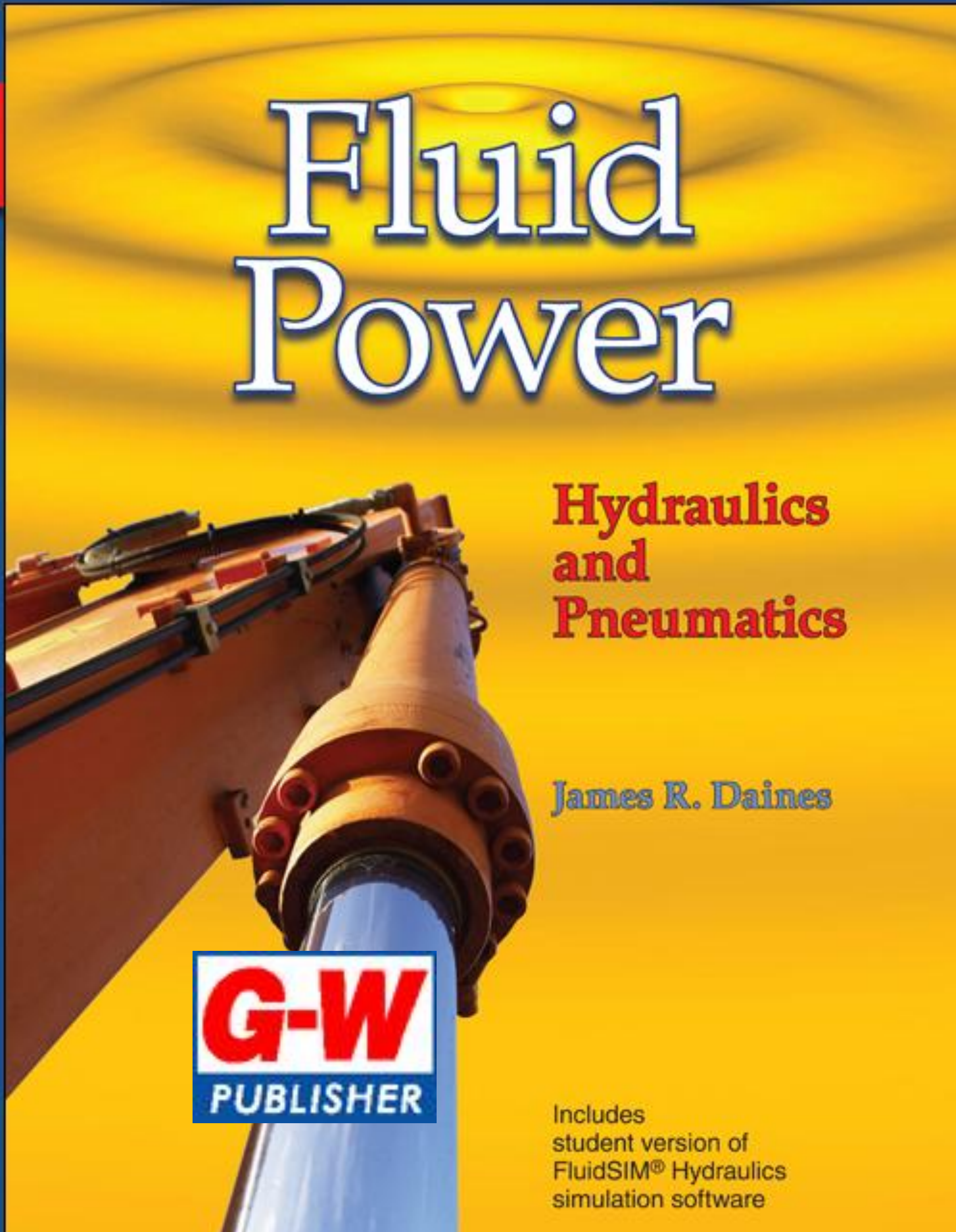


PowerPoint Presentations for

Fluid Power

James R. Daines

The Goodheart-Willcox Co., Inc.
Tinley Park, Illinois

Chapter 7

Source of Hydraulic Power

Power Units and Pumps

Objectives

- Describe the function of a hydraulic power unit and identify its primary components.
- Explain the purpose of a pump in a hydraulic system.
- Explain the operation of a basic hydraulic pump.
- Compare the operating characteristics of positive-displacement and non-positive-displacement hydraulic pumps.

Objectives

- Compare the operating characteristics of rotary and reciprocating hydraulic pumps.
- Compare the operating characteristics of constant- and variable-volume hydraulic pumps.
- Explain the principles involved in the operation of a pressure-compensated hydraulic pump.

Objectives

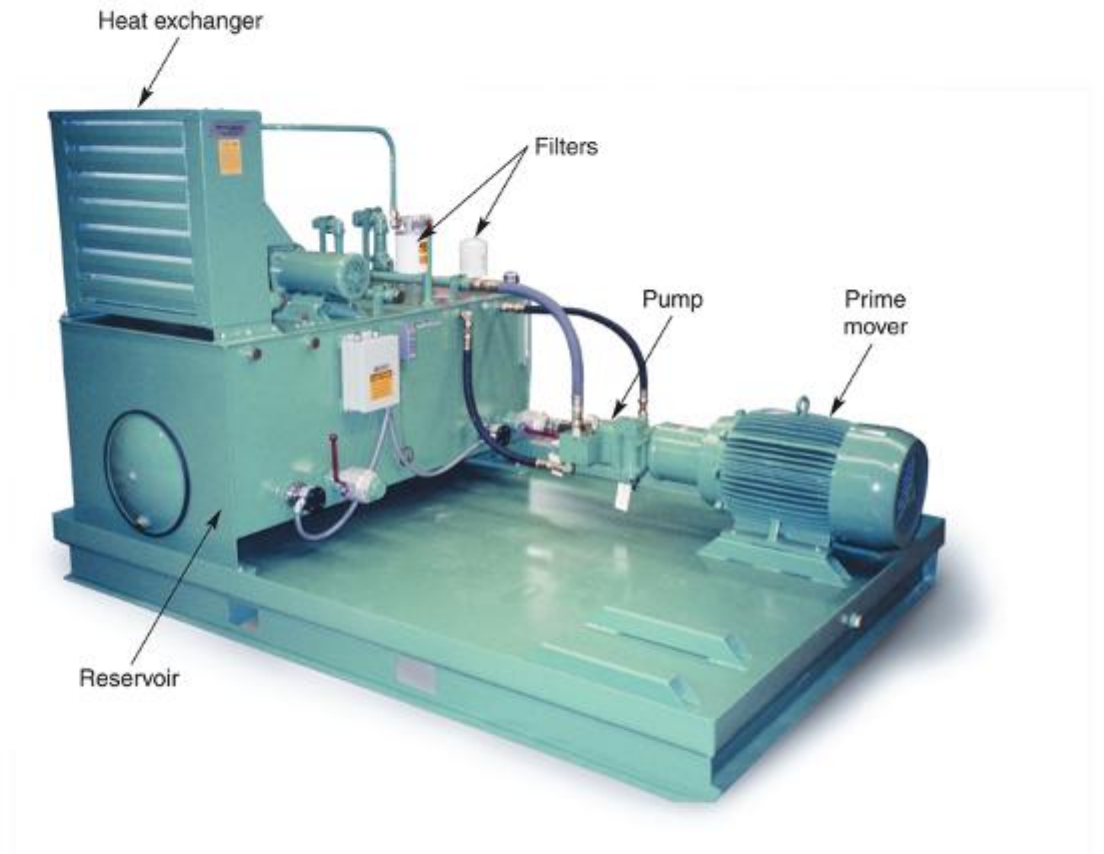
- Describe general construction for each of the various hydraulic pump designs.
- Explain cavitation and its effect on pump performance and service life.
- Interpret performance data supplied by a pump manufacturer.

Power Unit

- The power unit:
  - Provides energy for the operation of the hydraulic system
  - Moves fluid through the system
  - Provides a safe maximum system operating pressure
  - Assists in maintaining correct system operating temperature and fluid cleanliness

Power Unit

- Power units are often supplied by manufacturers as a package



Kim Hotstart Manufacturing Company

Power Unit

- A basic power unit consists of:
  - Prime mover to power the system
  - Pump to move fluid
  - Reservoir to store fluid
  - Relief valve or pump compensator to control maximum system pressure
  - Filter to clean the fluid
  - Plumbing to transport fluid to components

Power Unit

- A prime mover may be an electric motor

Continental Hydraulics

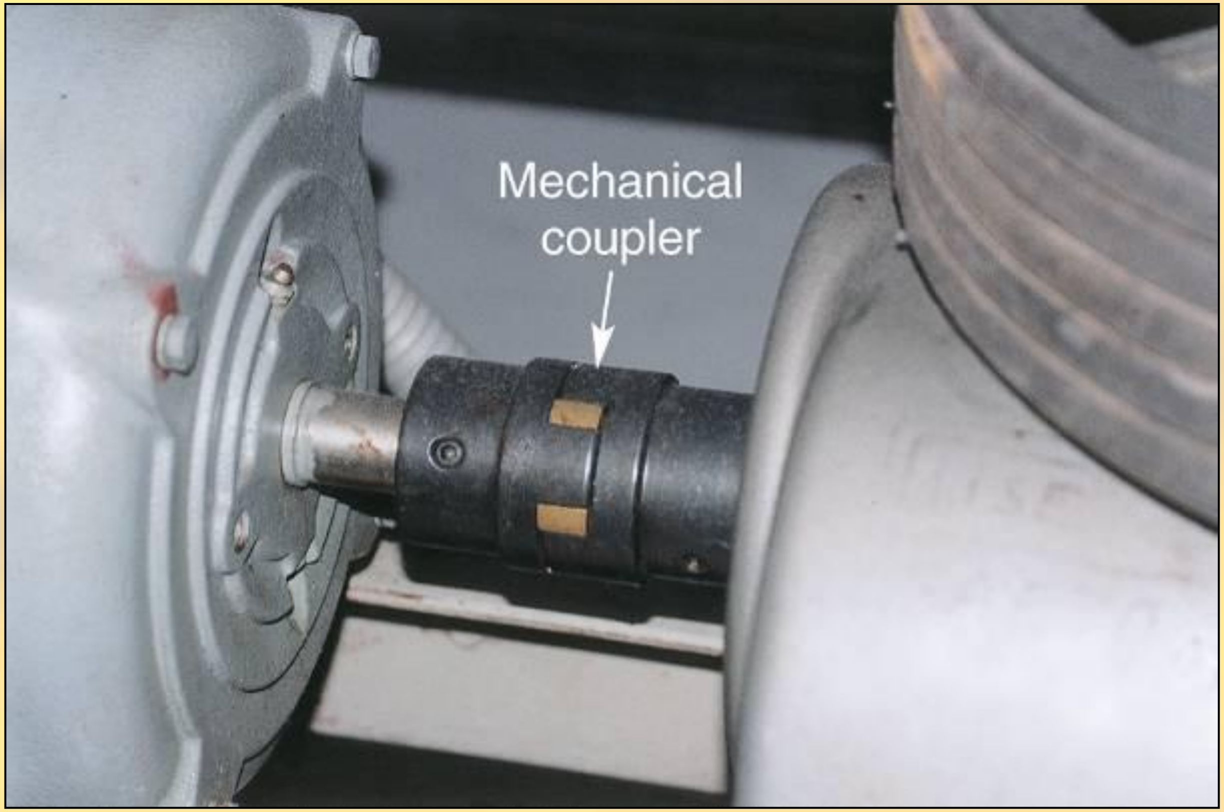
Power Unit

- A prime mover may be an internal combustion engine

Deere & Co.

Power Unit

- A coupler connects the prime mover to the pump

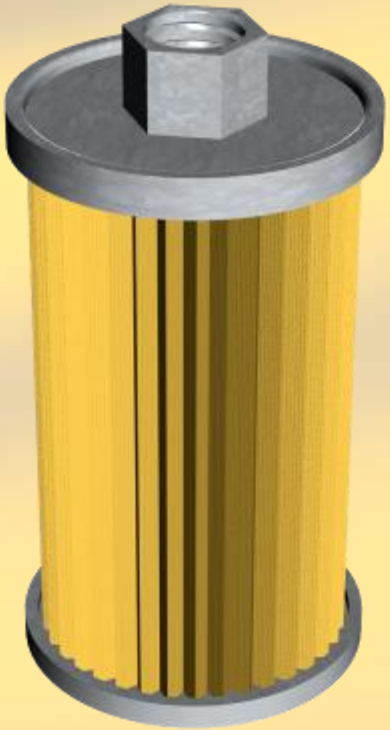


Power Unit

- The power unit includes a pressure control valve to limit pressure

Power Unit

- Filters and strainers are included in a power unit to remove debris from the fluid

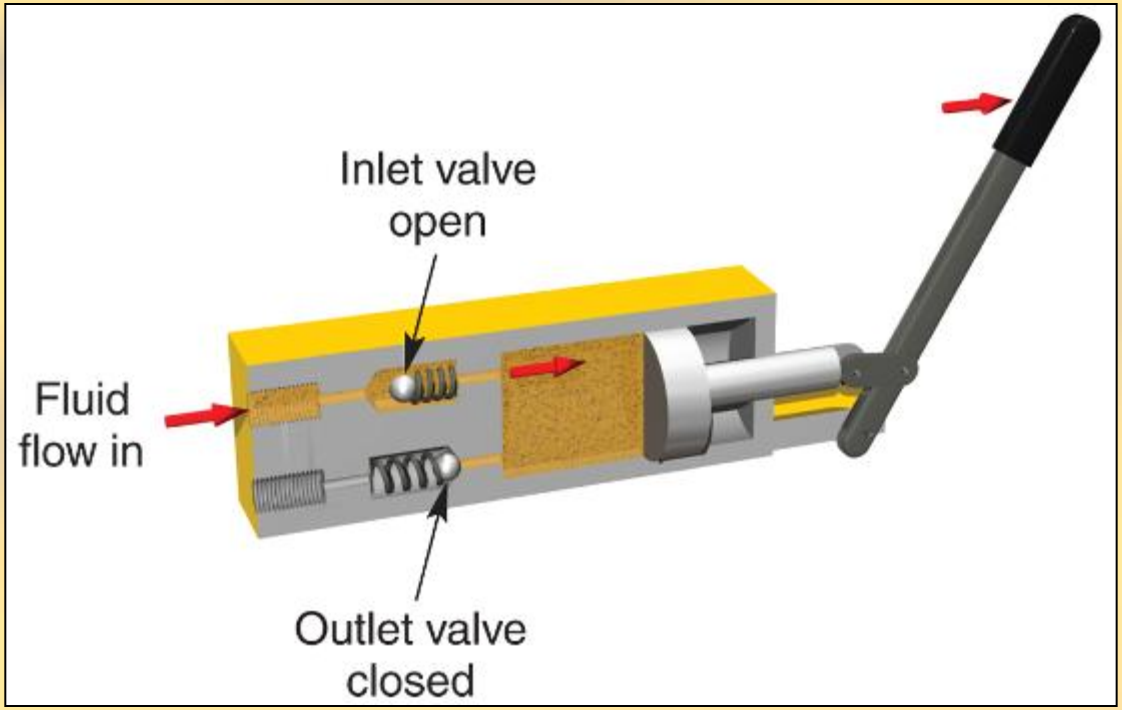


Basic Pump

- The basic operating principle that moves fluid through a pump is similar in all pumps
  - Enlarging the volume of a chamber allows fluid to enter the pump
  - Reducing the chamber volume moves fluid to the system
  - Inlet and discharge valves or ports control fluid movement through the pump

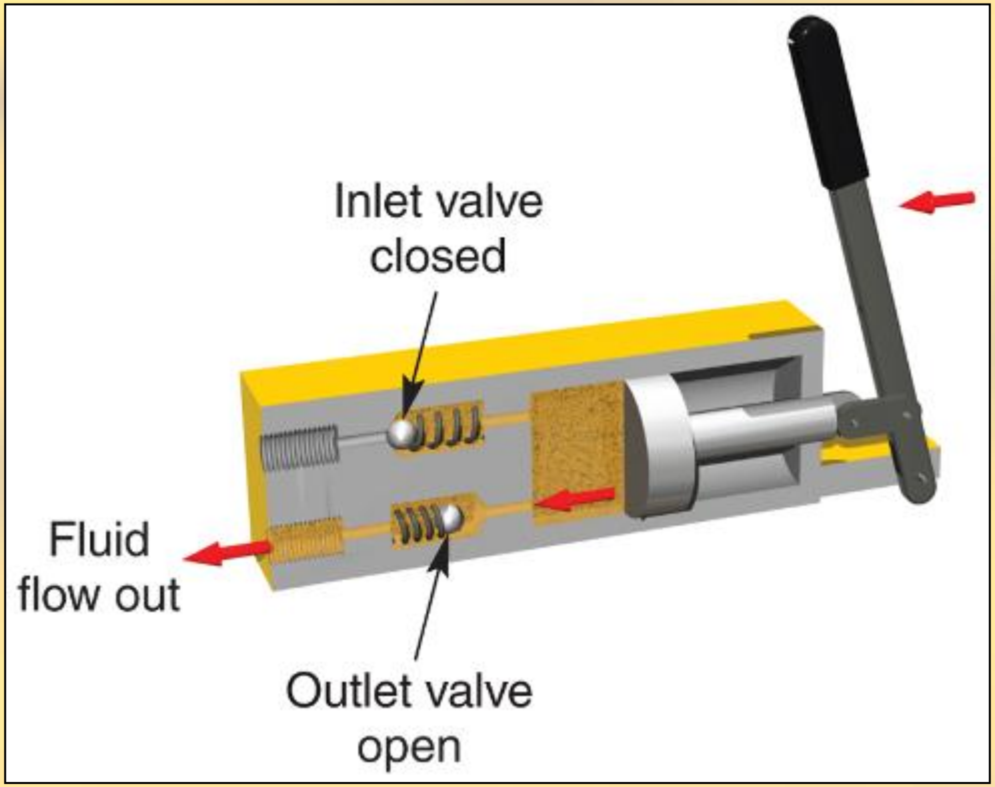
Basic Pump

- Increasing the size of the pumping chamber moves fluid into the pump



Basic Pump

- Reducing the size of the pumping chamber forces fluid into the system



Basic Pump

- The maximum pressure developed in a hydraulic system is determined by:
  - Resistance to fluid flow in the system
  - Force the prime mover can exert

Basic Pump

- The output flow rate of a hydraulic pump is determined by:
  - Volume of the pumping chamber
  - Operating speed of the prime mover

Basic Pump Classifications

- Hydraulic pumps can be classified using three basic aspects:
  - Displacement
  - Pumping motion
  - Fluid delivery characteristics

Basic Pump Classifications

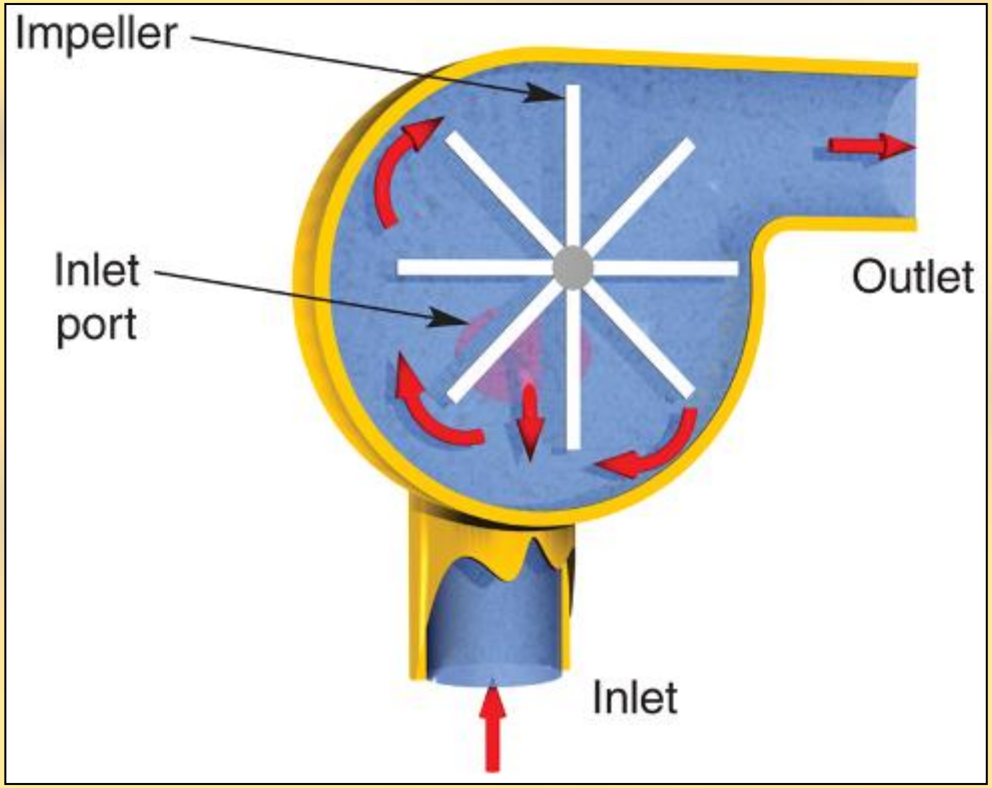
- Displacement relates to how the output of the pump reacts to system loads
  - Positive-displacement pumps produce a constant output per cycle
  - Non-positive-displacement pumps produce flow variations due to internal slippage

Basic Pump Classifications

- A non-positive-displacement pump has large internal clearances
  - Allows fluid slippage in the pump
  - Results in varying flow output as system load varies

Basic Pump Classifications

- Non-positive-displacement pump

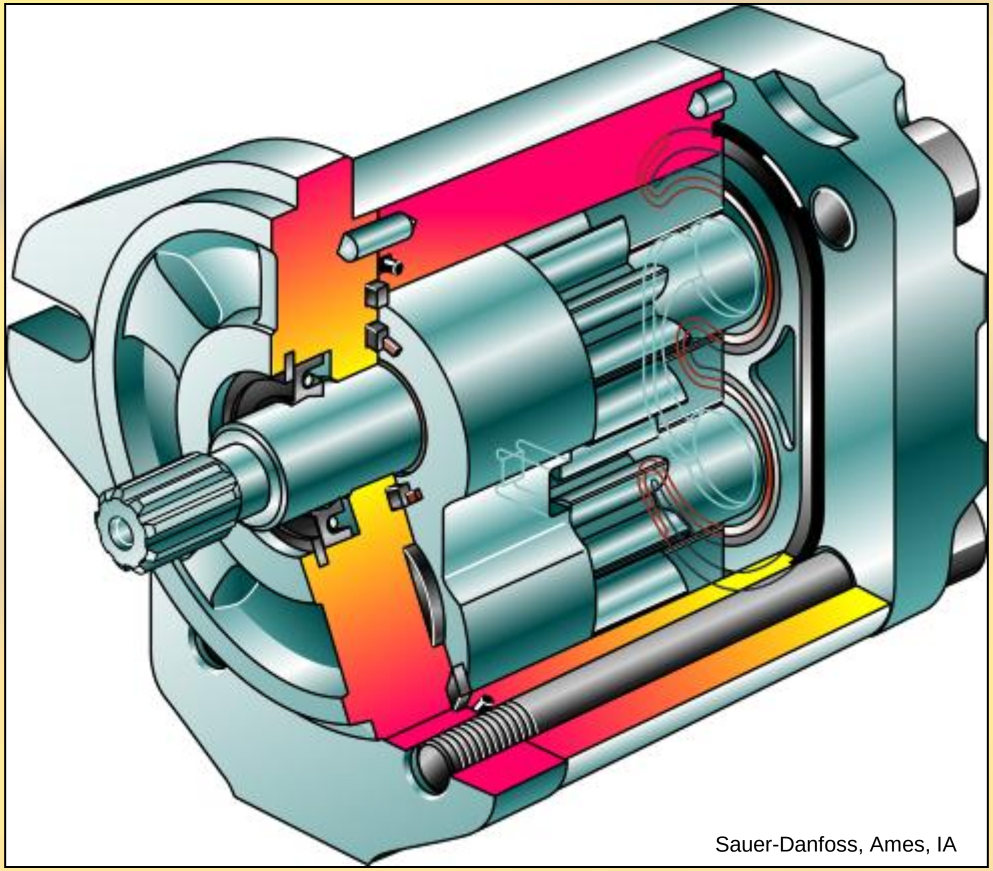


Basic Pump Classifications

- The basic pumping motions used in hydraulic pumps are:
  - Rotary
  - Reciprocating

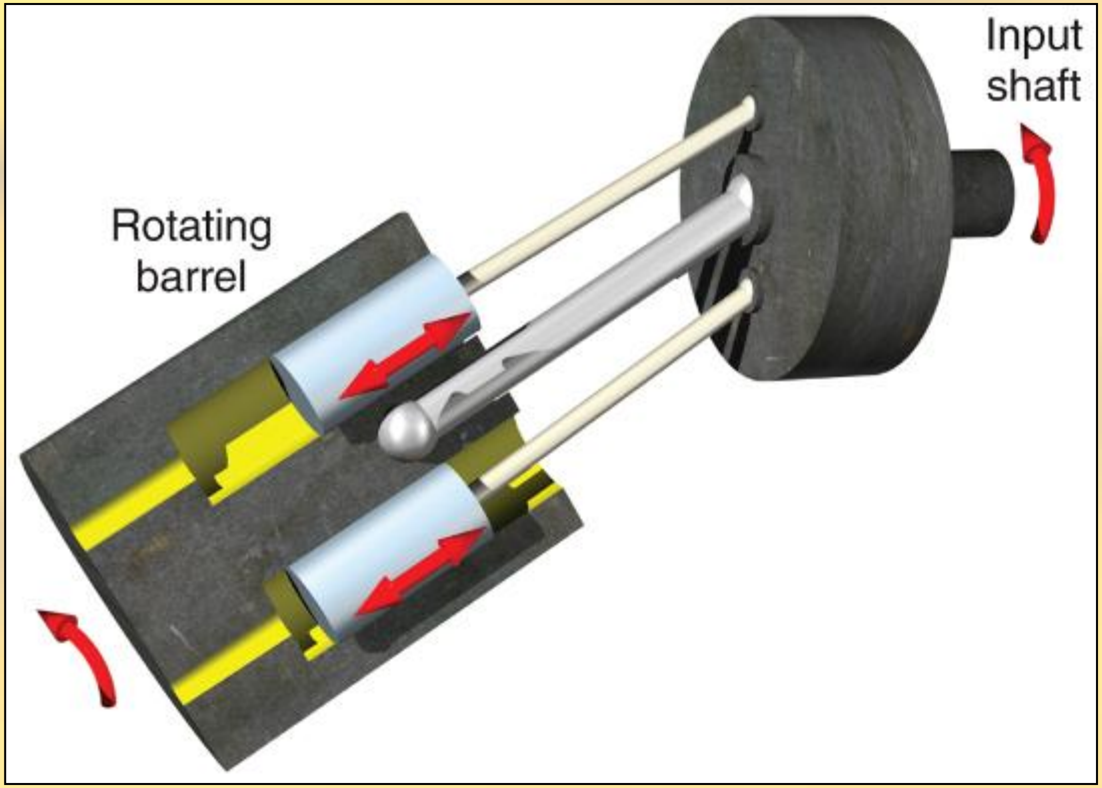
Basic Pump Classifications

- Gear pumps are rotary pumps


Sauer-Danfoss, Ames, IA

Basic Pump Classifications

- Piston pumps are reciprocating pumps



Reciprocating piston movement

Basic Pump Classifications

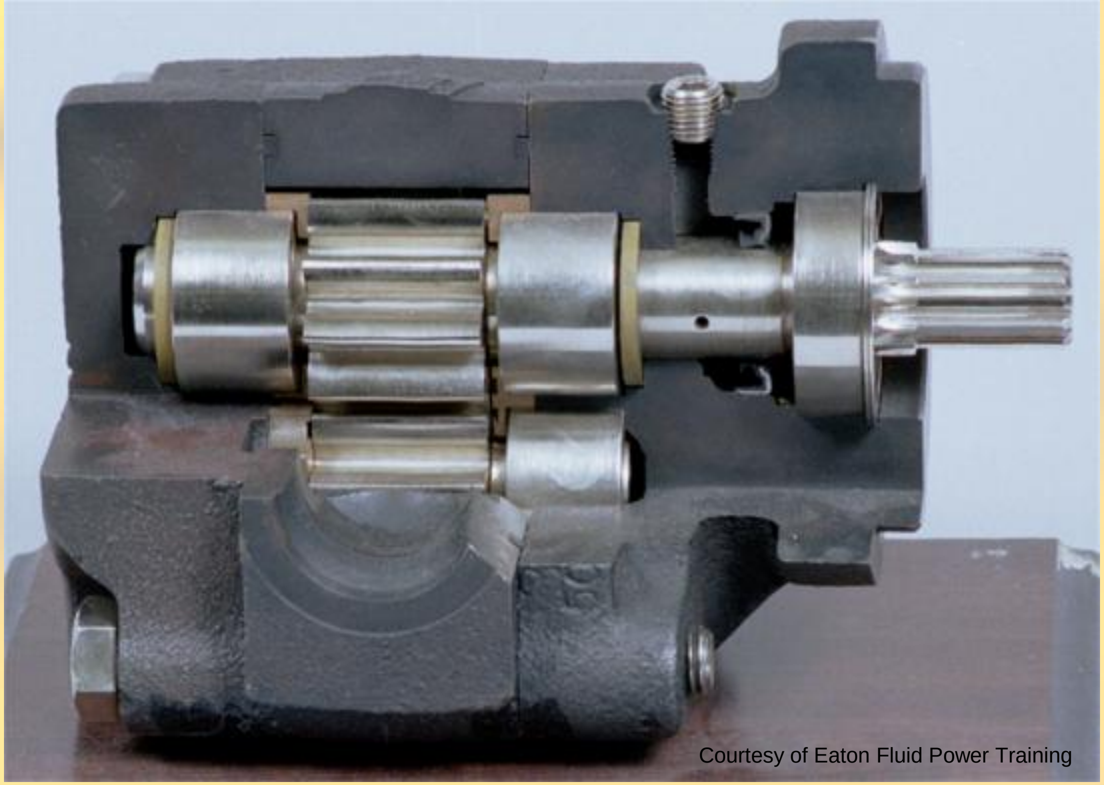
- In a rotary pump, the pumping action is produced by revolving components
- In a reciprocating pump, the rotating motion of the pump input shaft is changed to reciprocating motion, which then produces the pumping action

Basic Pump Classifications

- Hydraulic pumps are classified as either fixed or variable delivery
  - Fixed-delivery pumps have pumping chambers with a volume that cannot be changed; the output is the same during each cycle
  - In variable-delivery designs, chamber geometry may be changed to allow varying flow from the pump

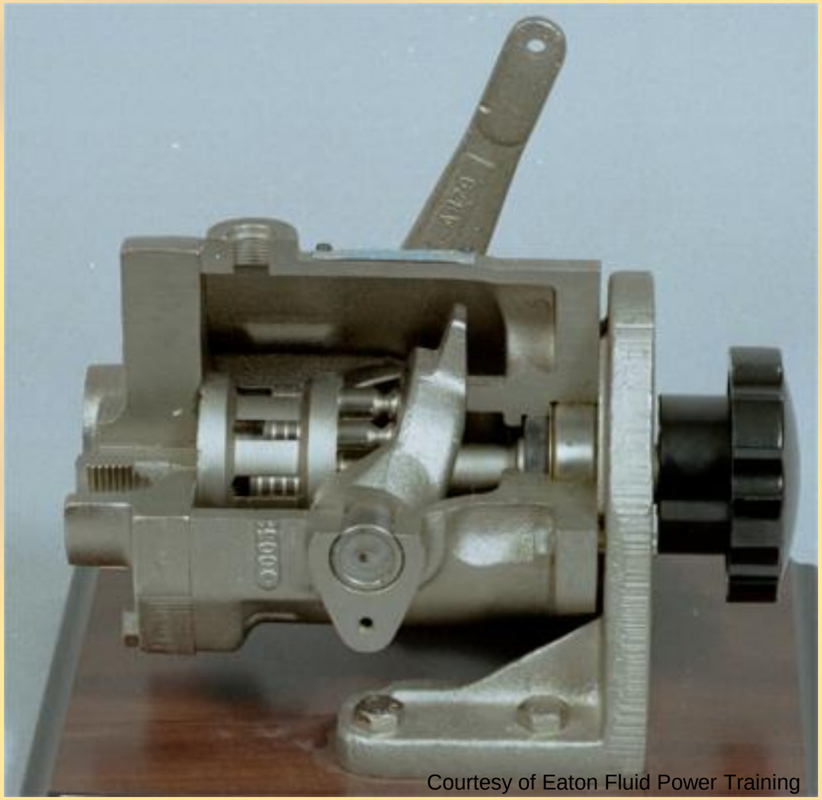
Basic Pump Classifications

- Gear pumps are fixed-delivery pumps


Courtesy of Eaton Fluid Power Training

Basic Pump Classifications

- Piston pumps may be designed as variable-delivery pumps



Courtesy of Eaton Fluid Power Training

Basic Pump Classifications

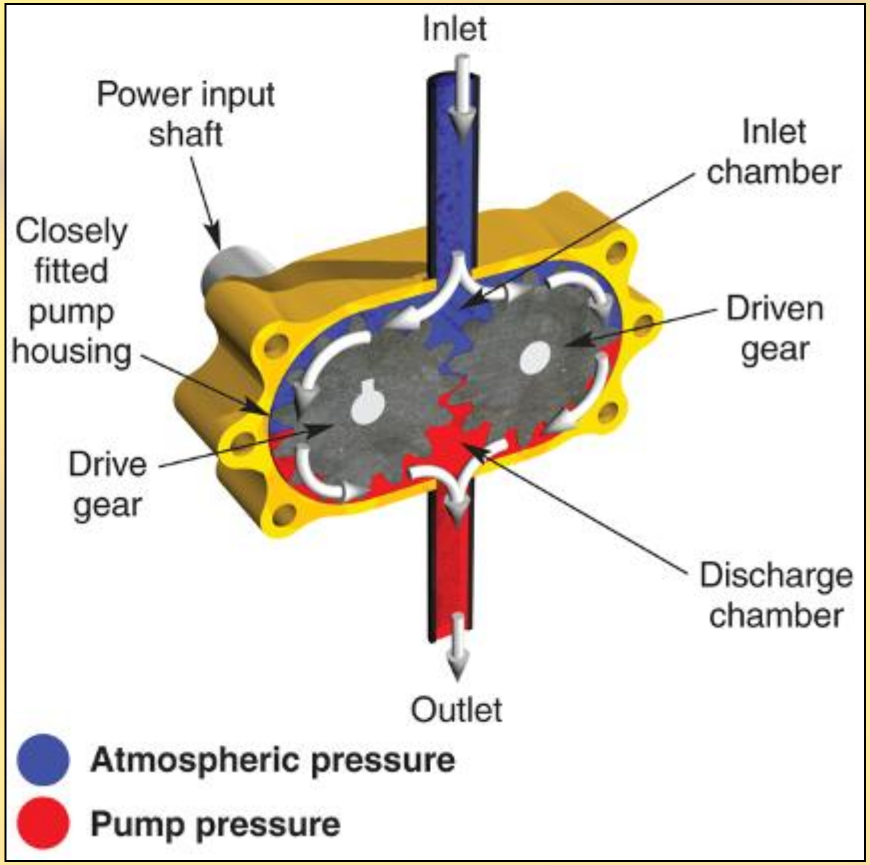
- When selecting a pump for a circuit, factors that must be considered are:
  - System operating pressure
  - Flow rate
  - Cycle rate
  - Expected length of service
  - Environmental conditions
  - Cost

Pump Design, Operation, and Application

- Gear pumps are positive-displacement, fixed-delivery, rotary units
- Gear pumps are produced with either external or internal gear teeth configurations

Pump Design, Operation, and Application

- Gear pumps are commonly used



Pump Design, Operation, and Application

- Pumping action of gear pumps results from unmeshing and meshing of the gears
  - As the gears unmesh in the inlet area, low pressure causes fluid to enter the pump
  - As the pump rotates, fluid is carried to the pump discharge area
  - When the gears mesh in the discharge area, fluid is forced out of the pump into the system

Pump Design, Operation, and Application

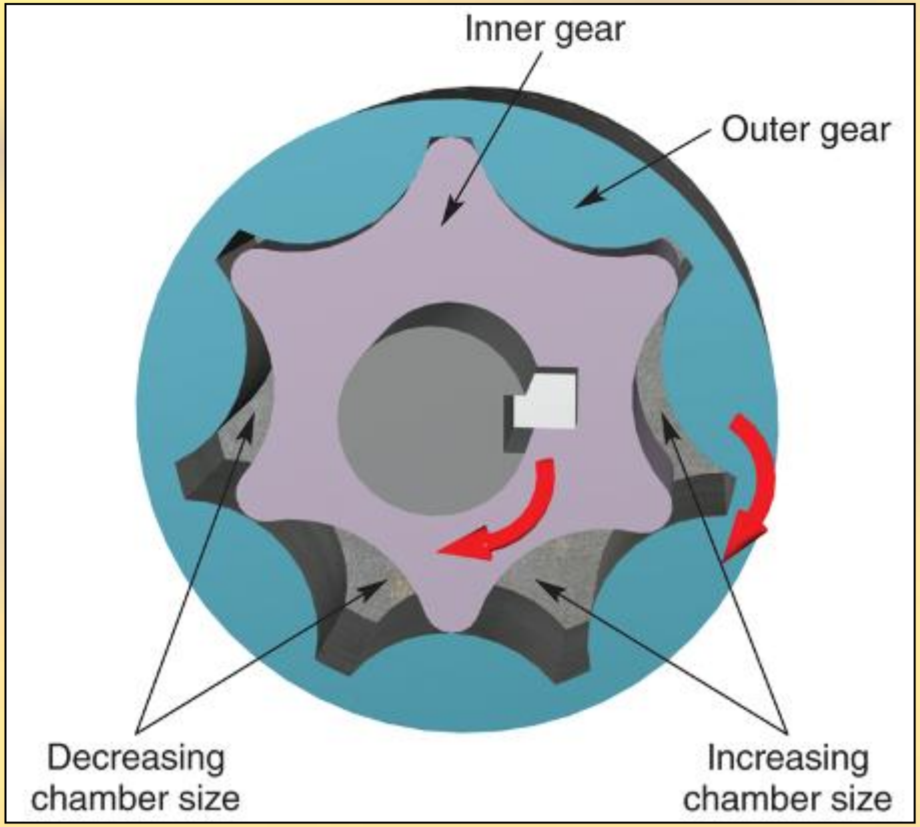
- Gear pumps are available in a wide variety of sizes
  - Flow outputs from below 1 gpm to 150 gpm
  - Pressure rating range up to 3000 psi

Pump Design, Operation, and Application

- The gerotor pump design is an internal-gear pump
  - Uses two rotating, gear-shaped elements that form sealed chambers
  - The chambers vary in volume as the elements rotate
  - Fluid comes into the chambers as they are enlarging and is forced out as they decrease in size

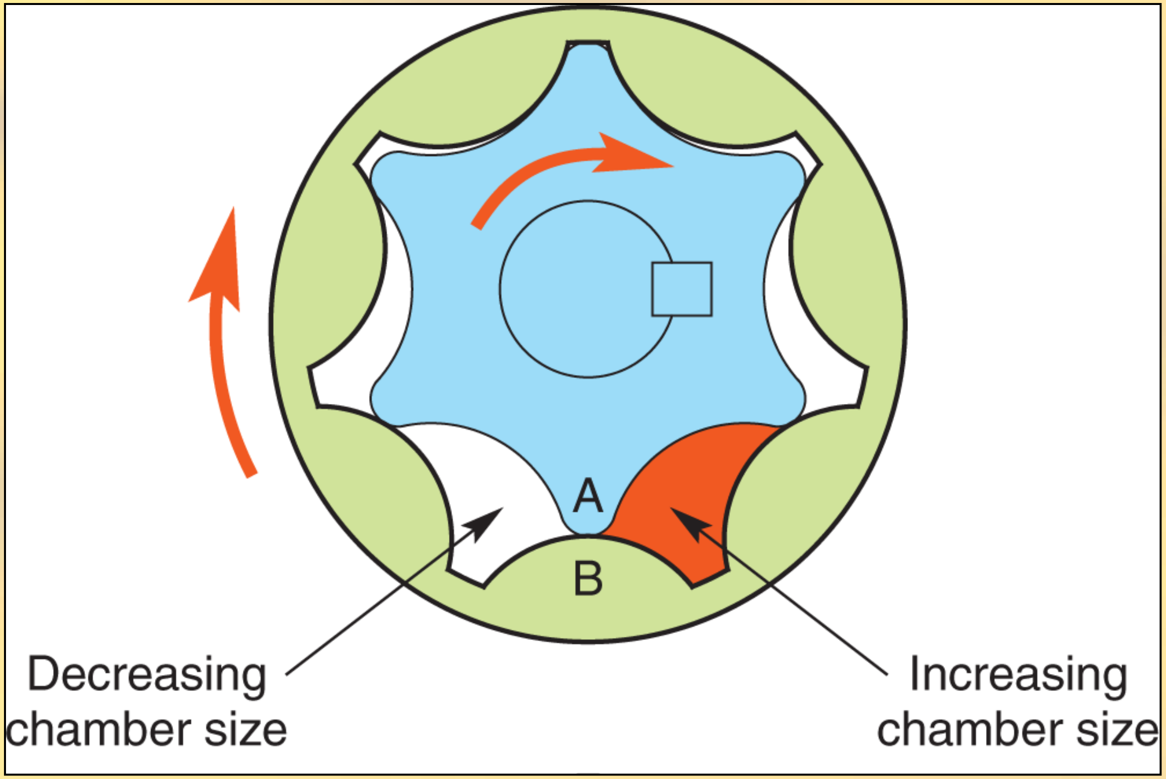
Pump Design, Operation, and Application

- The gerotor is a common internal-gear design



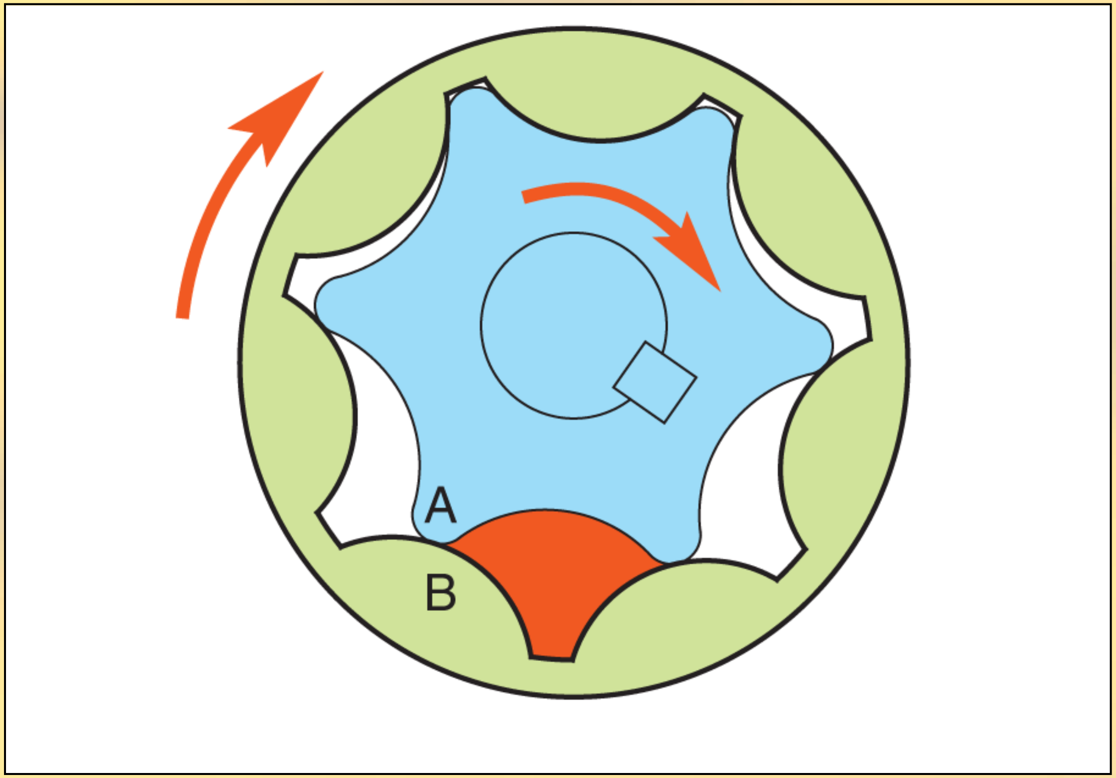
Pump Design, Operation, and Application

- Gerotor operation



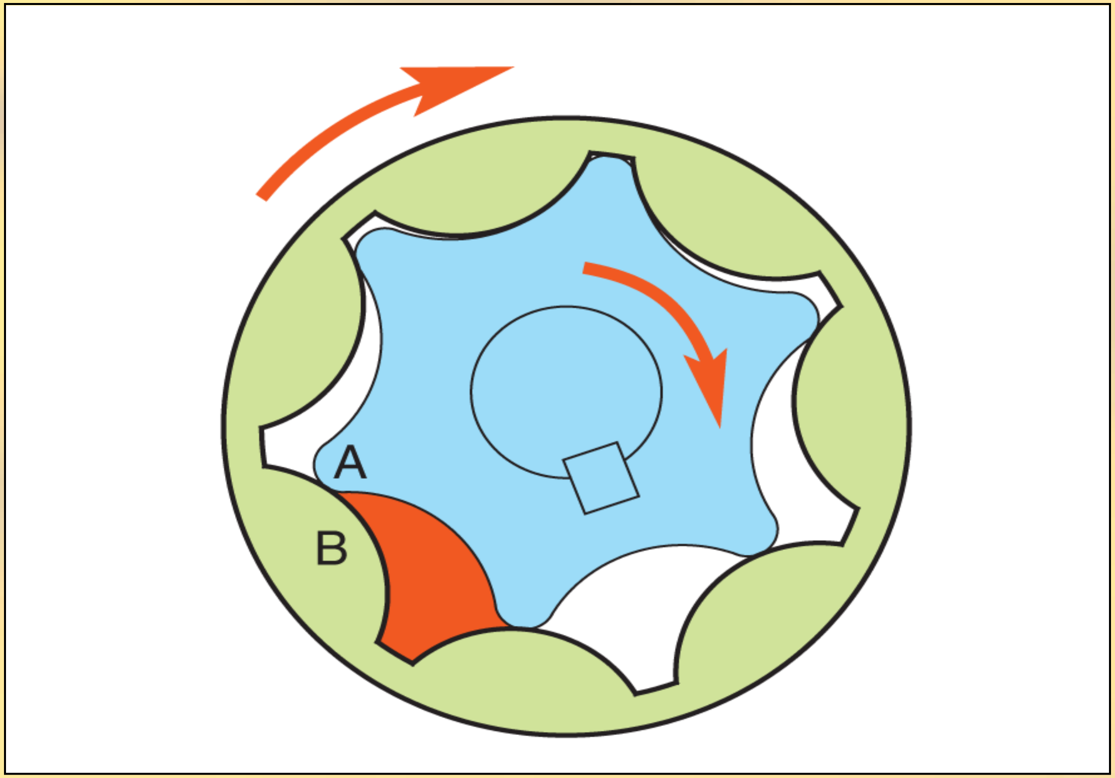
Pump Design, Operation, and Application

- Gerotor operation



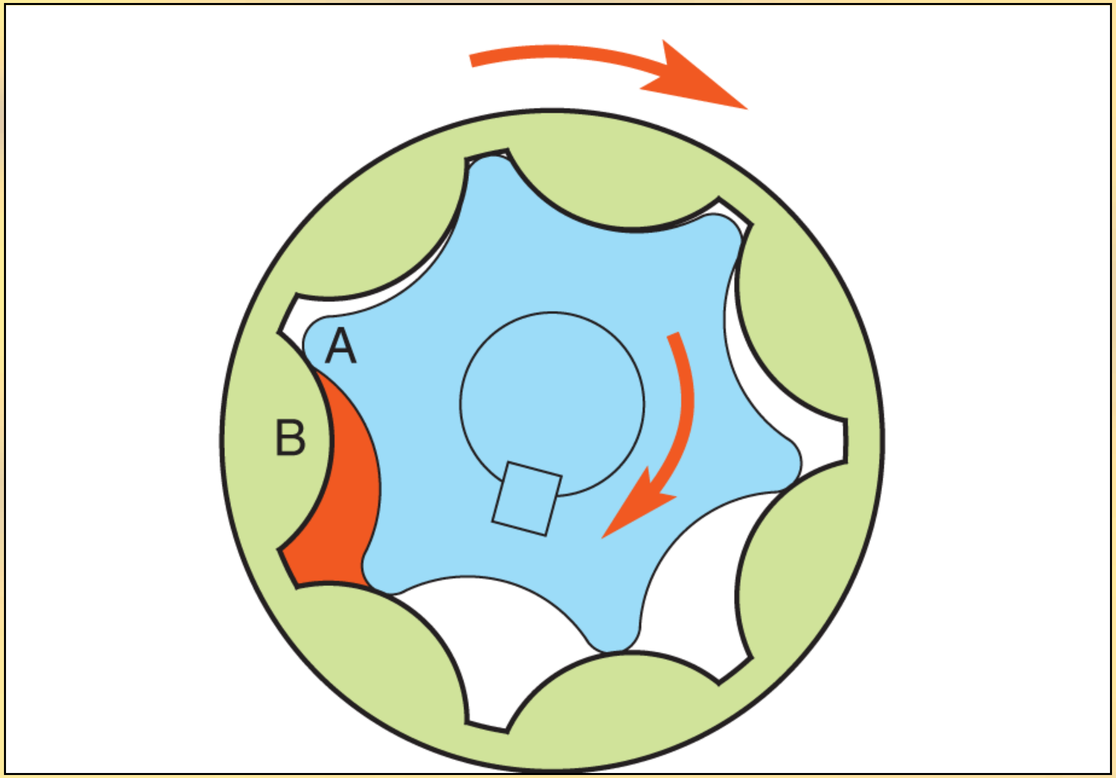
Pump Design, Operation, and Application

- Gerotor operation



Pump Design, Operation, and Application

- Gerotor operation



Pump Design, Operation, and Application

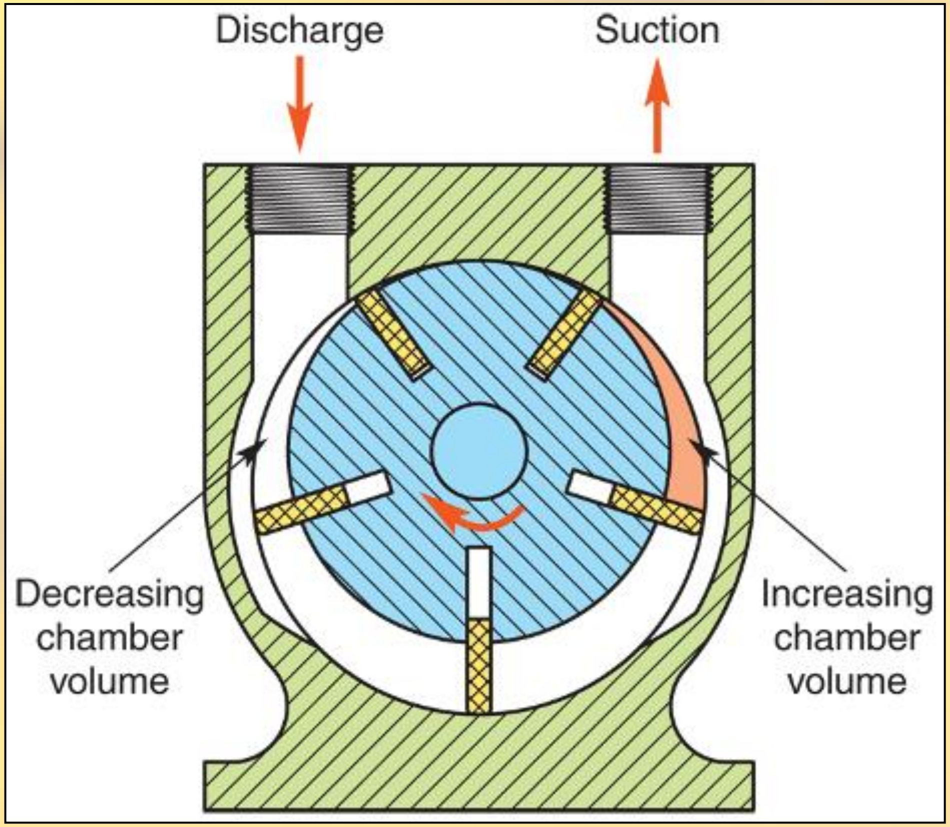
- Vane pumps are positive-displacement, fixed or variable delivery, rotary units.
  - Design is commonly used in industrial applications
  - Delivery can range up to 75 gpm
  - Maximum pressure of about 2000 psi

Pump Design, Operation, and Application

- Vane pump consists of a slotted rotor, fitted with moveable vanes, that rotates within a cam ring in the pump housing
  - Rotor is off center in the ring, which creates pumping chambers that vary in volume as the pump rotates
  - As chamber volume increases, pressure decreases, bringing fluid into the pump
  - As volume decreases, fluid is forced out into the system

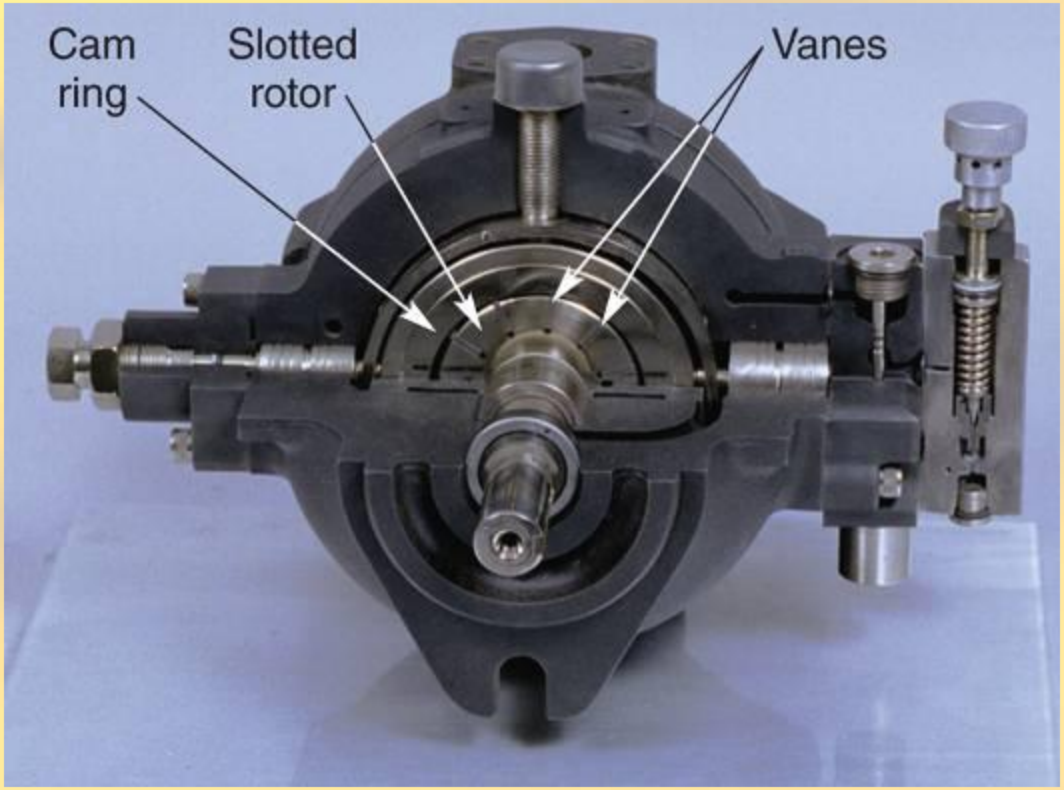
Pump Design, Operation, and Application

- Operation of a typical vane pump



Pump Design, Operation, and Application

- Parts of a typical vane pump



Courtesy of Eaton Fluid Power Training

Pump Design, Operation, and Application

- Vane pump may be pressure unbalanced or pressure balanced
  - Unbalanced has only one inlet and one discharge, which places a side load on the shaft
  - Balanced has two inlets and two discharges opposite each other, creating a pressure balance and, therefore, no load on the shaft

Pump Design, Operation, and Application

- Piston pumps are positive-displacement, fixed- or variable-delivery, reciprocating units
  - Several variations
  - Many provide high volumetric efficiency (90%), high operating pressure (10,000 psi or higher), and high-speed operation

Pump Design, Operation, and Application

- A basic piston pump consists of a housing that supports a pumping mechanism and a motion-converting mechanism
  - Pumping mechanism is a block containing cylinders fitted with pistons and valves
  - Motion converter changes rotary to reciprocating motion via cams, eccentric ring, swash plate, or bent-axis designs
  - Rotating the pump shaft causes piston movement that pumps the fluid

Pump Design, Operation, and Application

- Piston pump classification is based on the relationship between the axes of the power input shaft and piston motion
  - Axial
  - Radial
  - Reciprocating

Pump Design, Operation, and Application

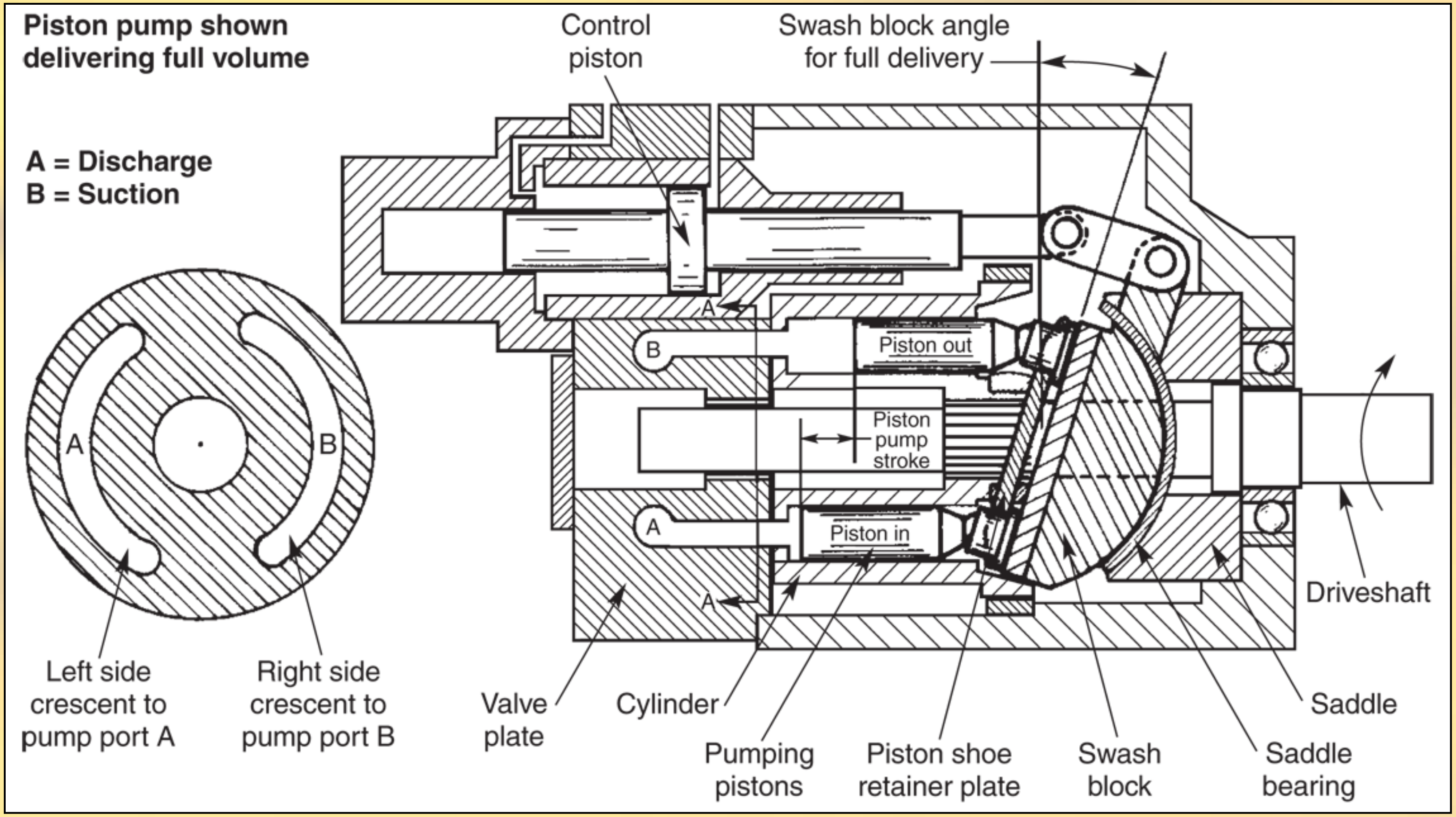
- Axial piston pumps use two design variations:
  - Inline
  - Bent axis

Pump Design, Operation, and Application

- Inline has the cylinder block and pistons located on the same axis as the pump input shaft
  – Pistons reciprocate against a swash plate
  – Very popular design used in many applications

Pump Design, Operation, and Application

- An inline axial-piston pump



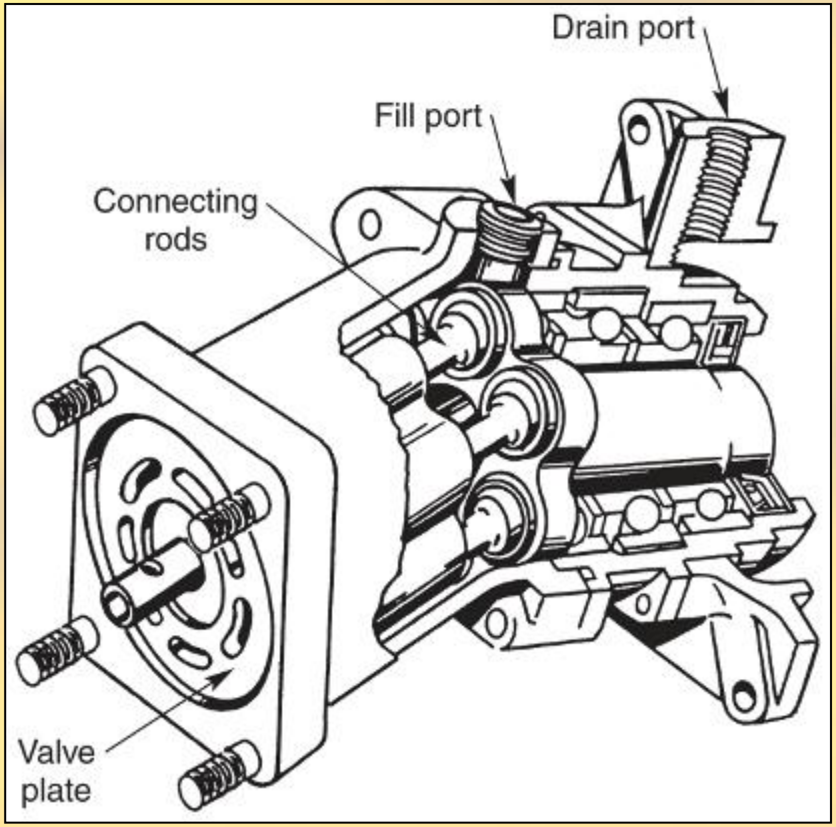
The Oilgear Company

Pump Design, Operation, and Application

- Bent axis has the cylinder block and pistons set at an angle to the input shaft
  - Geometry of the axis angle creates piston movement
  - Considered a more rugged pump than inline
  - Manufactured in high flow rates and maximum operating pressures

Pump Design, Operation, and Application

- A bent-axis axial-piston pump



Pump Design, Operation, and Application

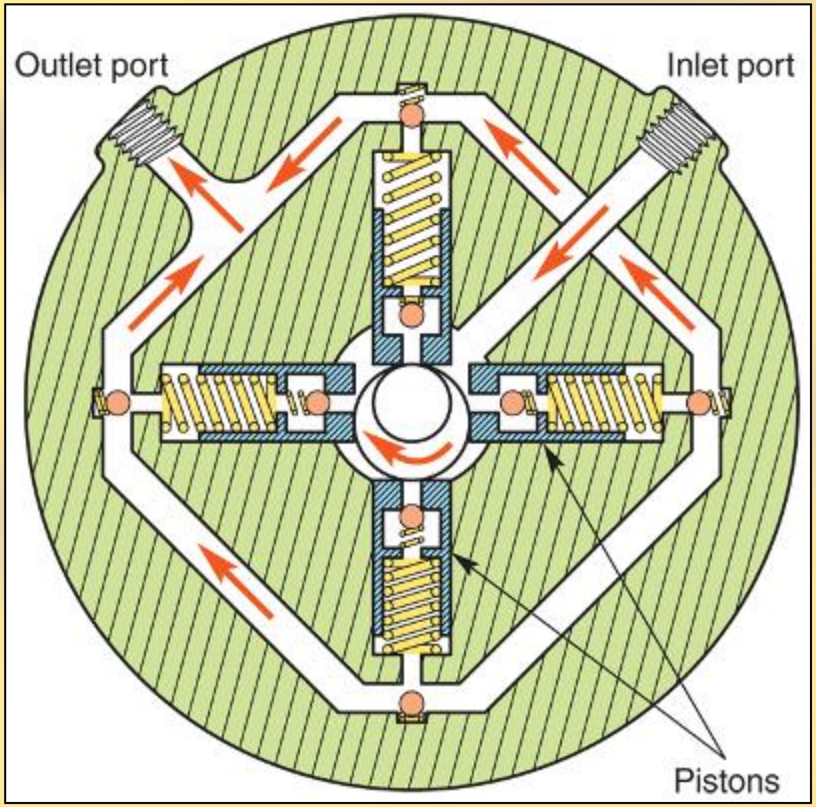
- Radial piston pumps have the highest continuous operating pressure capability of any of the pumps regularly used in hydraulic systems
- Models are available with operating pressure ratings in the 10,000 psi range

Pump Design, Operation, and Application

- Two variations of radial piston pumps:
  - Stationary-cylinder design uses springs to hold pistons against a cam that rotates with the main shaft of the pump
  - Rotating-cylinder design uses centrifugal force to hold pistons against a reaction ring
- When the main shaft is rotated, each piston reciprocates, causing fluid to move through the pump

Pump Design, Operation, and Application

- A stationary-cylinder radial-piston pump



Pump Design, Operation, and Application

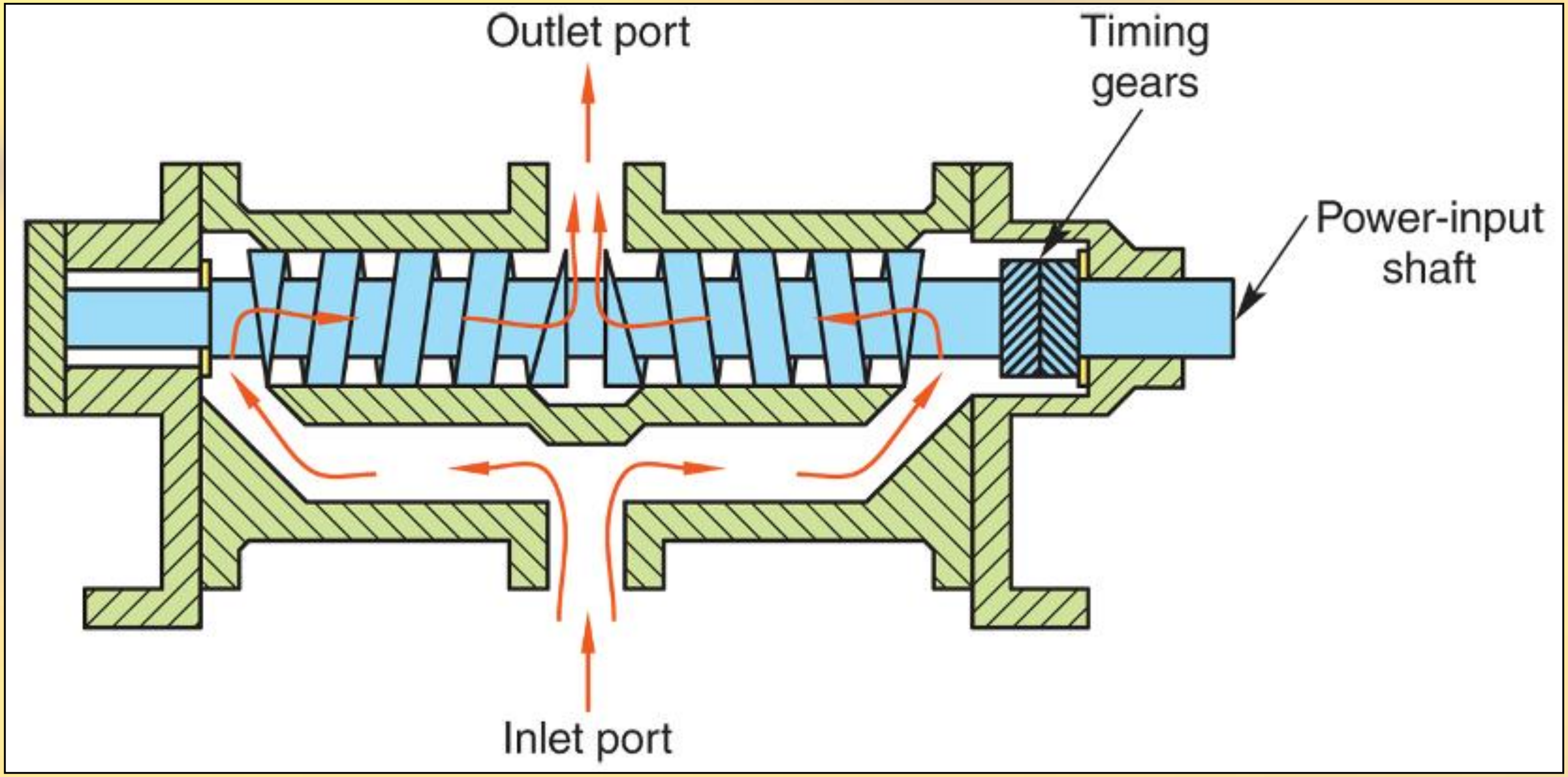
- Large, reciprocating-plunger pump designs were widely used when factories had a central hydraulic power source
- Today, plunger pumps are typically found in special applications requiring high-pressure performance

Pump Design, Operation, and Application

- Screw pumps have pumping elements that consist of one, two, or three rotating screws
- As the screws rotate, fluid is trapped and carried along to the discharge of the pump
- The design of screw pumps allows them to operate at a very low noise level

Pump Design, Operation, and Application

- A typical screw pump

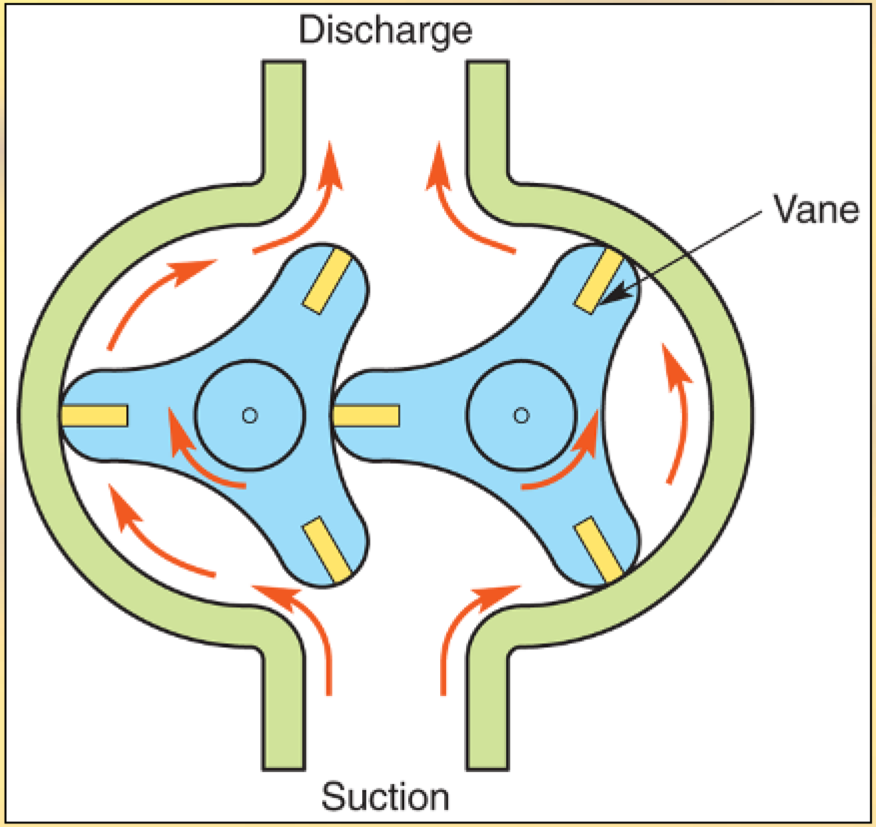


Pump Design, Operation, and Application

- The lobe pump is a close relative of the gear pump
  - Two three-lobed, gear-shaped units are often used to form the pumping element
  - Output flow is larger than a gear pump of comparable physical size because of pumping chamber geometry
  - Lower pressure rating than gear pumps
  - Tend to have a pulsating output flow

Pump Design, Operation, and Application

- Operation of a lobe pump

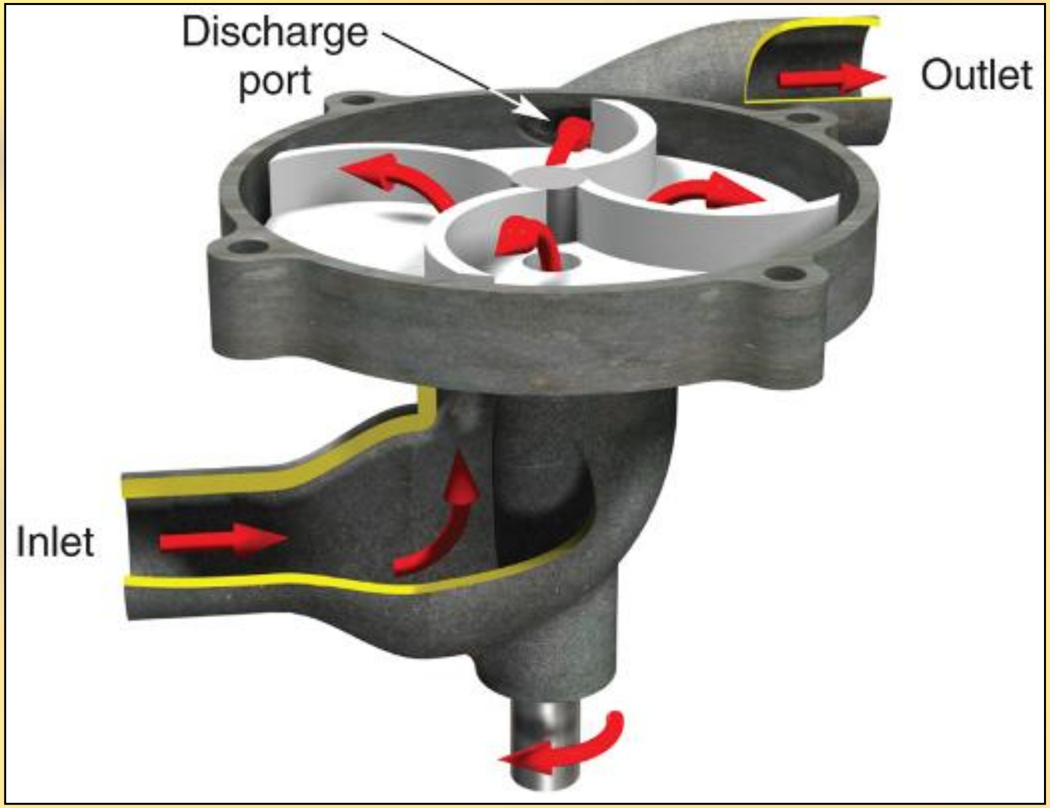


Pump Design, Operation, and Application

- Centrifugal pumps are non-positive-displacement units
  - Use centrifugal force generated by a rotating impeller to move fluid
  - Large clearances between the impeller and the pump housing allow internal pump slippage when resistance to fluid flow is encountered in the system
  - Typically used in hydraulic systems as auxiliary fluid transfer pumps

Pump Design, Operation, and Application

- Operation of a centrifugal pump

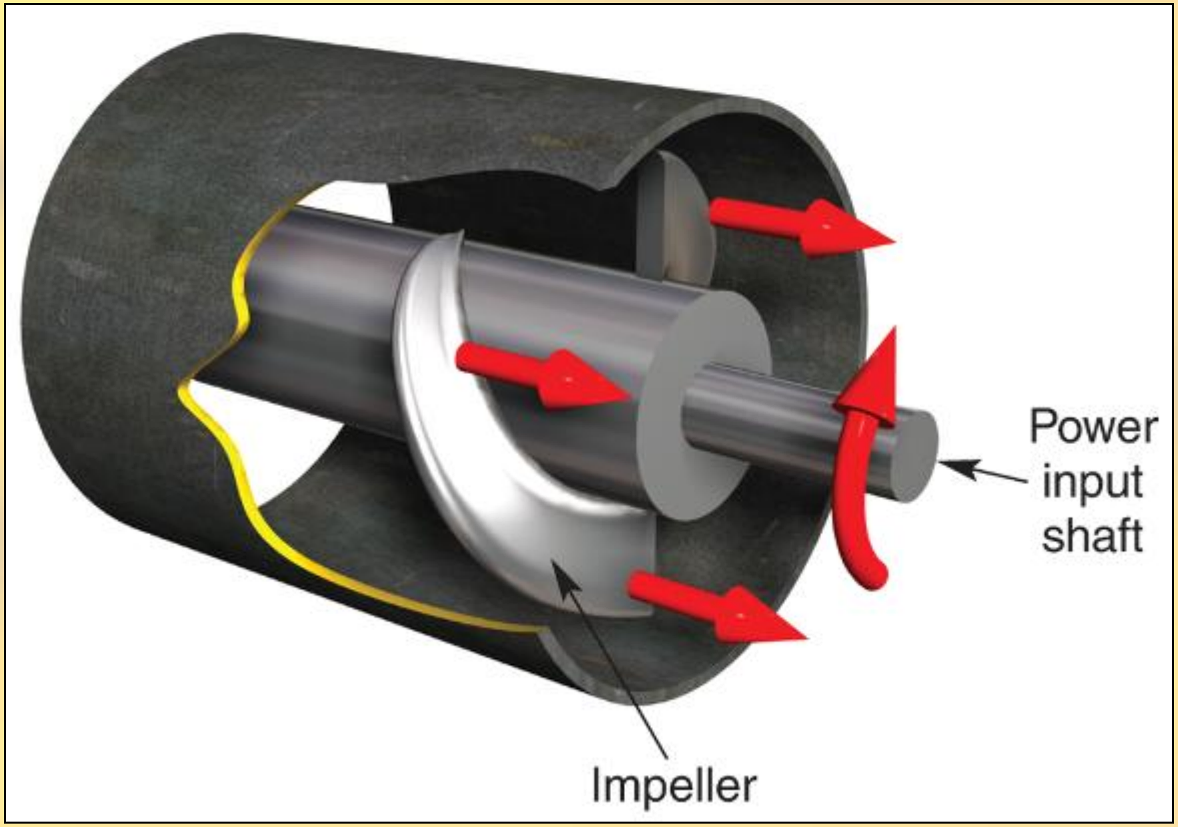


Pump Design, Operation, and Application

- Propeller and jet pumps are non-positive-displacement pumps
  - Sometimes used to transfer fluid within hydraulic systems
  - Propeller pump consists of a rotating propeller-shaped pumping element
  - Jet pump creates flow by pumping fluid through a nozzle concentrically located within a venturi

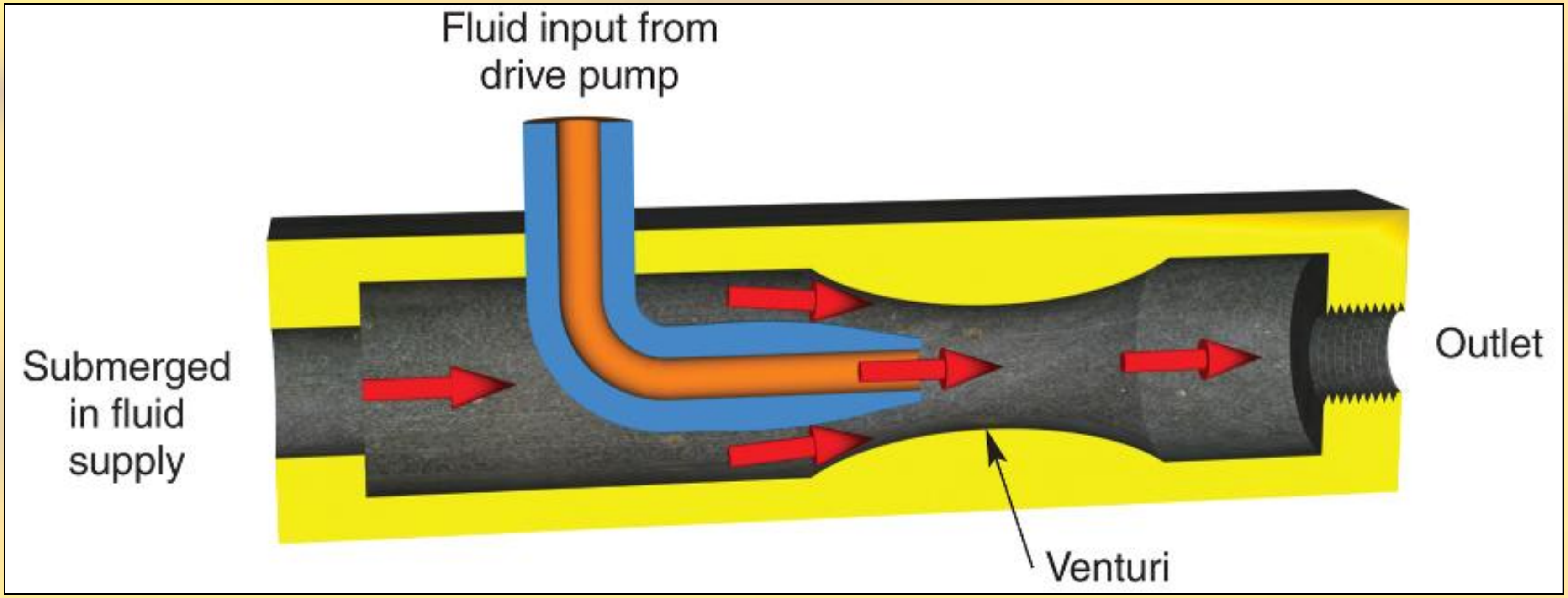
Pump Design, Operation, and Application

- Construction of a propeller pump



Pump Design, Operation, and Application

- Construction of a jet pump



Additional Design Features of Pumps

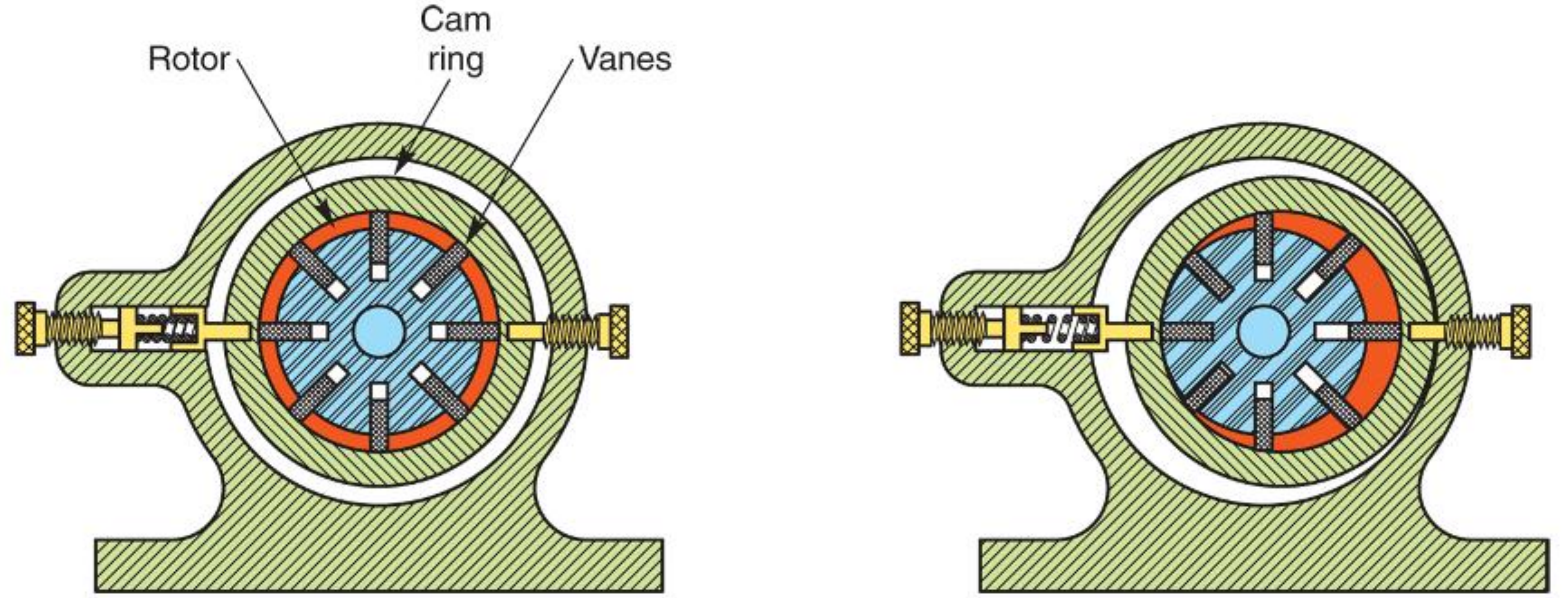
- Some basic pump designs can be modified to allow the unit to produce variable flow outputs at constant operating speeds
- This is achieved by including pump elements that allow the volume of the pumping chamber to be changed, either manually or by pressure-sensing devices

Additional Design Features of Pumps

- Unbalanced-vane pumps can be designed to produce variable flow outputs
  - A cam ring moves in relation to the center of the rotor
  - No flow output is produced when the centers of the ring and rotor are concentric
  - Flow increases as the centers move apart

Additional Design Features of Pumps

- A variable-flow, unbalanced-vane pump



Concentric Rotor and Cam Ring
(no fluid flow)

Eccentric Rotor and Cam Ring
(fluid flow)

Additional Design Features of Pumps

- Axial- and radial-piston pumps can include variable flow output
  - Variable flow is created by varying the length of the piston stroke
  - Inline design varies the angle of the swash plate
  - Bent-axis design varies the angle between the cylinder barrel and pump input shaft
  - Radial-piston design uses a moveable reaction ring

Additional Design Features of Pumps

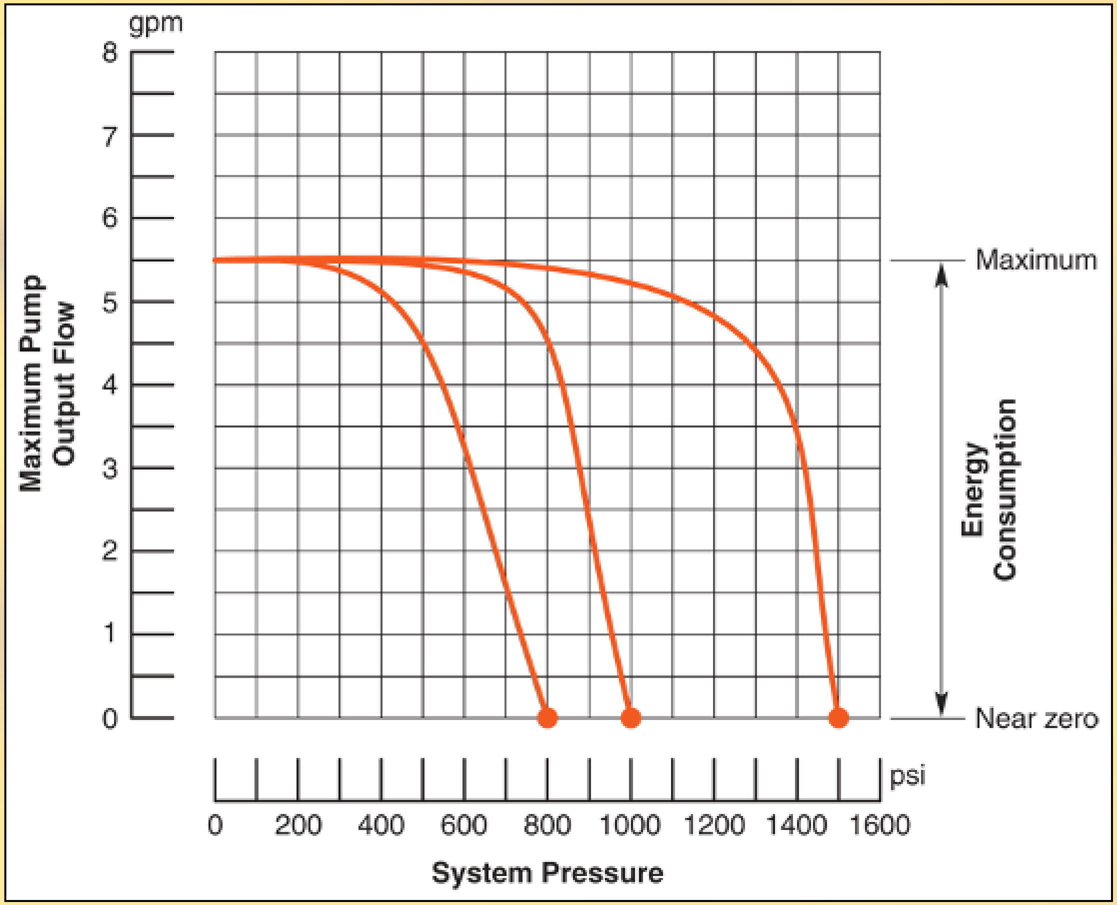
- Pressure compensation allows a pump to sense system pressure and vary pumping chamber volume
  - Provides only sufficient fluid to maintain the desired system operating pressure
  - When system resistance is low, the pump produces maximum flow

Additional Design Features of Pumps

- When system load increases, the pump adjusts and supplies only sufficient flow to maintain the desired operating pressure
- When the actuator stalls, fluid flow only sufficient to compensate for system leakage is produced
- Reduces the time the prime mover must spend producing maximum flow against maximum system pressure
- Reduces energy consumption

Additional Design Features of Pumps

- Pressure compensation reduces energy consumption

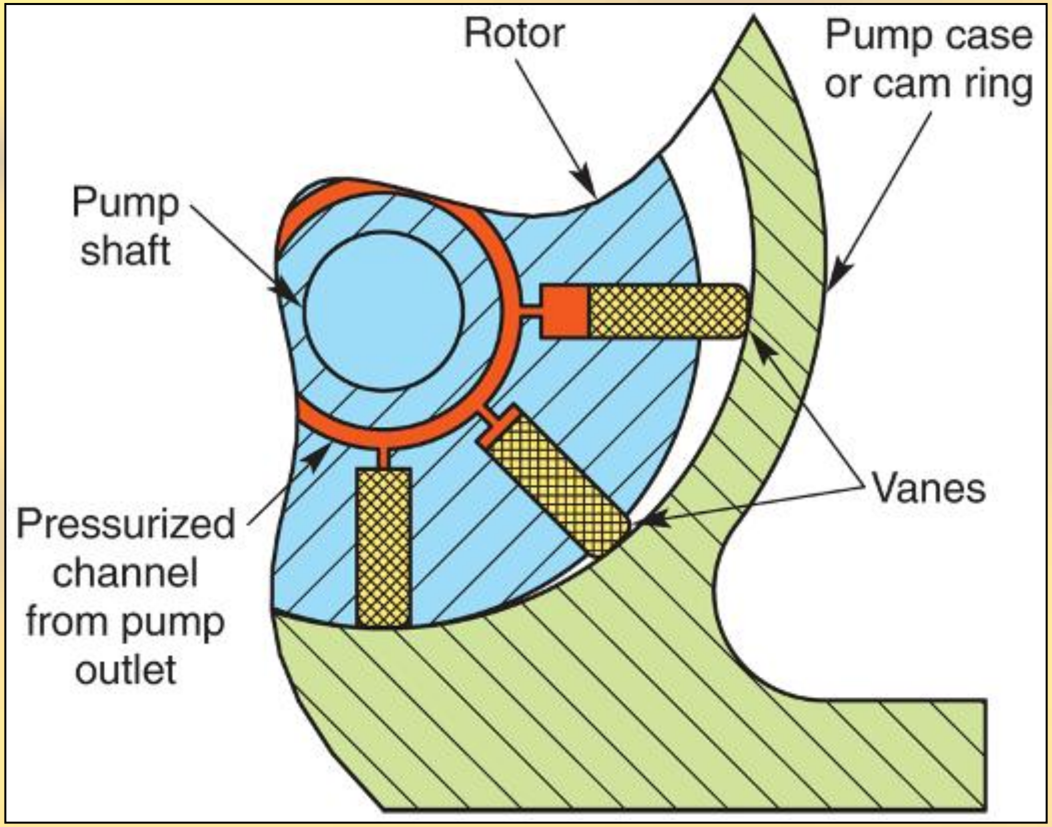


Additional Design Features of Pumps

- Pressures that occur in a hydraulic system exert force on all of the internal surfaces of pumps and other components
  - Pressure differences within a pump can cause uneven loads on bearings
  - Pressure balancing delivers pressurized fluid to critical locations to counteract these forces
  - Helps reduce wear and improve sealing between components

Additional Design Features of Pumps

- System pressure can be used to help create a seal

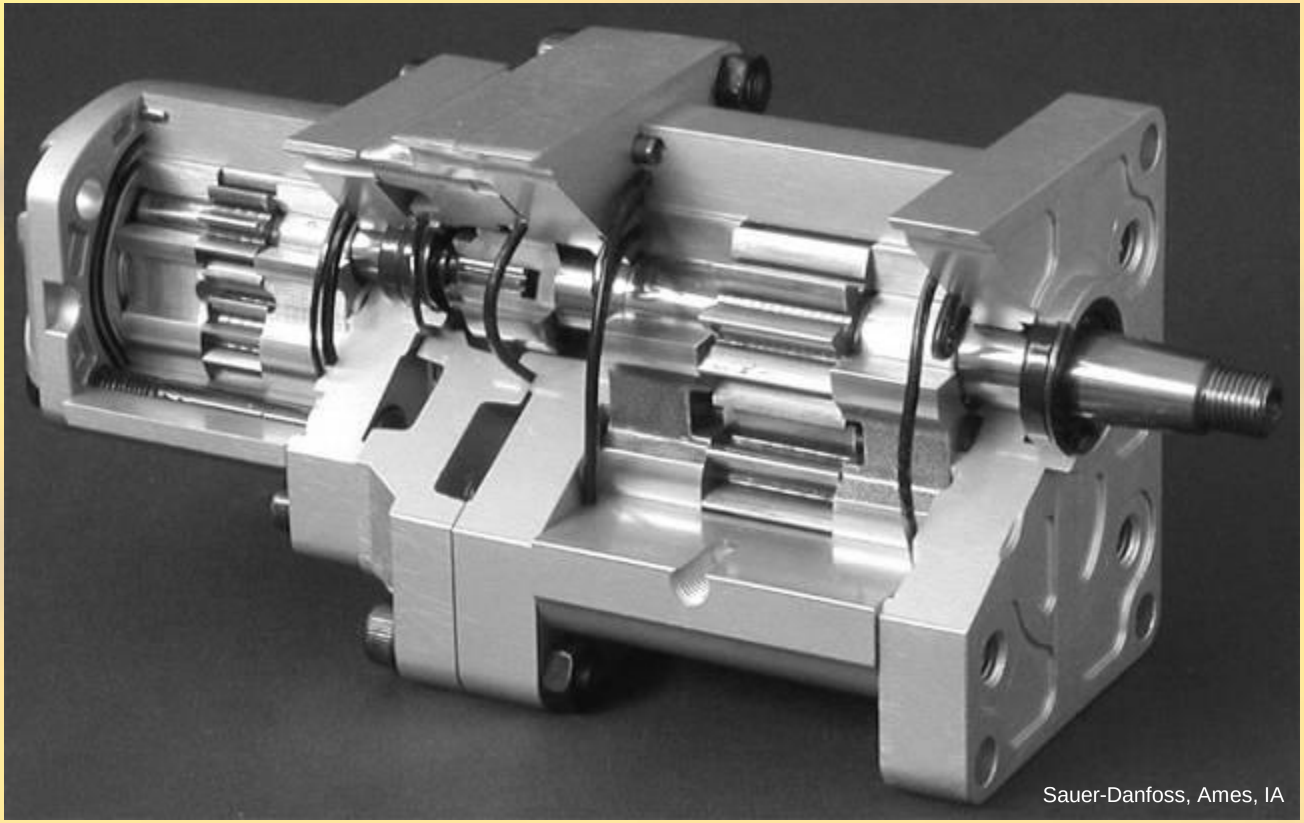


Additional Design Features of Pumps

- Dual pumps are two pumps housed in a single case and driven by a single prime mover
  - Some units include integral valving to provide relief and unloading capabilities
  - Typical application is a high-low circuit where a large cylinder quickly extends followed by high-pressure clamping

Additional Design Features of Pumps

- A dual-pump design



Pump and Power Unit Design and Operating Considerations

- Manufacturers supply considerable information about their pumps:
  - General specifications
  - Performance data
  - Installation drawings
  - Application information

Pump and Power Unit Design and Operating Considerations

- Careful analysis of these sheets provides the detailed information needed for selecting, installing and operating a hydraulic pump

Pump and Power Unit Design and Operating Considerations

- The size of the prime mover is established by the peak power needed during the system operating cycle
- Determining peak power requires careful system analysis as changes in actuator loads, pump efficiency, operating temperature, and fluid viscosity will change the power need

Pump and Power Unit Design and Operating Considerations

- Horsepower is defined as 33,000 foot pounds of work per minute
- In a hydraulic system, pressurized fluid is moved instead of an object
- The formula for general hydraulic horsepower is:

$$\frac{\text{pounds of the fluid moved per minute} \times \text{pressure in feet of head}}{\text{33,000 foot pounds per minute}}$$

Pump and Power Unit Design and Operating Considerations

- The pounds of fluid moved for use in the general hydraulic horsepower formula is calculated as:

$$\frac{\text{pump flow rate in gallons per minute} \times \text{weight of water} \times \text{specific gravity of the fluid}}{\text{gallons in a cubic foot of fluid}}$$

Pump and Power Unit Design and Operating Considerations

- The pressure in feet of head for use in the general hydraulic horsepower formula is calculated as:

$$\frac{\text{system pressure in pounds per square inch} \times \text{number of square inches in a square foot}}{\text{weight of a cubic foot of water} \times \text{specific gravity of the system fluid}}$$

Pump and Power Unit Design and Operating Considerations

- The general hydraulic formula can be reduced:

$$\frac{\text{pump flow rate} \times \text{system pressure}}{1714}$$

- Stated in mathematical form:

$$\frac{\text{gpm} \times \text{psi}}{1714}$$

or

$$\text{gpm} \times \text{psi} \times .000583$$

Pump and Power Unit Design and Operating Considerations

- Prime mover power actually required for the operation of a system will be greater than that calculated using the general hydraulic horsepower formula
- This is because of power losses in both the prime mover and the pump
  - Internal leakage
  - Internal friction

Pump and Power Unit Design and Operating Considerations

- Internal leakage:
  - Caused by clearances in the pump resulting from manufacturing tolerances and component wear
  - Expressed as volumetric efficiency
  - Volumetric efficiency is calculated as:

$$\frac{\text{actual pump flow rate}}{\text{theoretical pump flow rate}} \times 100$$

Pump and Power Unit Design and Operating Considerations

- Internal friction:
  - Caused by bearings, close contact of machined surfaces, fluid viscosity, and turbulence
  - Expressed as mechanical efficiency
  - Mechanical efficiency is calculated as:

$$\frac{\text{theoretical horsepower needed to operate the pump}}{\text{actual horsepower required to operate the pump}} \times 100$$

Pump and Power Unit Design and Operating Considerations

- Overall efficiency of a pump considers *all* energy losses in the unit
  - Combines the volumetric and mechanical efficiency ratings
  - Overall efficiency is calculated as:

$$\frac{\text{volumetric efficiency} \times \text{mechanical efficiency}}{100}$$

Pump and Power Unit Design and Operating Considerations

- Required prime mover input horsepower is equal to the calculated general hydraulic horsepower for the system divided by the overall efficiency of the pump:

$$\frac{\text{gpm} \times \text{psi}}{1714 \times \text{overall efficiency}}$$

Pump and Power Unit Design and Operating Considerations

- All of the fluid used in the operation of a hydraulic system enters the system through the inlet line of the pump
- The low pressure differential between the system reservoir and pump inlet can create problems
  – Cavitation
  – Air entrainment

Pump and Power Unit Design and Operating Considerations

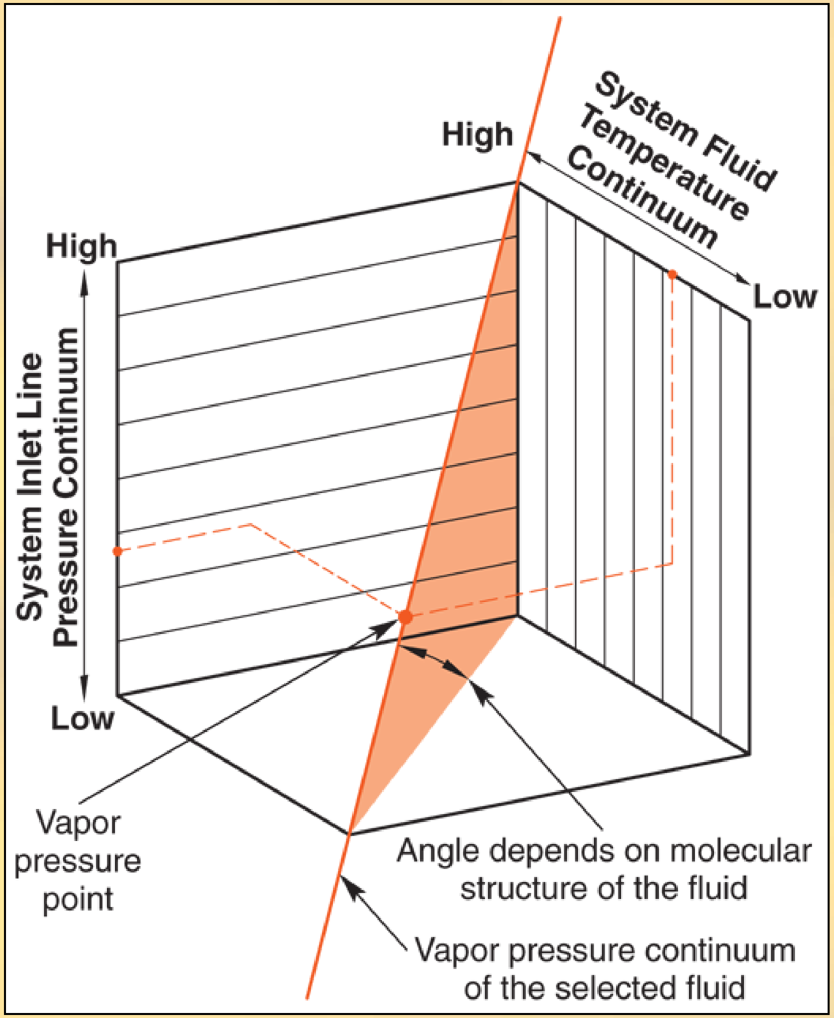
- Cavitation is caused when inlet line pressure drops below the vapor pressure of the fluid and bubbles form
  - Reduces lubricity of the system fluid
  - Collapsing bubbles produce severe shock waves that can damage pump parts
  - Collapsing bubbles also produce noisy pump operation

Pump and Power Unit Design and Operating Considerations

- Factors that influence the point at which a liquid begins to form a vapor:
  - Chemical makeup of the liquid
  - Pressure applied on the liquid
  - Temperature of the liquid

Pump and Power Unit Design and Operating Considerations

- Point at which liquid begins to form vapor depends on system pressure, temperature, and fluid characteristics



Pump and Power Unit Design and Operating Considerations

- Entrained air is air suspended in fluid
  - Enters the inlet line through leaks
  - Can produce a result similar to cavitation
  - Testing inlet line pressure can help indicate which condition exists
    - High negative pressure (vacuum) indicates cavitation
    - Pressure closer to 0 psi may indicate entrained air

Pump and Power Unit Design and Operating Considerations

- The inlet line of the pump must be carefully sized and configured to eliminate cavitation and air entrainment
  - Fluid velocity in the line should not exceed 4 feet per second
  - Lines should be no smaller than the diameter of the pump inlet fitting
  - Strainer and inlet line filters must not restrict fluid flow

Review Question

Name the five functions of a hydraulic system power unit.

A. Provide the energy for the operation of the system, B. move fluid through the system, C. limit the maximum pressure of the system, D. aid in maintaining proper system operating temperature, and E. aid in maintaining fluid cleanliness

Review Question

The device that is used to move fluid through a hydraulic system is called the ______.

pump

Review Question

During the _____ phase of basic pump operation, the pressure in the pumping chamber is below atmospheric pressure.

intake

Review Question

In a centrifugal pump, the primary element of the pumping mechanism is called a(n) _____.

impeller

Review Question

A(n) ______ valve found in some power units is set at a pressure slightly higher than the normal system operating pressure for protection if the relief valve fails.

safety

Review Question

Describe how variable flow can be achieved in an unbalanced-vane pump.

By incorporating a moveable cam ring.

Review Question

The pressure-compensating feature of a hydraulic pump is available only on those pump designs that are also capable of ______-flow delivery.

variable

Review Question

The type of pump that delivers the best pulse-free flow of fluid throughout the full range of operating speeds uses a(n) _____ pumping mechanism design.

screw

Review Question

A condition known as ______ exists when bubbles of vapor begin to appear in the inlet line of a pump. This is caused when the inlet pressure is too far below atmospheric pressure.

cavitation

Review Question

Overall efficiency and volumetric efficiency is typically found in the ______ section of pump information sheets.

performance data