate on the nomenclature and operation of pumps.

Objectives

Upon completion of this lesson, the student will be able to:

1. State the differences between non-positive and positive displacement pumps;
2. State the differences between fixed displacement and variable displacement pumps;
3. State the operation of different types of pumps;
4. State the similarity and differences between pumps and motors; and
5. State how pumps are rated.

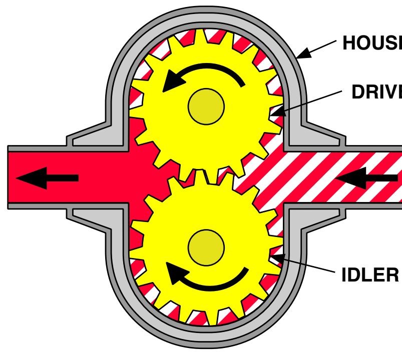


Fig. 3.3.1 Gear Pump

Hydraulic Pump

The hydraulic pump transfers mechanical energy into hydraulic energy. It is a device that takes energy from one source (i.e. engine, electric motor, etc.) and transfers that energy into a hydraulic form. The pump takes oil from a storage container (i.e. tank) and pushes it into a hydraulic system as flow.

All pumps produce oil flow in the same way. A vacuum is created at the pump inlet. The higher atmospheric or tank pressure pushes the oil through the inlet passage and into the pump inlet chambers. The pump gears carry the oil to the pump outlet chamber. The volume of the chamber decreases as the chamber approaches the outlet. This decrease in chamber size pushes the oil out the outlet.

Pumps produce only the flow (i.e. gallons per minute, liters per minute, cubic centimeters per revolution, etc.) used in the hydraulic system. Pumps DO NOT produce or cause "pressure". Pressure is caused by the resistance to the flow. Resistance can be caused by flow through hoses, orifices, fittings, cylinders, motors, or anything in the system that hinders free flow to the tank.

Pumps can be classified into two types: Non-positive displacement and positive displacement.

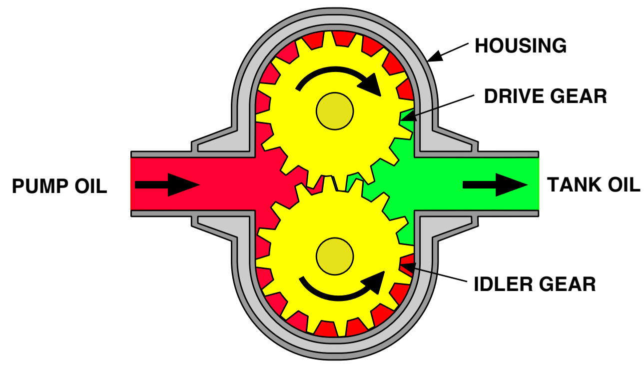


Fig. 3.3.2 Gear Motor

Hydraulic Motor

The hydraulic motor transfers hydraulic energy into mechanical energy. It uses the oil flow being pushed into the hydraulic system by a pump and transfers it into a rotary motion to drive another device (i.e. final drives, differential, transmission, wheel, fan, another pump, etc.).

Non-Positive Displacement Pumps

Non-positive displacement pumps have more clearances between the moving and stationary parts than positive displacement pumps. The extra clearance allows more oil to be pushed back between the parts as the outlet pressure (resistance to flow) increases. Non-positive displacement pumps are less efficient than positive displacement pumps because the output flow of the pump decreases greatly as the outlet pressure increases. Non-positive displacement pumps are generally either centrifugal impeller type or axial propeller type. These are used in low pressure applications such as automotive water pumps or charge pumps for piston pumps in high pressure hydraulic systems.

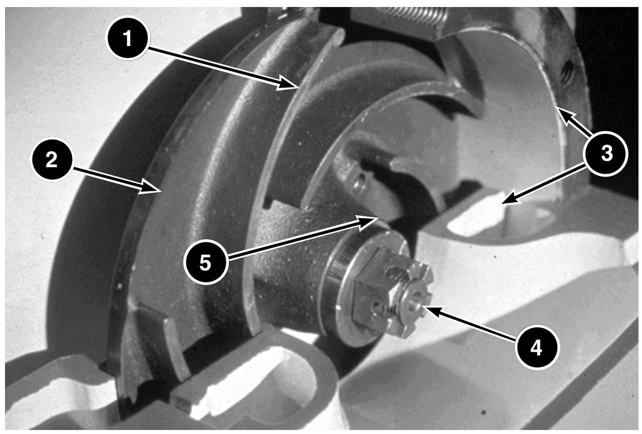


Fig. 3.3.3 Centrifugal Pump

Centrifugal Impeller Pump

The centrifugal impeller pump consists of two basic parts; the impeller (2) that is mounted on an input shaft (4) and the housing (3). The impeller has a solid disc back with curved blades (1) molded on the input side.

Oil enters the center of the housing (5) near the input shaft and flows into the impeller. The curved impeller blades propel the oil outward against the housing. The housing is shaped to direct the oil to the outlet port.

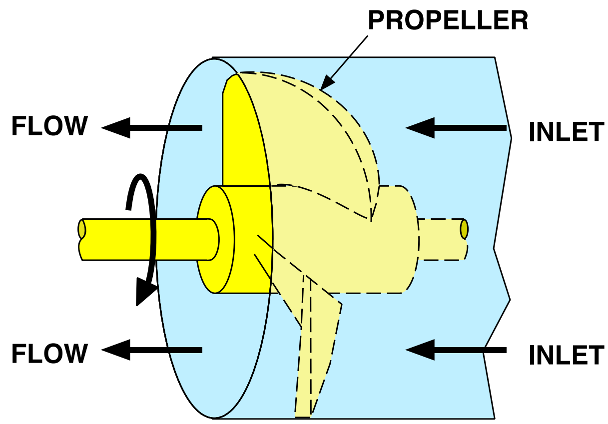


Fig. 3.3.4 Axial Propeller Pump

Axial Propeller Pump

The axial propeller type pump is shaped like an electric air fan. It is mounted in a straight tube and has an open bladed propeller. Oil is propelled down the tube by the rotation of the angled blades.

Positive Displacement Pumps

There are three basic types of positive displacement pumps: gear, vane and piston. Positive displacement pumps have much smaller clearances between components. This reduces leakage and provides a much higher efficiency when used in a high pressure hydraulic system. The output flow in a positive displacement pump is basically the same for each pump revolution. Positive displacement pumps are classified by both the control of their output flow and the construction of the pump.

Positive displacement pumps are rated two ways. One is by the maximum system pressure (i.e. 21,000 kPa or 3000 psi) at which the pump is designed to operate. The second is by the specific output delivered either per revolution or at a given speed against a specified pressure. The pumps are rated either by lpm @ rpm@ kPa or by gpm @ rpm @ psi (i.e. 380 lpm @ 2000 rpm @ 690 kPa or 100 gpm @ 2000 rpm @ 100 psi).

When expressed in output per revolution, the flow rate can be easily converted by multiplying by the speed in rpm (i.e.: 2000 rpm) and dividing by a constant. For example, we will calculate the flow of a pump that rotates 2000 rpm and has a flow of 11.55 in^3/rev or 190 cc/rev.

$$GPM = \frac{in^3/rev \times rpm}{231} \qquad LPM = \frac{cc/rev \times rpm}{1000}$$

$$GPM = \frac{11.55 \times 2000}{231} \qquad LPM = \frac{190 \times 2000}{1000}$$

$$GPM = 100 \qquad LPM = 380$$

Volumetric Efficiency

As pressure increases, the close clearances between the parts in a positive displacement pump do not produce the same output flow as input flow. Some oil will be forced back through the clearances between the high pressure chamber and the low pressure chamber. The resultant output flow, when compared to the input flow, is called "volumetric efficiency". (Input flow is generally defined as the "output flow @ 100 psi".) "Volumetric efficiency" changes as pressure changes and must be specified for a given pressure. When a pump that is rated at 100 gpm @ 2000 rpm @ 100 psi is operated against 1000 psi, its output may drop to 97 gpm. This pump would have a "volumetric efficiency" of 97% (97/100) @ 1000 psi.

$$\text{Volumetric efficiency @ 1000 psi} = \frac{\text{output flow}}{\text{input flow}}$$

$$\text{Volumetric efficiency @ 1000 psi} = \frac{97}{100}$$

Volumetric efficiency @ 1000 psi = .97 or 97% efficient at 1000 psi

When the pressure increases to 2000 psi, the output may drop to 95 gpm. It would then have a "volumetric efficiency" of .95 or 95% @ 2000 psi. The rpm must remain constant when measuring "volumetric efficiency".

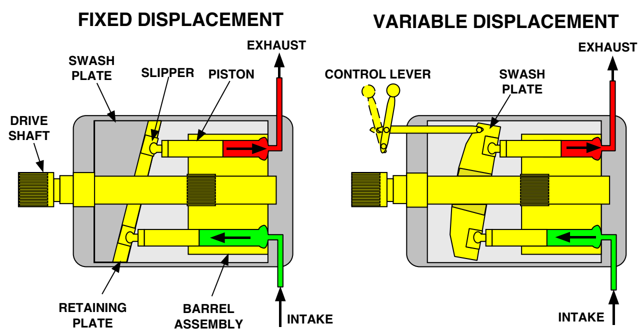


Fig. 3.3.5 Piston Pumps

Fixed Displacement Versus Variable Displacement

The output flow of a fixed displacement pump is only changed by varying the speed of the pump rotation. It must be rotated faster to increase the flow or rotated slower to decrease the flow. The gear type pump is a fixed displacement pump.

The vane type and piston type pumps may be fixed or variable. The output flow from a variable displacement pump may be increased or decreased independent of the speed of rotation. The output flow may be manual controlled, automatic controlled or a combination of manual and automatic controlled.

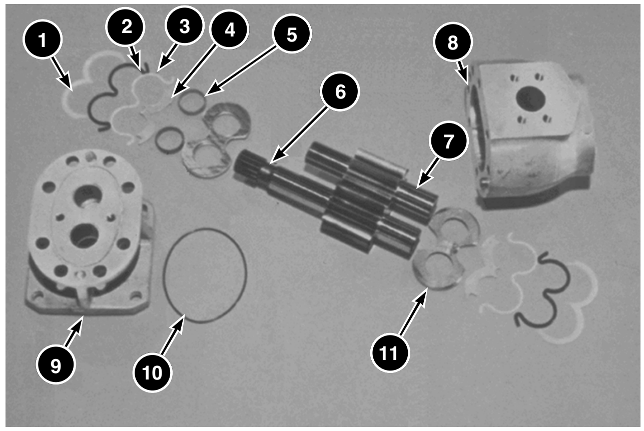


Fig. 3.3.6 Gear Pump

Gear Pumps

The gear pump consists of seal retainers (1), seals (2), seal back-ups (3), isolation plates (4), spacers (5), a drive gear (6), an idler gear (7), a housing (8), a mounting flange (9), a flange seal (10) and pressure balance plates (11) on either side of the gears. Bearings are mounted in the housing and mounting flange on the sides of the gears to support the gear shafts during rotation.

Gear pumps are positive displacement pumps. They deliver the same amount of oil for each revolution of the input shaft. The pump output is controlled by changing the speed of rotation. The maximum operating pressure for gear pumps is limited to 4000 psi. This pressure limitation is due to the hydraulic imbalance that is inherent in the gear pump design. The hydraulic imbalance produces a side load on the shafts that is resisted by the bearings and the gear teeth to housing contact. The gear pump maintains a "volumetric efficiency" above 90% when pressure is kept within the designed operating pressure range.

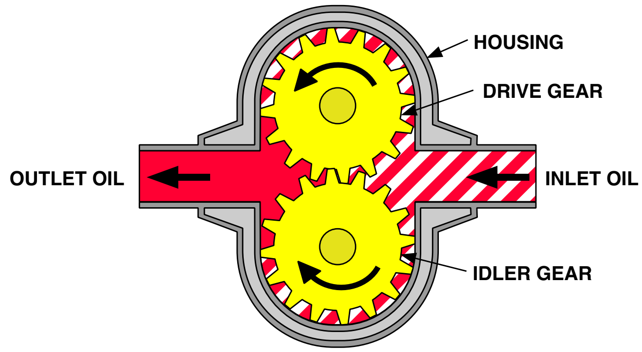


Fig. 3.3.7 Gear Pump Flow

Gear Pump Flow

The output flow of the gear pump is determined by the tooth depth and gear width. Most gear pump manufacturers standardized on a tooth depth and profile that is determined by the centerline distance (1.6", 2.0", 2.5", 3.0", etc.) between gear shafts. With standardized tooth depths and profiles, the flow differences within each centerline classification of pump is determined by the tooth width.

As the pump rotates, the oil is carried between the gear teeth and the housing from the inlet side to the outlet side of the pump. The direction of rotation of the drive gear shaft is determined by the location of the inlet and outlet ports. The direction of rotation of the drive gear will always be to move the oil around the outside of the gears from the inlet port to the outlet port. This is true on both gear pumps and gear motors. On most gear pumps the inlet port is larger in diameter than the outlet port. On bi-directional pumps and motors, the inlet port and outlet port will be the same size.

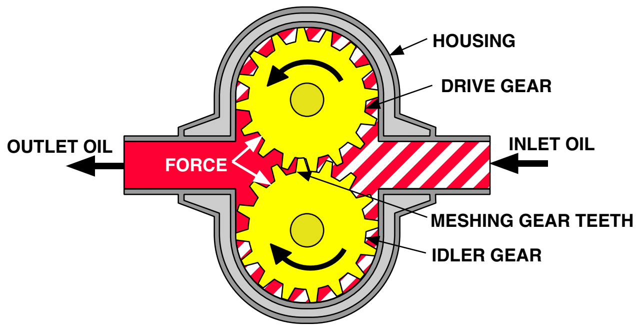


Fig. 3.3.8 Gear Pump Forces

Gear Pump Forces

The outlet flow from a gear pump is created by pushing the oil out of the gear teeth as they come into mesh on the outlet side. The resistance to oil flow creates the outlet pressure. The imbalance of the gear pump is due to outlet port pressure being higher than inlet port pressure. The higher pressure oil pushes the gears toward the inlet port side of the housing. The shaft bearings carry the majority of the side load to prevent excessive wear between the tooth tips and the housing. On the higher pressure pumps, the gear shafts are slightly tapered from the outboard end of the bearings to the gear. This allows full contact between the shaft and bearing as the shaft bends slightly under the pressure.

The pressurized oil is also directed between the sealed area of the pressure balance plates and the housing and mounting flange to seal the ends of the gear teeth. The size of the sealed area between the pressure balanced plates and the housing is what limits the amount of force that pushes the plates against the ends of the gears.

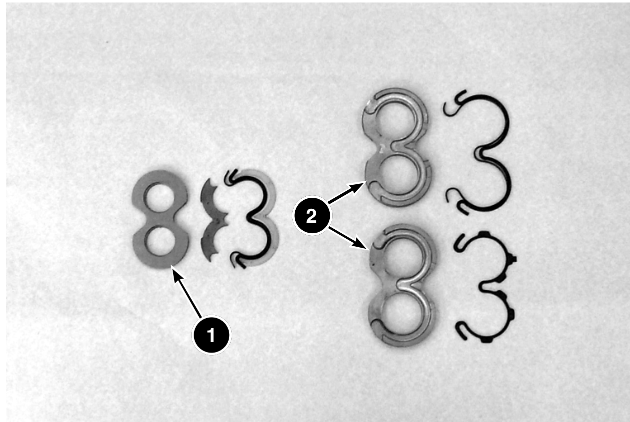


Fig. 3.3.9 Pressure Balance Plates

Pressure Balance Plates

There are two different types of pressure balance plates used in gear pumps. The earlier type (1) has a flat back. This type uses an isolation plate, a back-up for the seal, a seal shaped like a 3 and a seal retainer. The later type (2) has a groove shaped like a 3 cut into the back and is thicker than the earlier type. Two different types of seals are used with the later type of pressure balance plates.

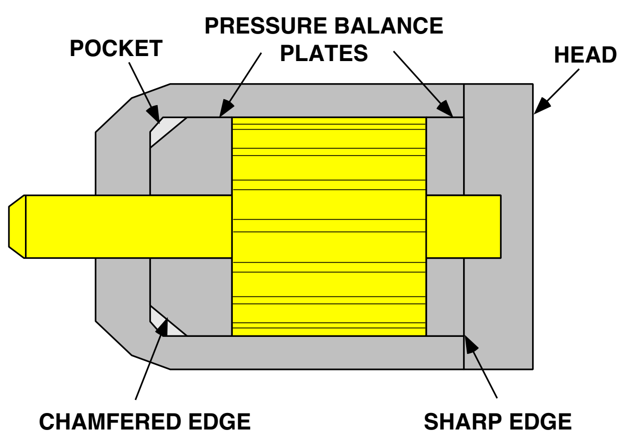


Fig. 3.3.10 Gear Pumps With Pocket

Gear Pumps with Pockets

Gear pumps with a housing that is machined with pockets for the gears have a radius from the pocket walls to the bottom of the pockets. The isolation plate or the later pressure balanced plate used in the pocket must have chamfered or curved outer edges to fit fully against the bottom of the pocket. Using a sharp edge isolation plate, a sharp edge seal retainer or a sharp edge pressure balance plate in a housing pocket will force the pressure balance plates against the ends of the gears and cause a failure.

Vane Pumps

Vane pumps are positive displacement pumps. The pump output can be either fixed or variable.

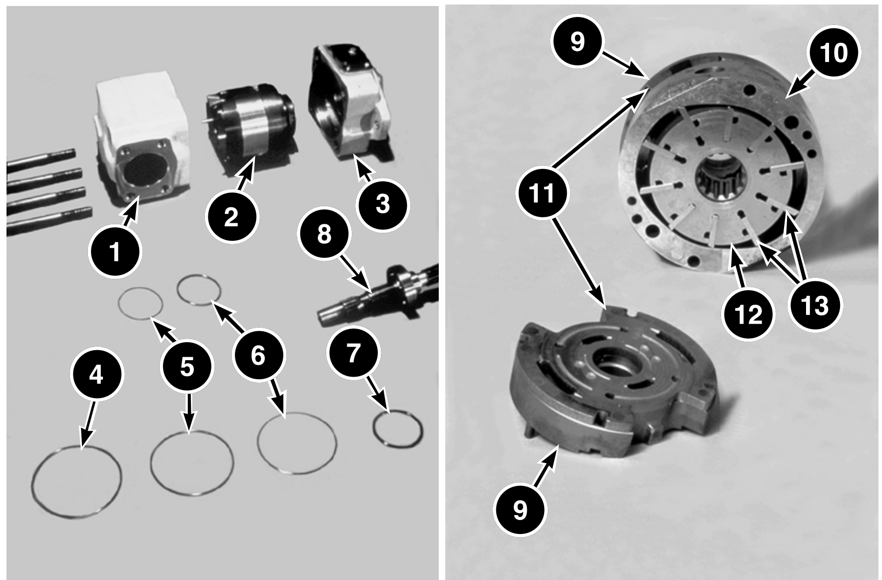


Fig. 3.3.11 Vane Pump

Both the fixed and variable vane pumps use common part nomenclature. Each pump consists of the housing (1), the cartridge (2), the mounting plate (3), the mounting plate seal (4), the cartridge seals (5), the cartridge backup rings (6), the snap ring (7) and the input shaft and bearing (8). The cartridge consists of the support plates (9) the ring (10), the flex plates (11), the slotted rotor (12) and the vanes (13).

The slotted rotor is turned by the input shaft. The vanes move in and out of the slots in the rotor and seal on the outer tips against the cam ring. The inside of the fixed pump displacement ring is elliptical in shape. The inside of the variable pump displacement ring is round in shape. The flex plates seal the sides of the rotor and the ends of the vanes. In some lower pressure designs, the support plates and housing seal the sides of the rotating rotor and the ends of the vanes. The support plates are used to direct the oil into the proper passages in the housing. The housing, in addition to providing support for the other parts of the vane pump, directs the flow in and out of the vane pump.

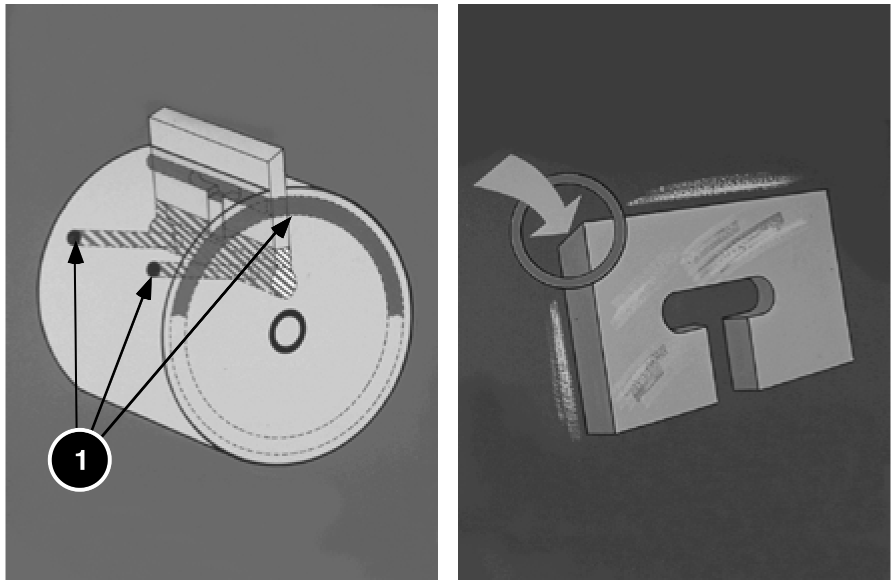


Fig. 3.3.12 Vane Pressurization

Vanes

The vanes are initially held against the cam ring by centrifugal force created by the rotation of the rotor. As flow increases, the resultant pressure that builds from the resistance to that flow is directed into passages in the rotor beneath the vanes (1). This pressurized oil beneath the vanes keep the vane tips pushed against the cam ring to form a seal. To prevent the vanes from being pushed too hard against the cam ring, the vanes are beveled back (arrow) to permit a balancing pressure across the outer end.

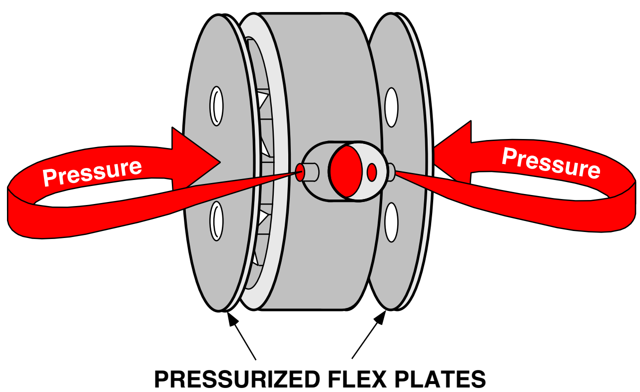


Fig. 3.3.13 Pressurized Flex Plates

Flex Plates

The same pressurized oil is also directed between the flex plates and the support plates to seal the sides of the rotor and the end of the vanes. The size of the seal area between the flex plate and the support plates is what controls the force that pushes the flex plates against the sides of the rotor and the end of the vanes. The kidney shaped seals must be installed in the support plates with the rounded o-ring side into the pocket and the flat plastic side against the flex plate.

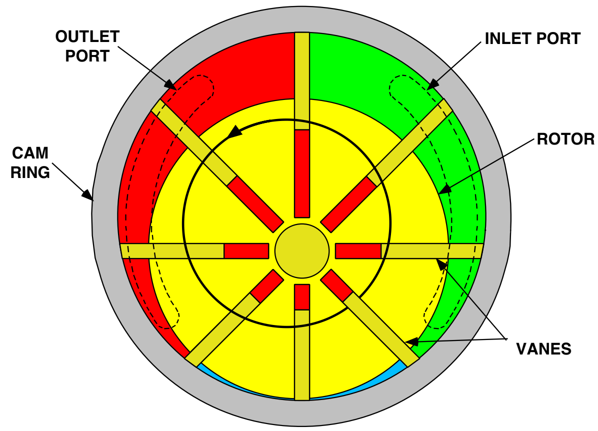


Fig. 3.3.14 Vane Pump Operation

Vane Pump Operation

When the rotor rotates around the inside of the cam ring, the vanes slide in and out of the rotor slots to maintain the seal against the cam ring. As the vanes move out of the slotted rotor, the volume between the vanes changes. An increase in the distance between the cam ring and the rotor causes an increase in the volume. The increase in volume creates a slight vacuum that allows the inlet oil to be pushed into the space between the vanes by atmospheric or tank pressure. As the rotor continues to rotate, a decrease in the distance between the ring and the rotor causes a decrease in the volume. The oil is pushed out of that segment of the rotor into the outlet passage of the pump.

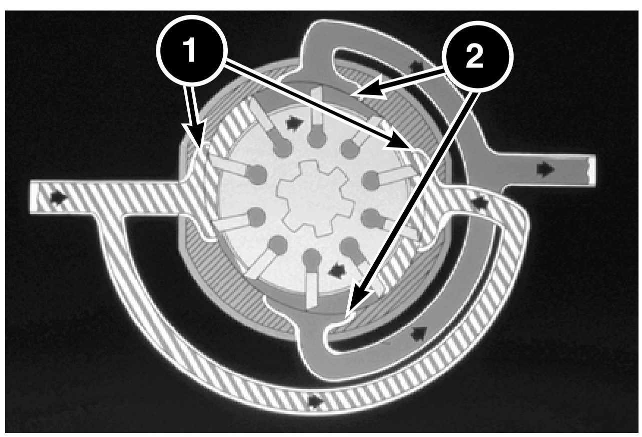


Fig. 3.3.15 Balanced Vane Pump

Balanced Vane Pump

The balanced vane pump has an elliptical shaped cam ring. This shape results in the distance between the rotor and the cam ring increasing and decreasing twice for each revolution. The two inlets (1) and two outlets (2) opposite each other balance the forces against the rotor. This design does not require large bearings and housings to support the rotating parts. The maximum operating pressure for vane pumps is 4000 psi. Vane pumps used in mobile hydraulics have a maximum operating pressure of 3300 psi, or less.

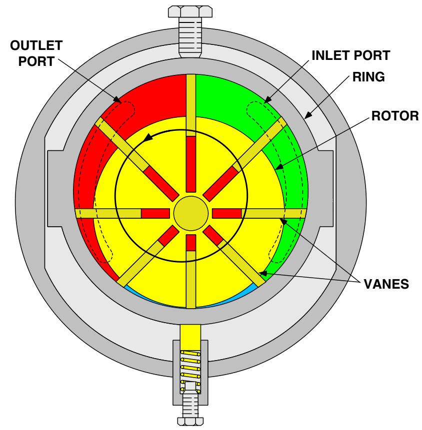


Fig. 3.3.16 Variable Vane Pump

Variable Vane Pump

Variable output vane pumps are controlled by shifting a round ring back and forth in relation to the rotor centerline. Variable output vane pumps are seldom, if ever, used in mobile hydraulic applications.

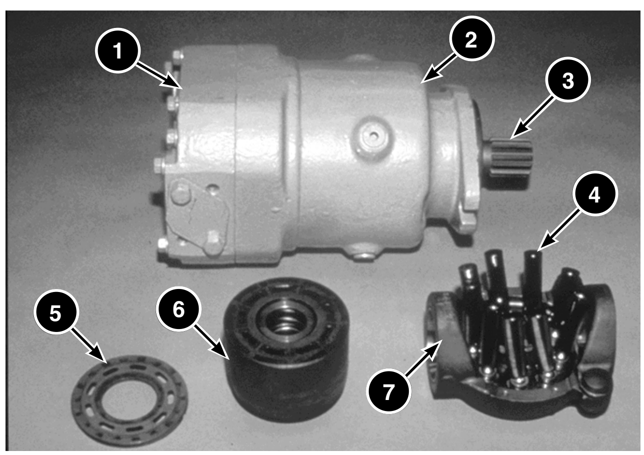


Fig. 3.3.17 Common Parts

Piston Pumps

Most piston pumps and motors have similar or common parts and use the same nomenclature. The pump parts in Figure 3.3.17 are the head (1), the housing (2), the shaft (3), the pistons (4), the port plate (5), the barrel (6) and the swashplate (7).

The two designs of piston pumps are the axial piston pump and the radial piston pump. Both pumps are highly efficient, positive displacement pumps. However, the output of some pumps are fixed and the output of some pumps are variable.

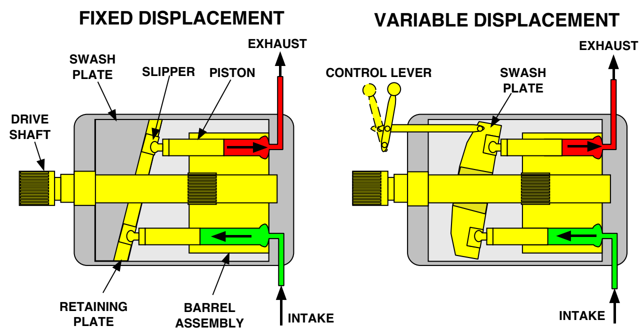


Fig. 3.3.18 Common Parts

Axial Piston Pumps and Motors

The fixed displacement axial piston pumps and motors are built in a straight housing or in an angled housing. The basic operation of piston pumps and motors are the same.

Straight Housing Axial Piston Pumps and motors

Figure 3.3.18 shows an illustration of the positive displacement fixed output axial piston pump and the positive displacement variable output axial piston pump. In most publications the fact that both pumps are positive displacement is considered to be understood and the pumps are refered to as fixed displacement pumps and variable displacement pumps.

In the fixed displacement axial piston pumps, the pistons move backward and forward in a line that is near parallel to the centerline of the shaft.

In the straight housing piston pump shown in the left illustration of Figure 3.3.18, the pistons are held against a fixed, wedge-shaped swashplate. The angle of the swashplate controls the distance the pistons move in and out of the barrel chambers. The larger the angle of the wedge-shaped swashplate, the greater the distance of piston movement and the greater the pump output per revolution.

In the variable displacement axial piston pump, either the swashplate or the barrel and port plate may pivot back and forth to change its angle to the shaft. The changing angle causes the output flow to vary between the minimum and maximum settings although the shaft speed is held constant.

On either pump, when a piston moves backward, oil flows through the intake and fills the space left by the piston movement. As the pump rotates, the piston moves forward, the oil is pushed out through the exhaust and into the system.

Most piston pumps used on mobile equipment are axial piston pumps.

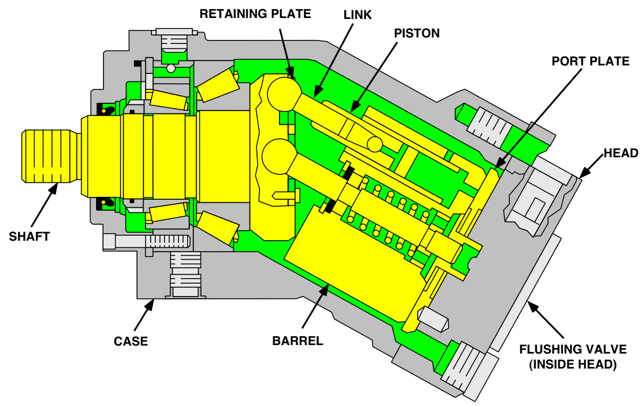


Fig. 3.3.19 Angled Housing Axial Piston Motor

Angled Housing Axial Piston Pump

In the angled housing piston pump shown in Figure 3.3.19, the pistons are connected to the input shaft by piston links or spherical piston ends that fit into sockets in a plate. The plate is an integral part of the shaft. The angle of the housing to the shaft centerline controls the distance the pistons move in and out of the barrel chambers. The larger the angle of the housing, the greater the pump output per revolution.

The output flow of a fixed displacement piston pump can only be changed by changing the input shaft speed.

Straight and Angle Housing Piston Motors

In the straight housing fixed displacement piston motor, the angle of the wedge-shaped swashplate determines the speed of the motor output shaft.

In the angle housing fixed displacement piston motor, the angle of the housing to the shaft centerline determines the speed of the motor output shaft.

In both motors, the output shaft speed can only be changed by changing the input flow to the motor.

Some smaller piston pumps are designed for pressures of 10000 psi or more. Piston pumps used in mobile equipment are designed for a maximum pressure of 7000 psi or less.

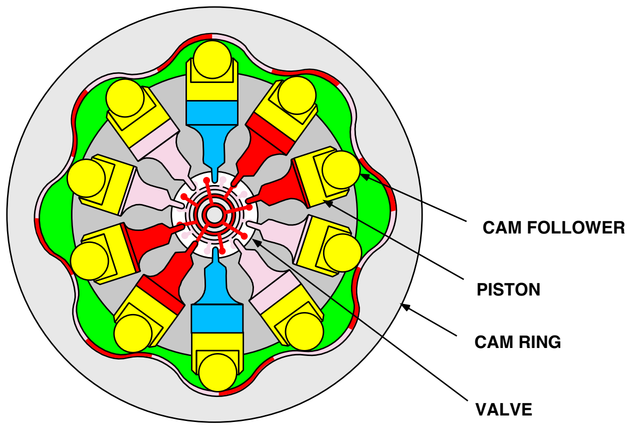


Fig. 3.3.20 Radial Piston Pump

Radial Piston Pump

In the radial piston pump Figure 3.3.20, the pistons moves outward and inward in a line that is 90 degrees to the centerline of the shaft.

When the cam follower rolls down the cam ring, the piston moves outward. Atmospheric pressure or a charge pump pushes oil through the valve inlet port and fills the space left by the piston movement. When the cam follower rolls up the cam ring, the piston moves inward. Oil is pushed out of the cylinder and through the outlet port.

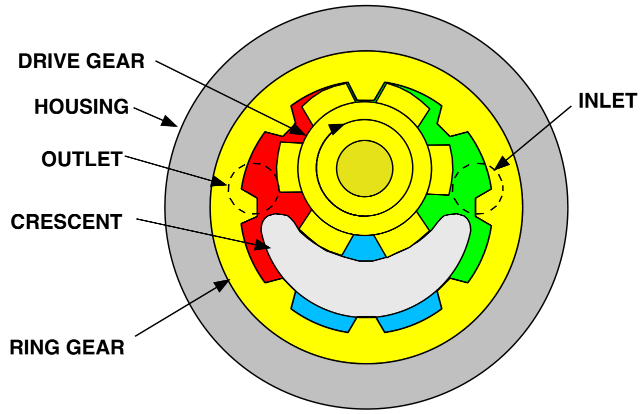


Fig. 3.3.21

Internal Gear Pump

The internal gear pump (Figure 3.3.21) has a small drive gear (pinion gear) that drives a large ring gear (outer gear). The ring gear is slightly larger in pitch than the drive gear. A stationary crescent is located below the pinion gear between the drive gear and the ring gear. The inlet and outlet ports are located at either end of the crescent.

When the pump rotates, the teeth of the drive gear and the ring gear unmesh at the pump inlet port. The void between the teeth increases and fills with inlet oil. The oil is carried between the drive gear teeth and the crescent, and the ring gear teeth and the crescent to the outlet port. When the gears pass the outlet port, the void between the teeth decreases and the teeth mesh. This action forces the oil out from between the teeth and into the outlet port.

The internal gear pump is used as the charging pump in some large piston pumps.

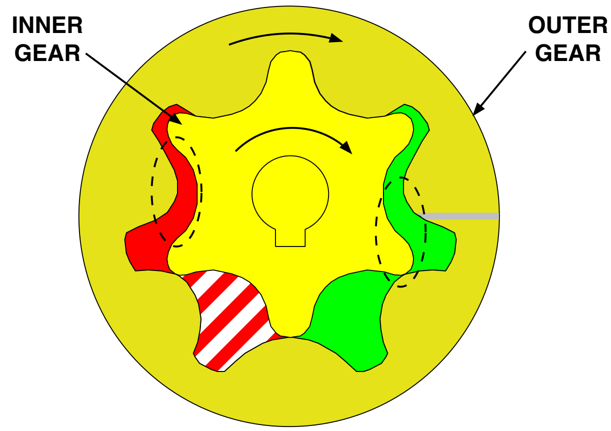


Fig. 3.3.22

Conjugate Curve Pump

The conjugate curve pump (Figure 3.3.22) is also called a GEROTOR™ pump. The inner and outer members rotate within the pump housing. Pumping is achieved by the way the lobes on the inner and the outer member contact each other during rotation. As the inner and outer members rotate, the inner member walks around inside the outside member. The inlet and outlet ports are located on the end covers of the housing. The fluid entering through the inlet is carried around to the outlet and squeezed out when the lobes mesh.

A modified conjugate curve pump is used in many steering systems steering control unit (SCU). When used in the SCU, the outer gear is stationary and only the inner gear rotates.

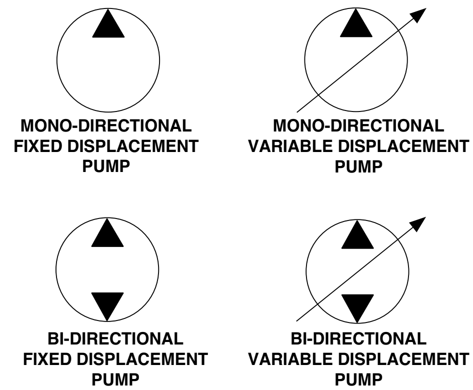


Fig. 3.3.23 Pump ISO Symbols

Pump ISO Symbols

Pump ISO symbols are distinguished by a dark triangle in a circle with the point of the triangle pointing toward the edge of the circle. An arrow across the circle indicates a variable output per revolution.

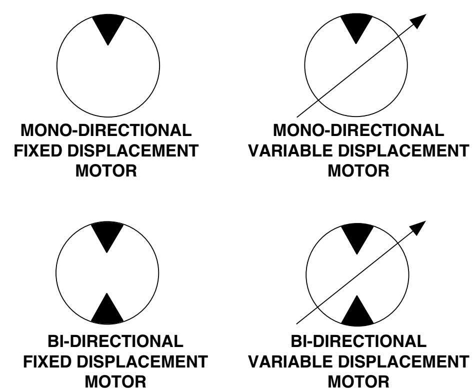


Fig. 3.3.24 Motor ISO Symbols

Motor ISO Symbols

Motor ISO symbols are distinguished by a dark triangle in a circle with the point of the triangle pointing toward the center of the circle. An arrow across the circle indicates a variable input per revolution.

NOTES

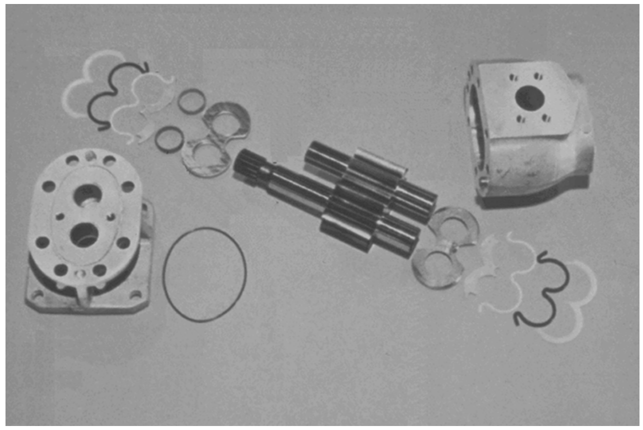


Fig. 3.3.25 Gear Pump

LAB 3.3.1: GEAR PUMP CONSTRUCTION

Purpose

To disassemble and assemble three types of gear pumps and identify and explain components.

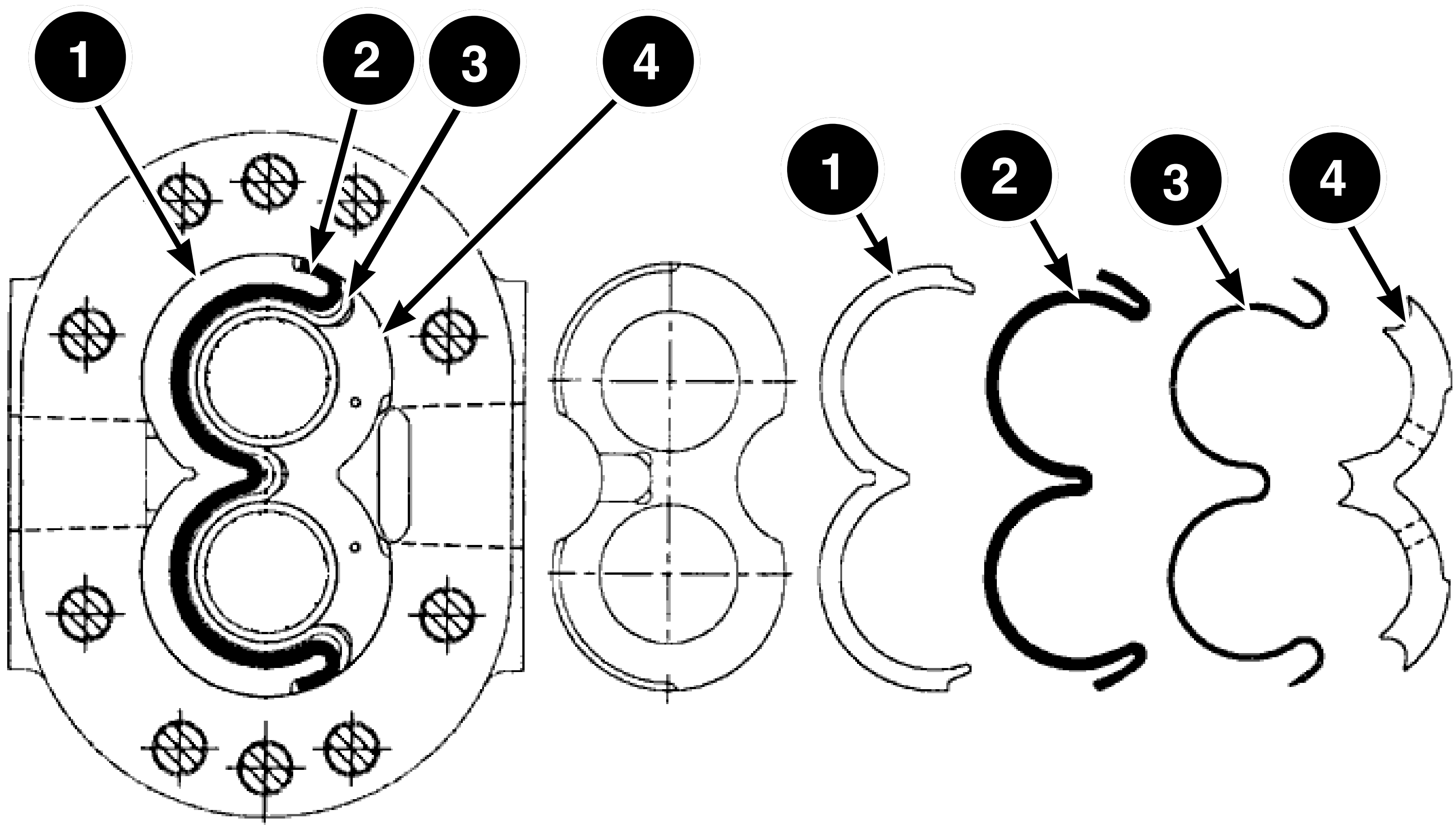
Materials Needed

1. "Diagnosing Tyrone Gear Pump Failures" - (Form No. FEG45137).
2. Gear pump (20 Series) with isolation plate and seals design.
3. Gear pump (16 Series) with aluminum/bronze bearing design.
4. Gear pump (FL7) with pressure balance plates.
5. Two sets of pressure balance plates with different seals.

Procedure

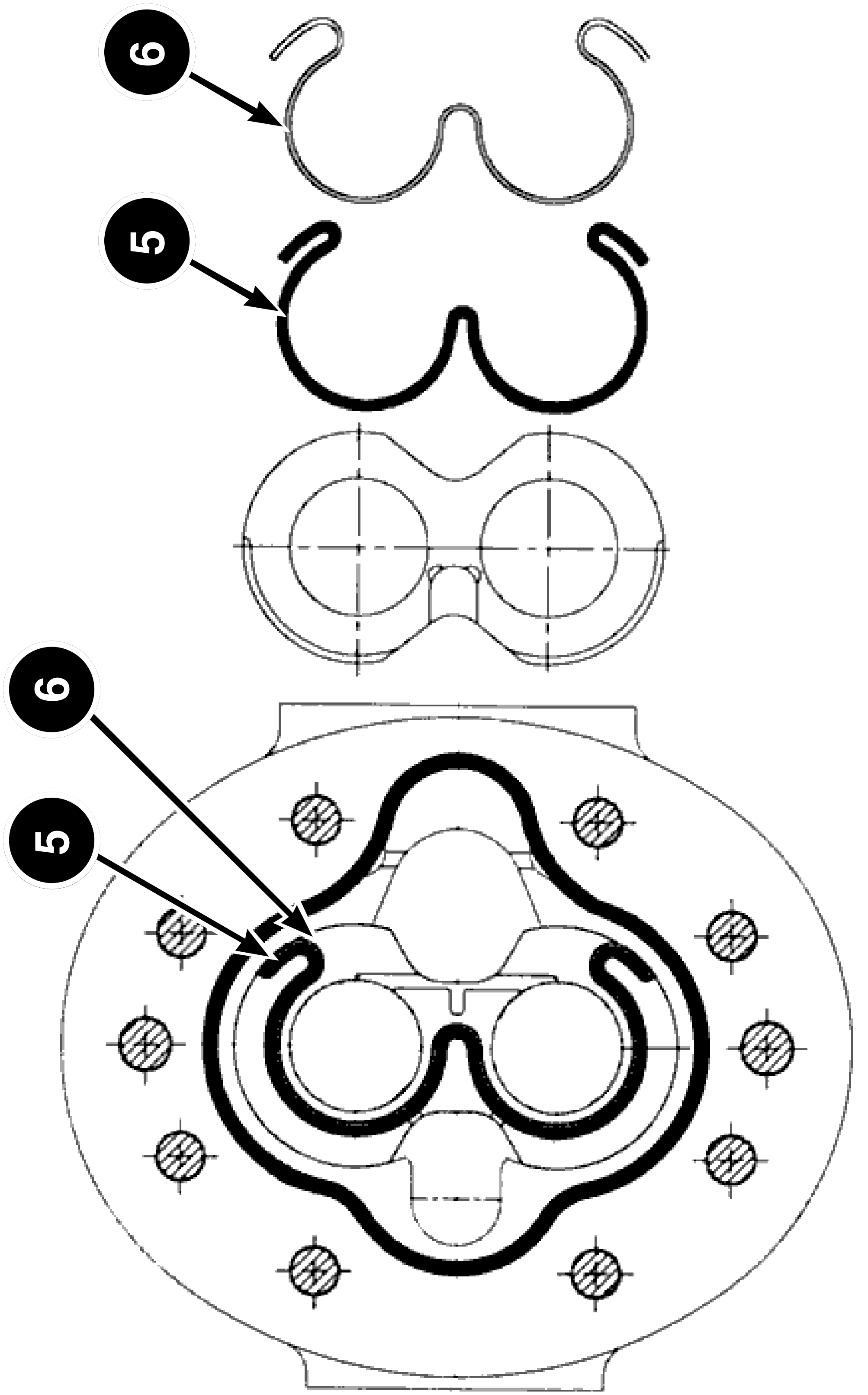
1. Using "Diagnosing Tyrone Gear Pump Failures" - (Form No. FEG45137) page 5, disassemble pumps and identify components for the instructor. Assemble pump when finished.
2. Using attached charts on pages 2, 3 and 4 and the sets of pressure balance plates with different seals, demonstrate the proper assembly of the seals to the instructor.

Earlier Sealing System
Used on 20 Series



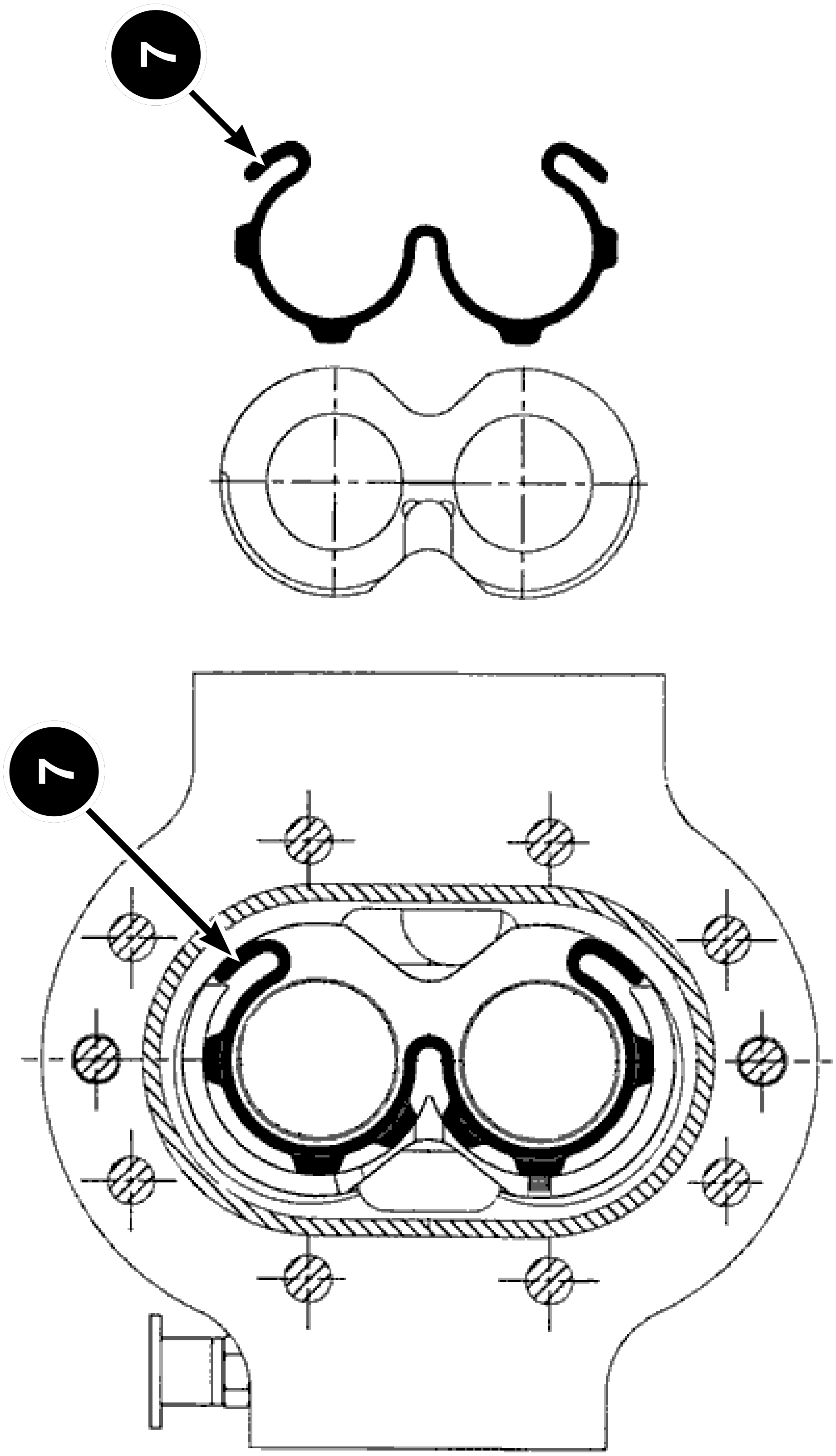
(1) Seal retainer, (2) Seal, (3) Seal backup, (4) Isolation plate

First Rear Grooved - Thicker Pressure Plate Seals Used on FP8



(5) Seal, (6) Seal backup

Later Rear Grooved - Thicker Plate Seals
Used on FL7



(7) Seal

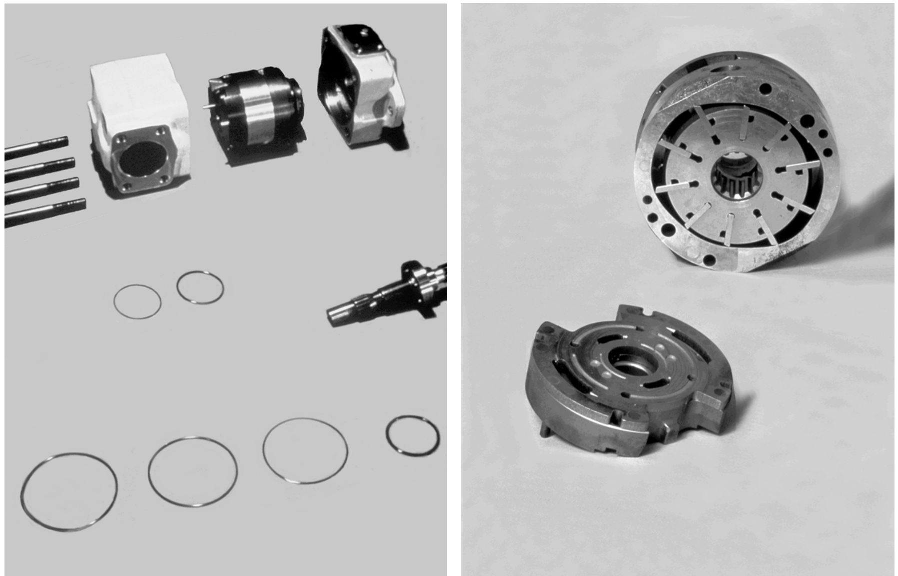


Fig. 3.3.26 Vane Pump

LAB 3.3.2: VANE PUMP CONSTRUCTION

Purpose

To disassemble and assemble three different vane pumps and identify and explain components.

Materials Needed

1. "Diagnosing Hydraulic Pump Failures: (Form No. SEBD0501)
2. "Guidelines for Reusable Parts and Salvage Operation" (Form No. SEBF8080)
3. "Vane Type Hydraulic Pump Identification Guideline" (Form SEHS9353)
4. Vane pump without flex plates.
5. Vane pump (VQ) with flex plate.
6. Vane pump (30 Series) with insert vanes and flex plates

Procedures

1. Using "Diagnosing Hydraulic Pump Failures: (Form No. SEBD0501) - Pages 4 and 5, and "Guidelines for Reusable Parts and Salvage Operation" (Form No. SEBF8080) - Page 5, disassemble and reassemble each pump or cartridge and explain the three different types of construction for the instructor.
2. Using "Guidelines for Reusable Parts and Salvage Operation" (Form No. SEBF8080), page 5, examine rotor, flexplates and seals from VQ or 30 Series pump and explain how pressure loads vanes and flex plates for the instructor.
3. Using ""Diagnosing Hydraulic Pump Failures" (Form No. SEBD0501) - Page 7 and "Vane Type Hydraulic Pump Identification Guidelines" (Form SEHS9353) - Page 4, examine rings for flow rates and demonstrate to the instructor the ability to locate the flow rate in gpm at 1200rpm.

NOTES

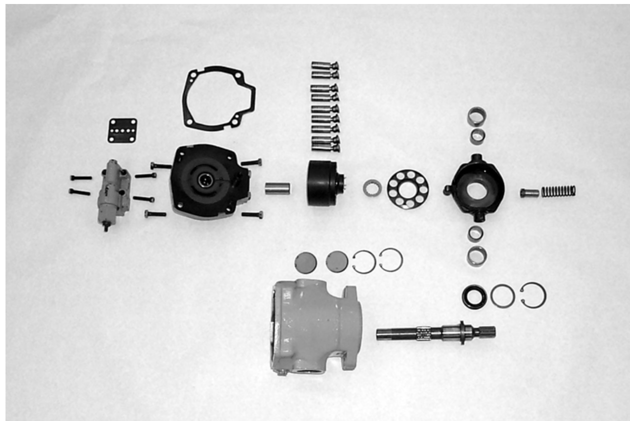


Fig. 3.3.27 Piston Pump Construction

LAB 3.3.3: PISTON PUMP CONSTRUCTION

Purpose

To disassemble and assemble several different piston pumps and identify components and pumps construction.

Materials needed

1. "Piston Pump Assembly Procedures" -- (Form No. SENR5207)
2. "Swing and Track Motor Assembly Procedures" -- (Form No. SENR4939)
3. "Track Motor Assembly Procedure for 973 Track Motor" -- (Form No. SENR4940)
4. "Guideline for Reusable Parts and Salvage Guide" - (Form No. SEBF8133)
5. "Guideline for Reusable Parts" - (Form No. SEBF8136)
6. "Analyzing Axial Piston Pump and Motor Failures" - (Form No. SEBD0641)
7. "Guideline for Reusable Parts and Salvage Operations" - (Form No. SEBF8253)
8. Vickers PVE pump
9. Vickers PVH pump
10. Fixed angle piston pump or motor
11. Over center piston pump (Rexroth or Linde)
12. Piston pump demonstration unit

Procedure

1. Using the appropriate "Reference" from references listed below to match the pumps being used, disassemble each piston pump and identify components for the instructor. Explain differences in construction to the instructor. Assemble pumps when finished.

   References: "Piston Pump Assembly Procedures" - (Form No. SENR5207)
   "Swing and Track Motor Assembly Procedures" - (Form No. SENR4939)
   "Track Motor Assembly Procedure for 973 Track Motor" - (Form No. SENR4940)
   "Guideline for Reusable Parts and Salvage Guide" - (Form No. SEBF8133)
   "Guideline for Reusable Parts" - (Form No. SEBF8136)
   "Analyzing Axial Piston Pump and Motor Failures" - (Form No. SEBD0641)
   "Guideline for Reusable Parts and Salvage Operations" - (Form No. SEBF8253)

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