Hydraulic Power Supply and Motors Concept and Theory

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Hydraulic Systems

Component Identification and Function

A typical hydraulic fluid handling system, shown in Figure 1, is one in which the power supply, or power pack, provides hydraulic fluid at a given pressure and flow to operate differential hydraulic motors. These motors, in turn, drive fluid displacement pumps that deliver fluid at a given pressure and flow for a specific application.

This module will discuss in detail only these parts of the hydraulic system - the hydraulic power supply and differential hydraulic motors. Fluid displacement pumps and application equipment are covered in other training modules.

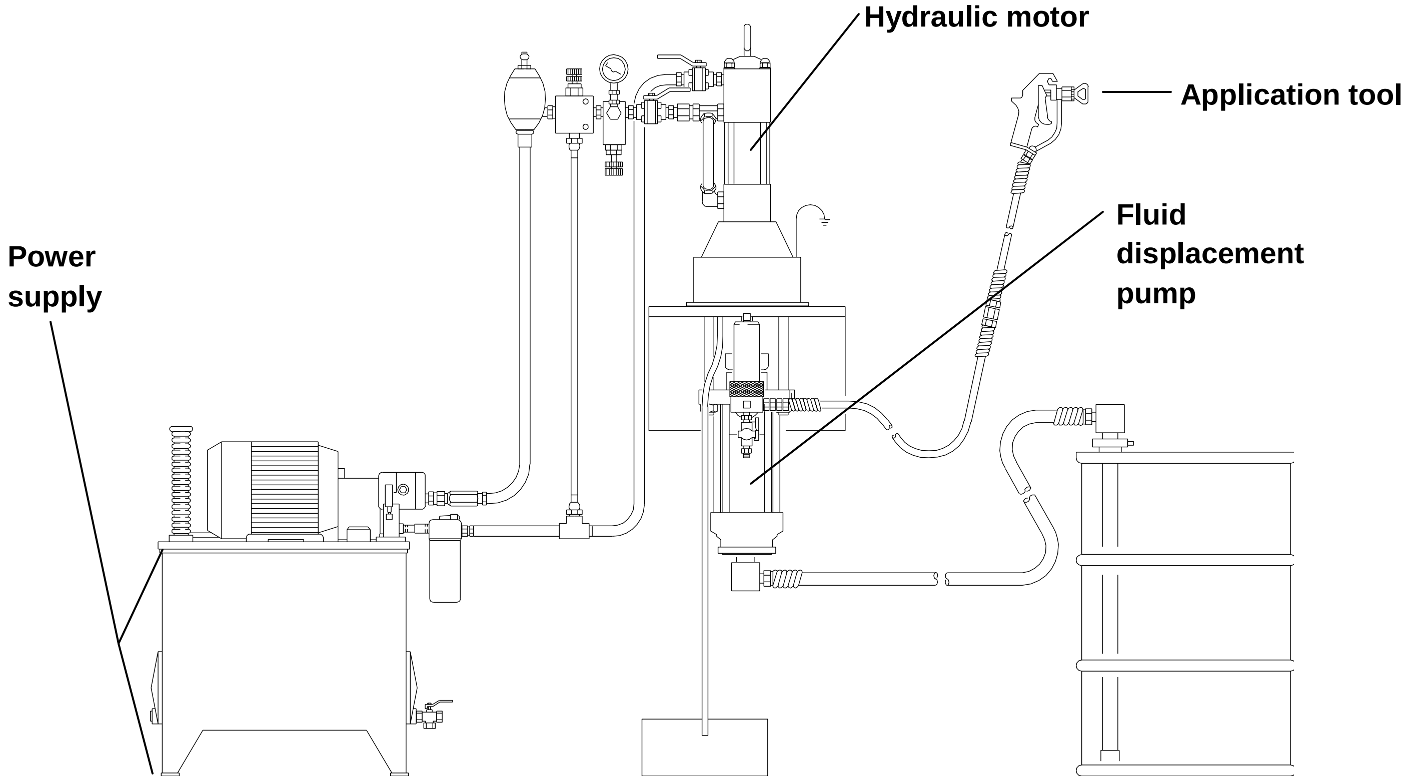

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Figure 1 Hydraulic Fluid Handling System

Figure 2 shows the basic components of a hydraulic power supply. Their functions are:

The **reservoir** stores and cools hydraulic oil and provides the mounting surface for other power supply components. It contains:

- *Clean-out doors* and a *fluid drain port* that are used for cleaning and maintenance.
- A *filler breather port/cap* that is used to fill the reservoir for with oil. The reservoir must breathe to atmosphere for proper operation.
- A *low level/high temperature sensor* that detects a low hydraulic oil level in the reservoir or a high oil temperature condition.
- A *hydraulic oil level/temperature indicator* that provides a visual check for oil level and temperature during operation.

The **hydraulic pump** provides hydraulic oil to all hydraulic motors in the system. It contains a manually adjustable pressure compensator that is used to adjust the hydraulic oil pressure to the header, or piping, system.

The **motor** drives the hydraulic pump. For industrial in-plant applications, it is usually electric. For mobile applications, the engine power take-off, or PTO, may drive the hydraulic pump.

The **oil supply line** supplies hydraulic oil under pressure from the power supply to the hydraulic motor.

The **oil return line** returns hydraulic oil, usually at low pressure, from the hydraulic motor back to the power supply's reservoir.

The **return oil filter,** located on the return line between the last hydraulic-powered device and the reservoir, removes contaminants from the hydraulic oil.

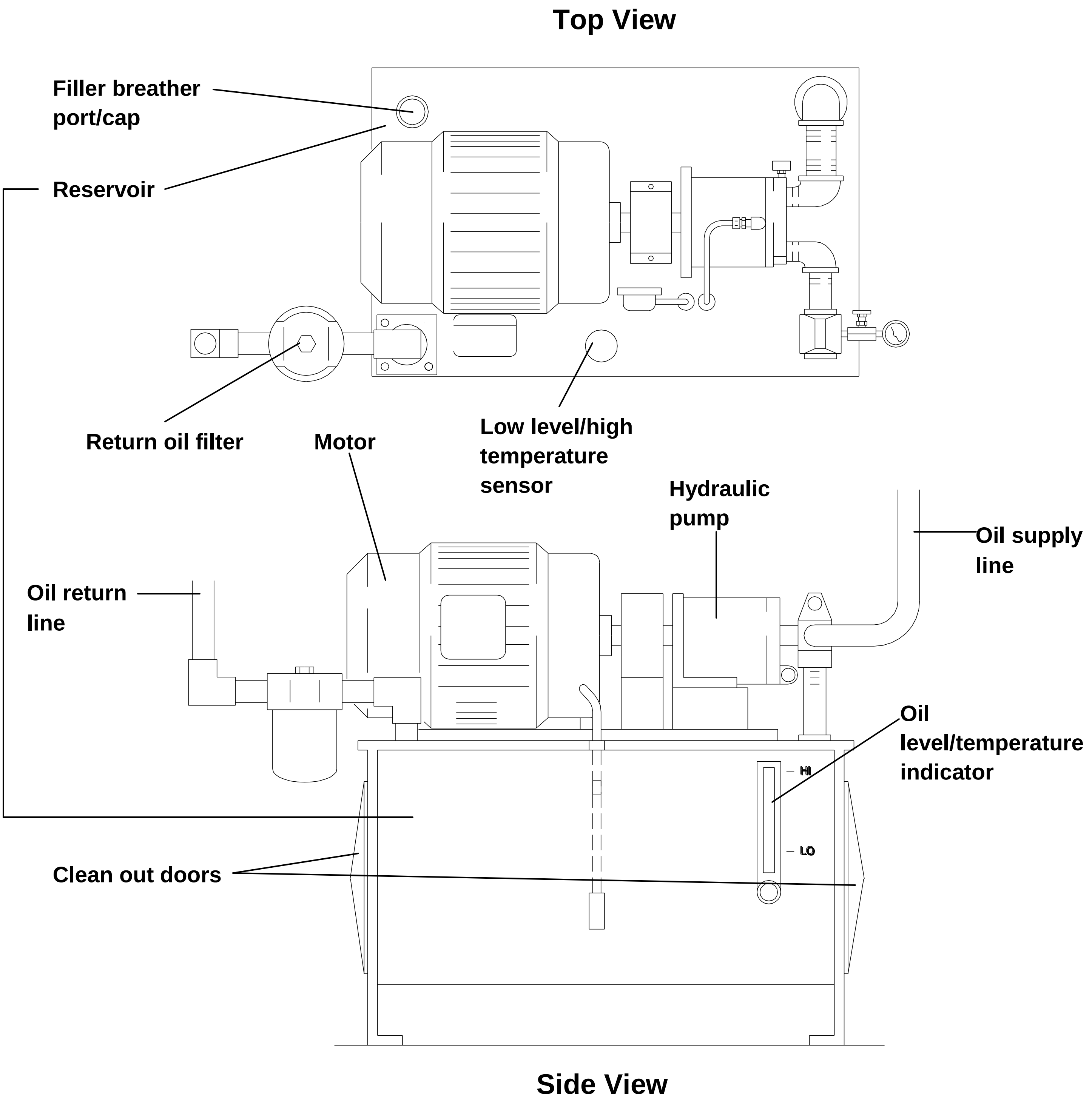

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Figure 2 Components of a hydraulic power supply

How Hydraulic Systems Work

A typical hydraulic system operates as shown in Figure 3:

1. The motor, usually electric, drives a hydraulic pump.
2. The hydraulic pump draws oil from the reservoir and pumps it to the hydraulic motor via the oil supply line.
3. Hydraulic oil enters and exits the hydraulic motor, causing it to reciprocate.
4. The reciprocation of the hydraulic motor drives the fluid section or displacement pump.
5. The displacement pump delivers the fluid in conjunction with the application equipment.
6. The hydraulic oil that leaves the hydraulic motor returns to the reservoir via the oil return line.

A hydraulic system is a closed loop power supply system. It uses hydraulic oil to power devices. The oil is not exhausted out of the system after the devices are powered, but is routed back to the power supply reservoir and reused in a continuous loop.

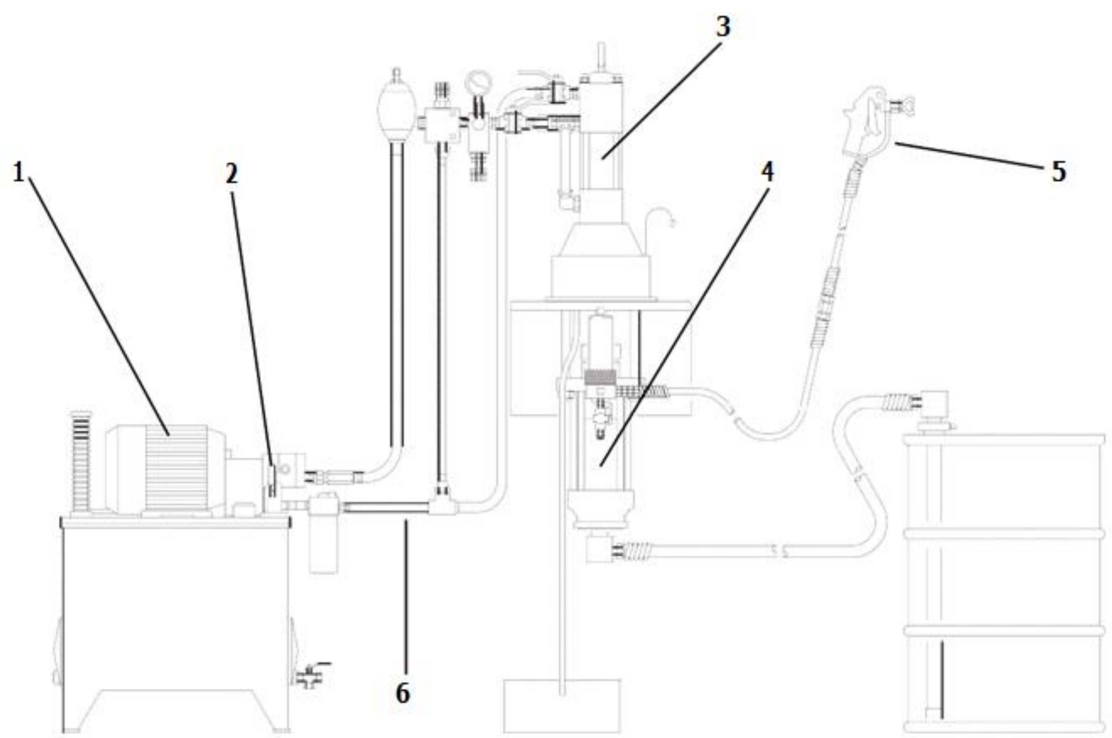

Figure 3 Hydraulic system operation

Pressure and Flow Control

In a **hydraulic fluid handling system,** hydraulic fluid controls are used to regulate the hydraulic oil pressure and flow to each hydraulic motor to keep the system balanced and functioning more productively. These controls include the hydraulic pressure reducing valve and the flow control valve:

The **hydraulic pressure reducing valve** is used to adjust the hydraulic system oil pressure to the operating pressure required by the fluid pump for the specific application. A pressure gauge is provided to verify the pressure setting.

The **flow control valve** limits the maximum amount of hydraulic oil flow to the hydraulic motor, ensuring that it operates at the recommended cycle rate. This prevents pump runaway when a supply container empties or a fluid line ruptures.

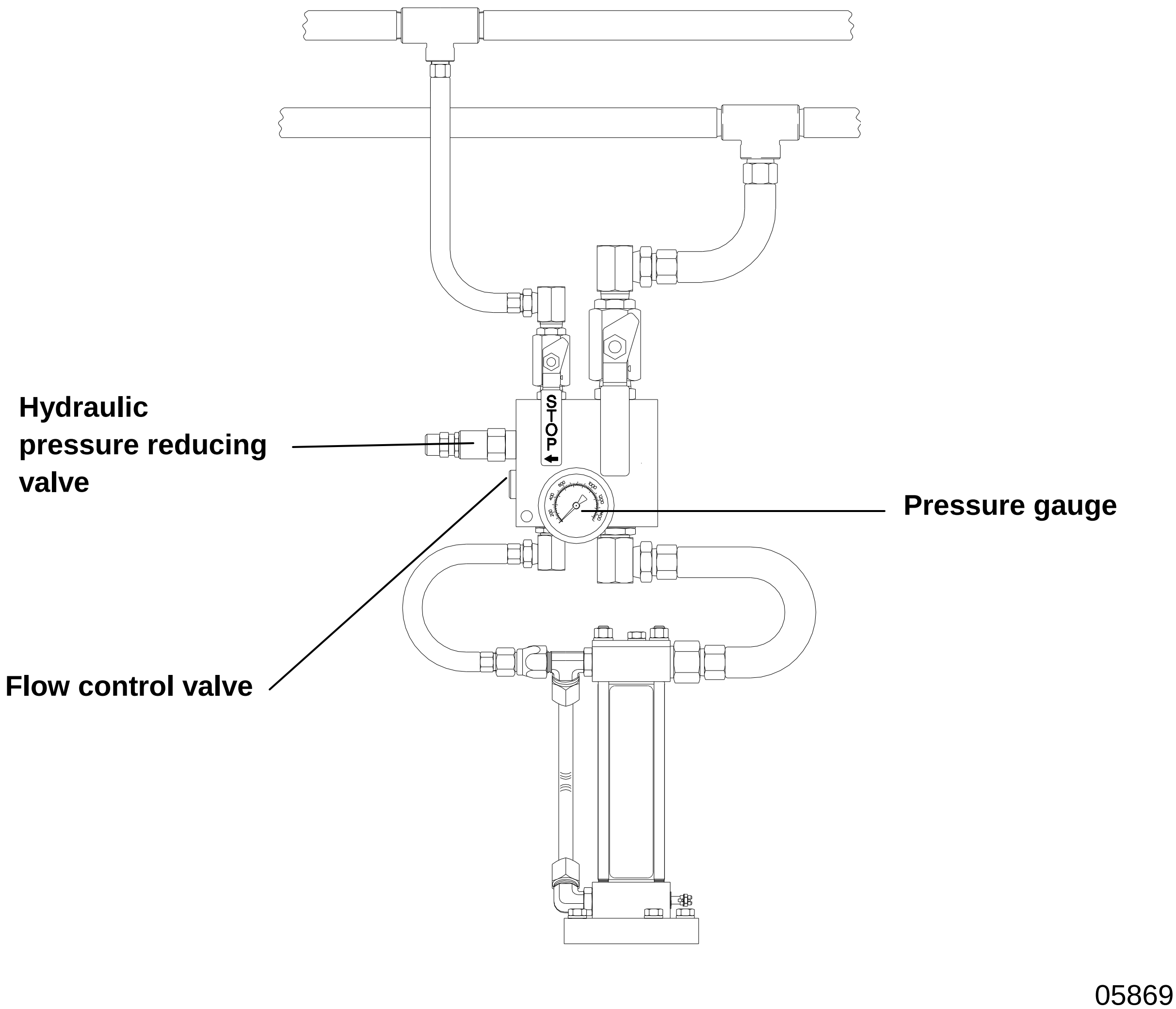

Figure 4 Hydraulic fluid controls

Power Supply Sizing

When selling hydraulics, you'll need to know how to determine the correct size for a proposed hydraulic system's power supply. To do so, follow these basic steps:

1. Figure out the required fluid pressure and flow at each point of application.
2. Select the pump package with the correct motor-to-pump ratio. Hydraulic-driven pumps require higher input pressures to the motor than air-driven pumps. Since the hydraulic input pressure is greater, pump ratios are smaller. Refer to the ***Pump Ratio and Performance Charts*** module for more information on pump and motor selection.
3. Determine the hydraulic oil consumption rate for all the hydraulic motors in the system at the required cycle rate. Check the pump performance charts for the selected pump for this information. See Figure 5 for an example of a pump performance chart.
4. Refer to the technical data sheets for the hydraulic motor to determine the maximum working pressure.
5. Provide the oil consumption rate and maximum working pressure information for the hydraulic motor to the power supply supplier to ensure that the power supply built for the proposed hydraulic system will have the horsepower required to perform the desired application and handle future expansion.

Note: Hydraulic fluid is exhausted from differential hydraulic motors only on the upstroke of the operating cycle so the oil return line must have at least twice the flow capacity as the oil supply line. Otherwise, back pressure on the hydraulic motor piston will slow down the motor and the fluid dis- placement pump, resulting in a loss of pump performance.

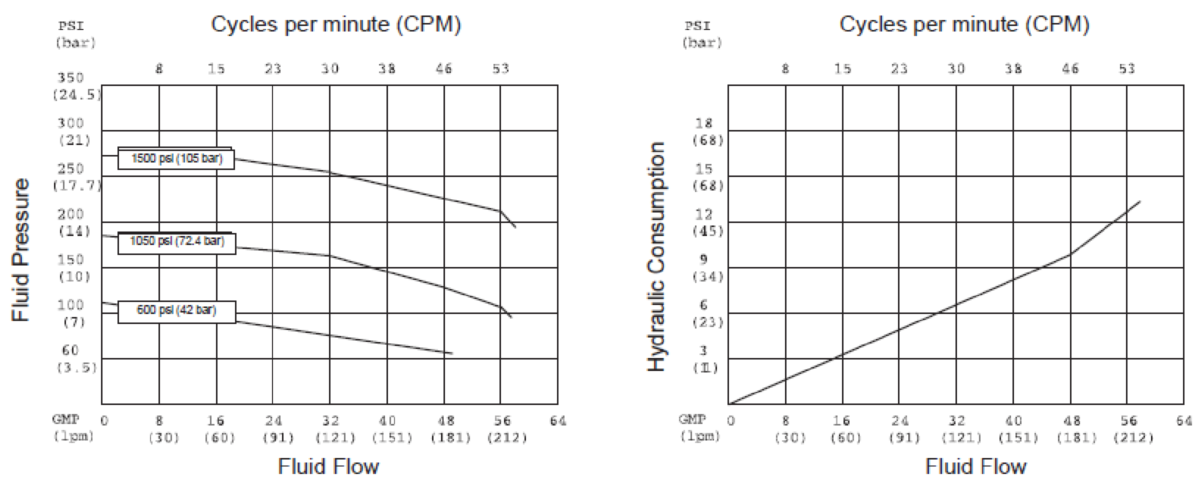

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Figure 5 Pump performance charts

Progress Check

Directions: After answering the following questions, compare your answers with those provided in the answer key following the progress check. If you respond to any items incorrectly, return to the text and review the appropriate topics.

1. *Write the name of the correct hydraulic power supply component in the blank following each number*.

Hydraulic pump	Oil return line	Return oil filter
Motor	Oil supply line	Reservoir

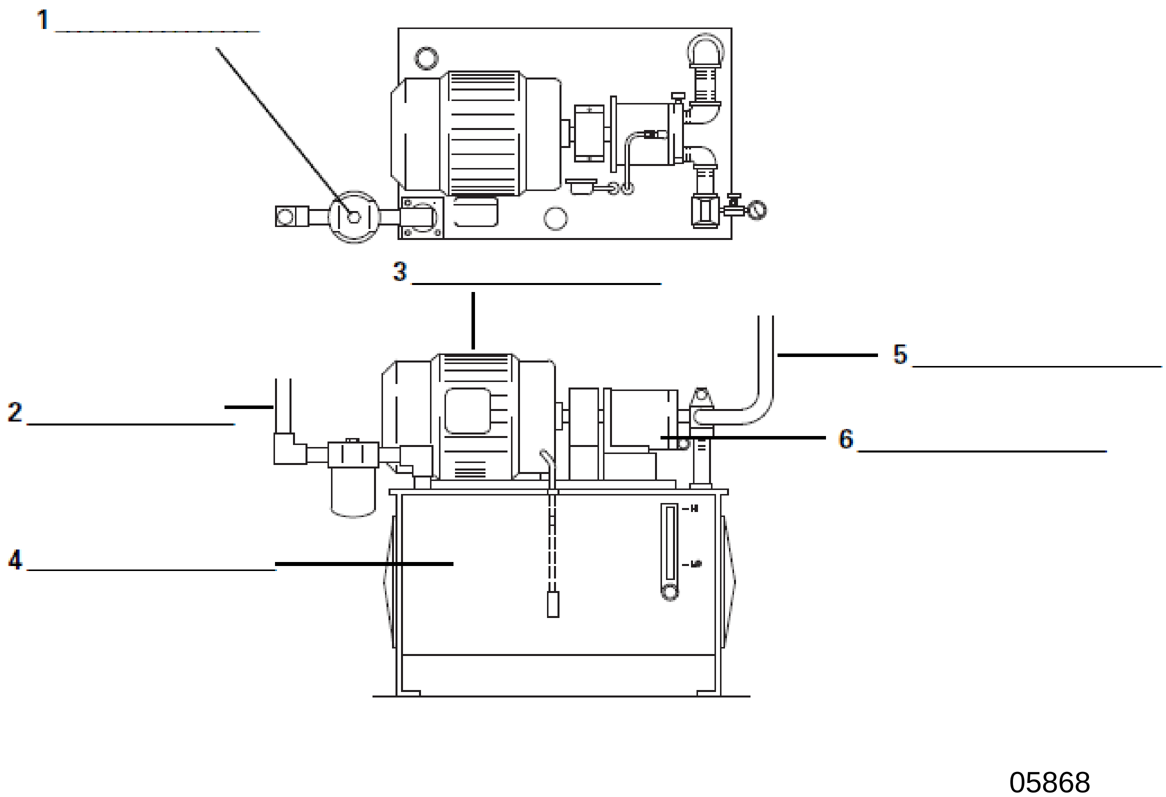

Figure 2 Components of a hydraulic power supply

2. *In each blank, write the name of the hydraulic power supply component that matches the described function. Choose from the list in the previous question.*
   a. ______________________ Removes contaminants from the hydraulic oil.
   b. ______________________ Drives the hydraulic pump.
   c. ______________________ Stores and cools the hydraulic oil.
   d. ______________________ Carries pressurized hydraulic oil to powered device.
   e. ______________________ Provides pressurized hydraulic oil to all pumps in the system.
   f. ______________________ Carries hydraulic oil back to reservoir from powered device.
3. *Number the hydraulic system operational steps below in the correct order from 1 to 5.*

   ______ Displacement pump and application equipment deliver fluid

   ______ Hydraulic pump draws oil from reservoir and pumps it to hydraulic motor via oil supply line; oil returns to reservoir via oil return line

   ______ Hydraulic motor reciprocates

   ______ Hydraulic motor reciprocation drives displacement pump

   ______ Motor drives hydraulic pump

Answers to Progress Check

1. The correct answers are:

   [1] Return oil filter

   [2] Oil return line

   [3] Motor

   [4] Reservoir

   [5] Oil supply line

   [6] Hydraulic pump

2. The correct answers are:

   a. The return oil filter removes contaminants from the hydraulic oil.

   b. The motor drives the hydraulic pump.

   c. The reservoir stores and cools the hydraulic oil.

   d. An oil supply line carries pressurized hydraulic oil to a powered device.

   e. The hydraulic pump provides pressurized hydraulic oil to all hydraulic motors in the system.

   f. An oil return line carries hydraulic oil back to the reservoir from a powered device.

3. The correct answers are:

   5 Displacement pump and application equipment deliver fluid

   2 Hydraulic pump draws oil from reservoir and pumps it to hydraulic motor via oil supply line; oil returns to reservoir via oil return line

   3 Hydraulic motor reciprocates

   4 Hydraulic motor reciprocation drives displacement pump

   1 Motor drives hydraulic pump

Hydraulic Motors

Component Identification and Function

Differential hydraulic motors are devices that are powered by pressurized hydraulic oil provided by a hydraulic power supply. The flow of the pressurized oil through the motor, shown in Figure 6, causes it to reciprocate. The reciprocation of the motor drives the fluid section or pump.

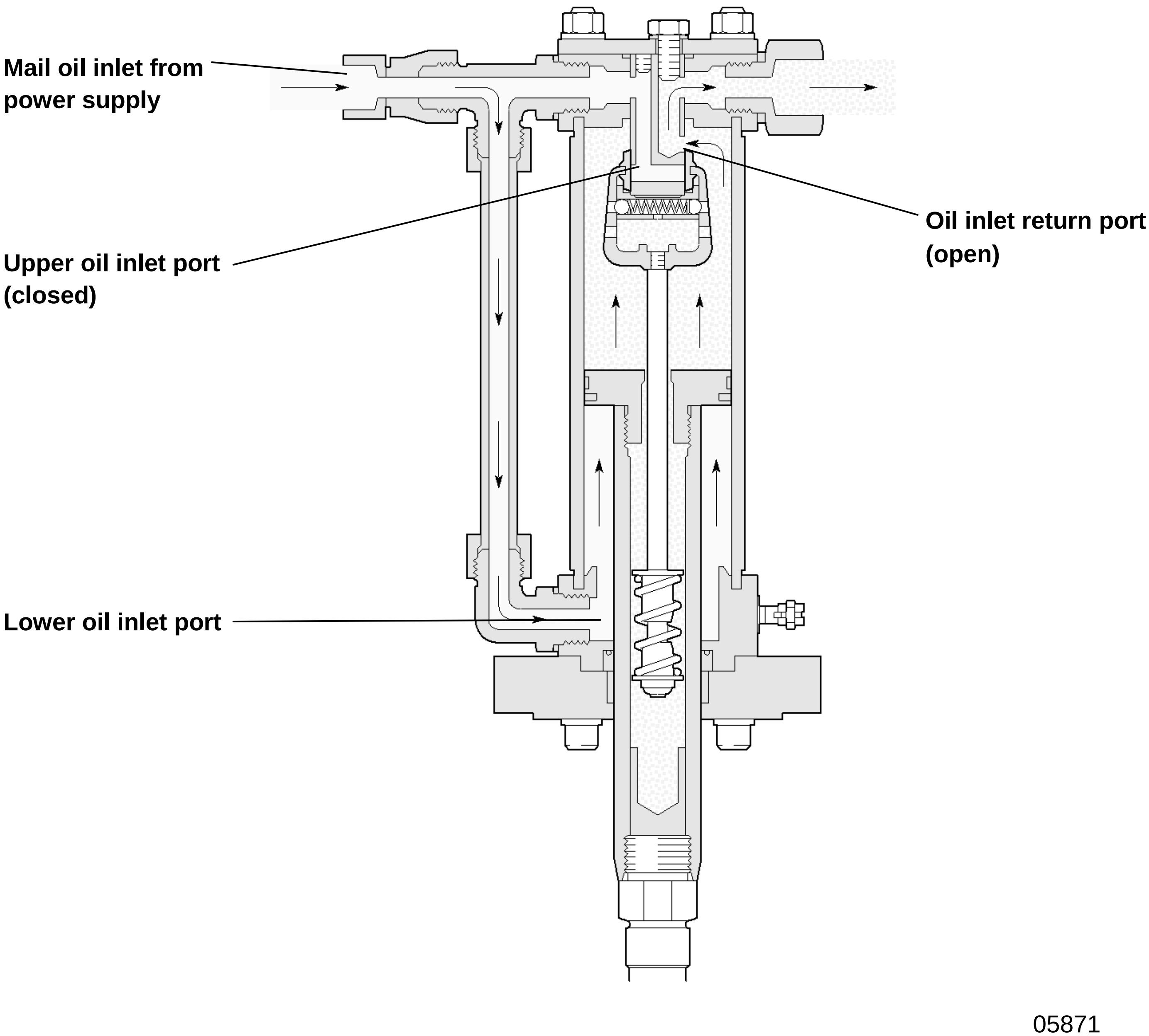

Figure 6 Differential hydraulic motor

The trade names for Graco's hydraulic motors are Viscount I, I+ and II, Dyna-Star and Power-Star. Viscount I, I+, and II are divorced-design industrial motors. Dyna-Star and Power-Star are in-line lubrication motors. Differential hydraulic motors contain the basic components shown in Figures 7 and 8.

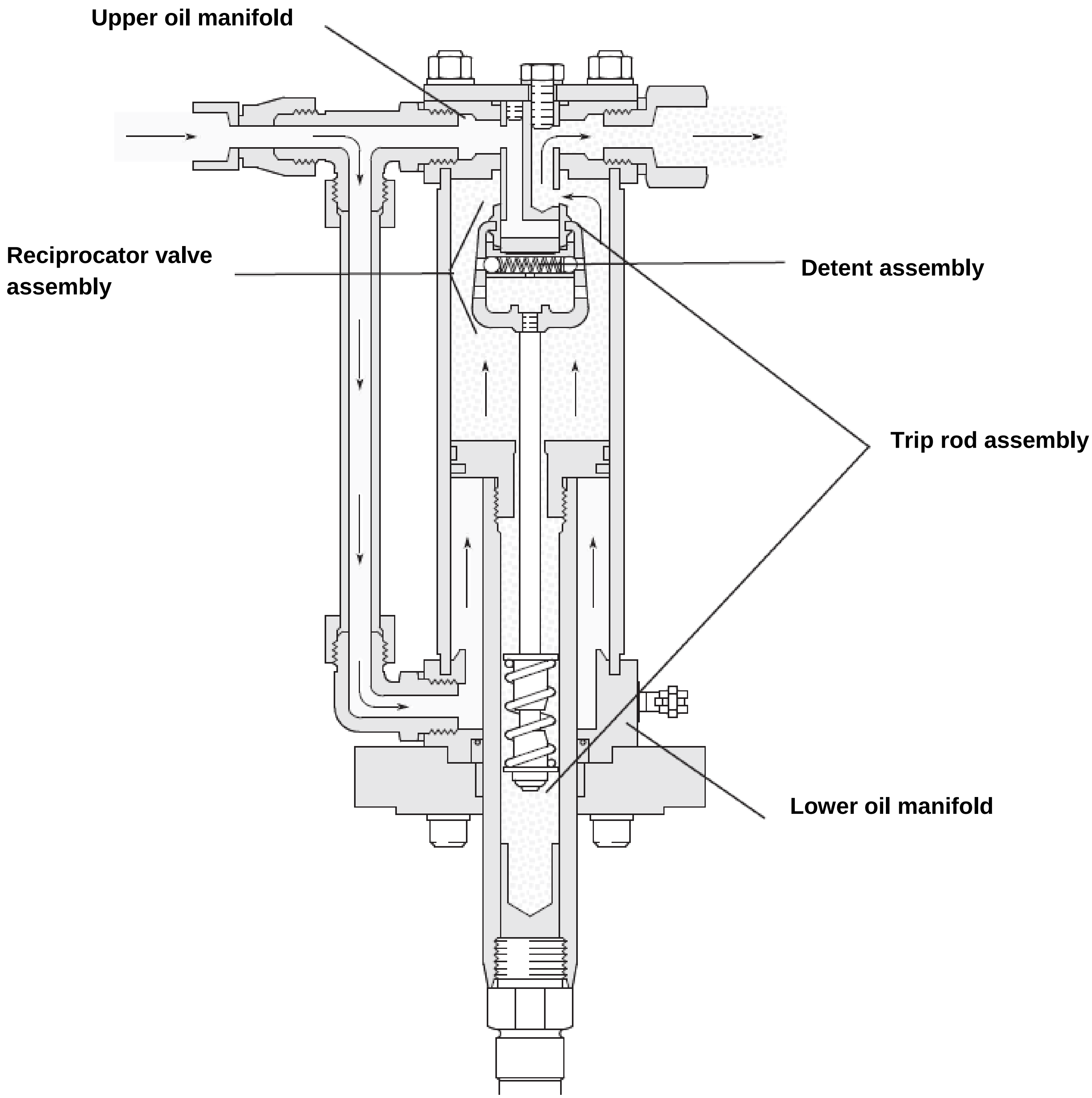

Figure 7 Assemblies of a hydraulic motor

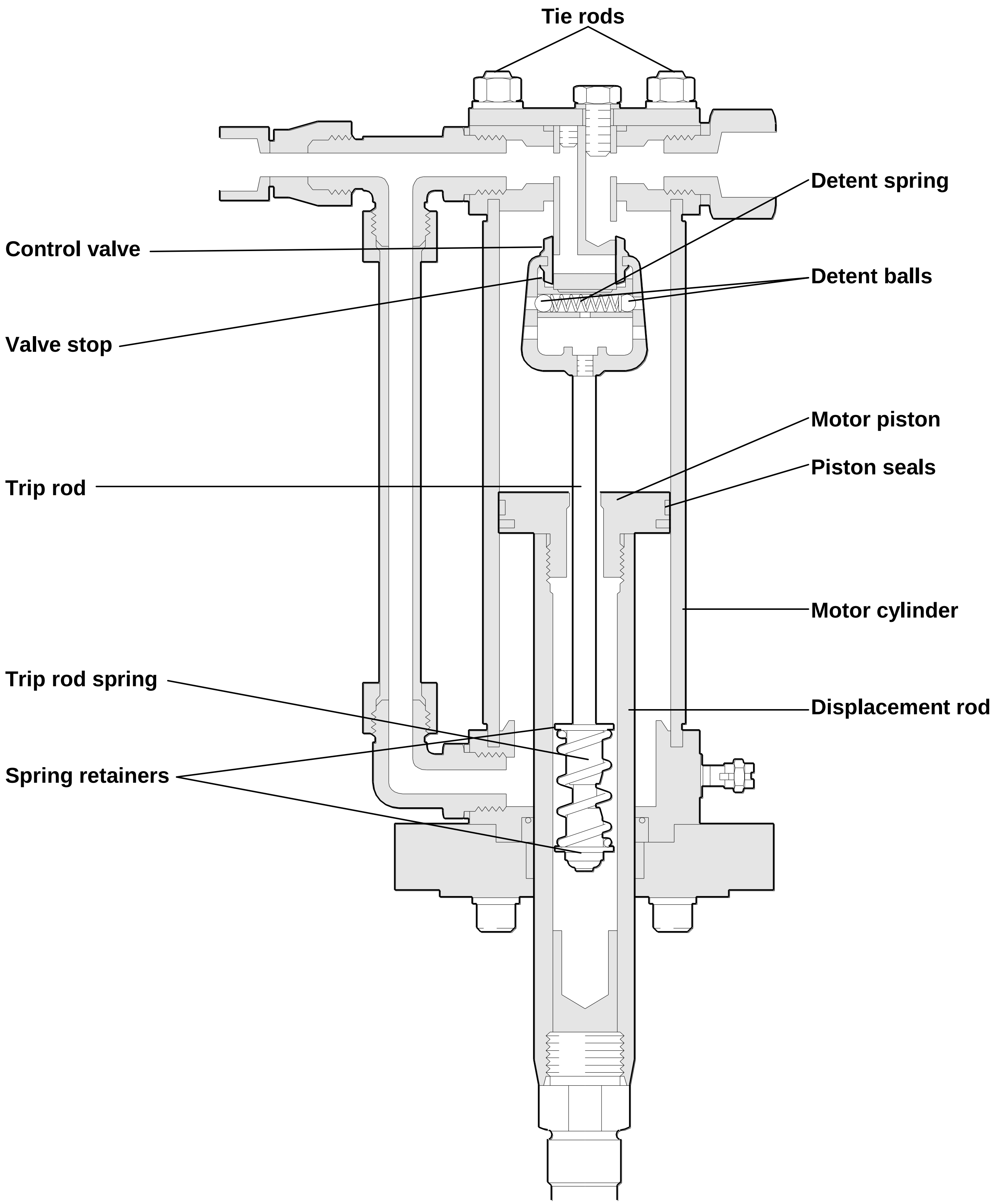

Figure 8 Other components of a hydraulic motor

These components function as follows:

The **trip rod assembly** consists of the *trip rod, trip rod spring,* and *spring retainers*. It controls the position of the reciprocator valve assembly by providing the tension needed to actuate the detent assembly at the appropriate times. It also acts as a shock absorber to minimize wear on contact surfaces.

The **reciprocator valve assembly** contains a *control valve* that provides directional flow for hydraulic oil through the motor. It does this by opening and closing appropriate oil ports, controlling the oil flow to and from the top side of the motor piston. The reciprocator valve assembly moves very rapidly during changeover at the end of each piston stroke to ensure that the motor changes direction quickly.

The **detent assembly** provides the pressure that keeps the reciprocator valve assembly properly positioned during the upstroke and down stroke phases of motor operation. During changeover at the end of each piston stroke, it moves very rapidly to ensure that the motor changes direction quickly. The detent assembly consists of detent springs and steel detent balls. The *detent spring* provides the spring tension needed to make the *detent balls* hold the control valve of the reciprocator valve assembly in the proper position.

The **upper oil manifold,** which is part of the upper cylinder cap assembly, contains the main oil inlet which delivers high pressure oil from the power supply to the motor. It also contains the *upper oil inlet port* to the top side of the motor piston and the *oil return port* to the hydraulic system reservoir.

The **lower oil manifold**, which is part of the bottom cylinder cap, contains the lower *oil inlet port* to the bottom side of the motor piston.

The **valve stop** limits the downward travel of the reciprocator valve assembly. It contains the detent assembly.

The **motor piston** provides the surface area for the hydraulic oil to exert pressure against, thus trans- forming the oil pressure into mechanical force.

The **piston seals** seal the motor piston tightly to the motor cylinder, preventing oil leaks between the top and bottom sides of the piston.

The **motor cylinder** provides the surface against which the motor piston seals.

The **displacement rod** is a hollow cylinder that surrounds the trip rod assembly. It is connected to the motor piston and to the fluid piston rod of the pump. The mechanical force from the motor piston is transferred to the pump via this rod.

Tie rods hold the motor assembly together.

Progress Check

Directions: After answering the following questions, compare your answers with those proved in the answer key following this progress check. If you respond to any items incorrectly, return to the text and review the appropriate topics.

1. *Write the name of the correct hydraulic motor component in the blank following each number. Choose from the list below.*

Control valve	Motor cylinder	Upper oil manifold
Detent spring	Motor piston	Valve stop
Displacement rod	Piston seals	
Lower oil manifold	Tie rods	

2.

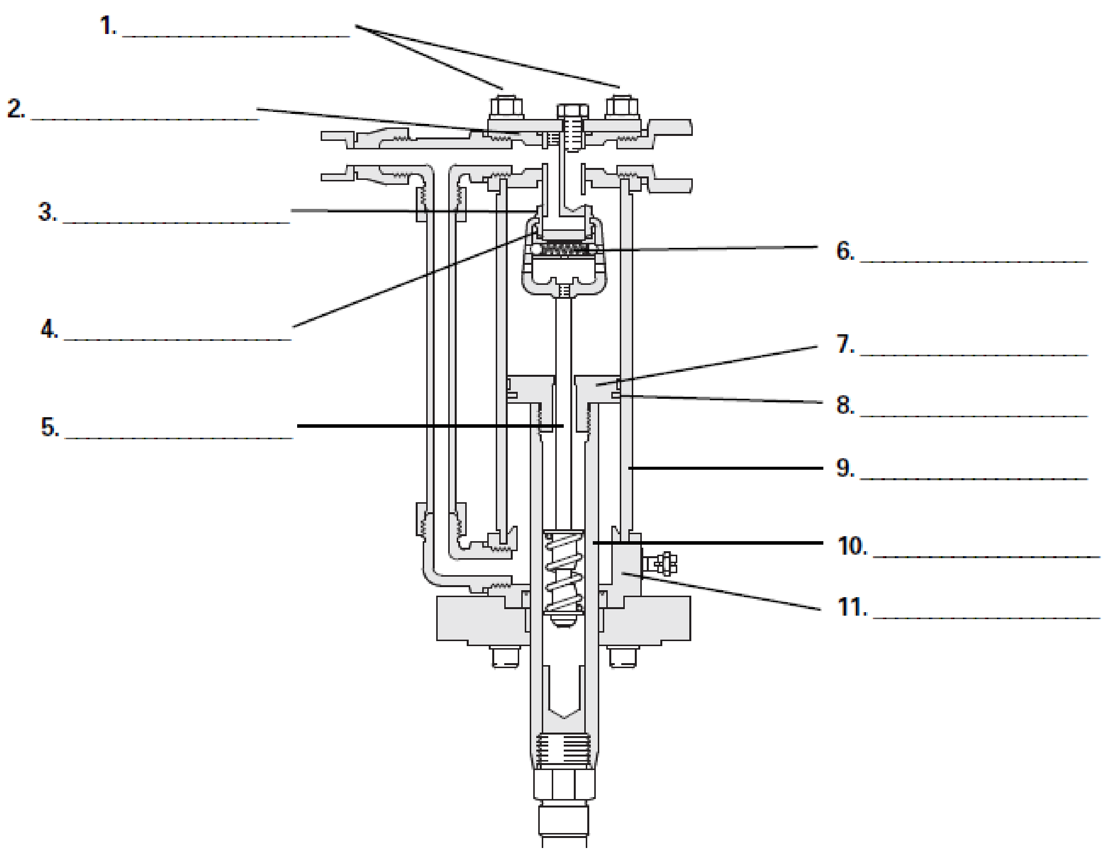

Figure 8 Other components of a hydraulic motor

3. *In each blank, write the name of the hydraulic motor component that matches the described function. Choose from the list below.*

Detent assembly	Motor piston	Tie rods
Displacement rod	Piston seals	Trip rod assembly
Lower oil manifold	Reciprocator	Upper oil manifold
Motor cylinder	Valve assembly	Valve stop

4.

a. ____________________ Controls the flow of oil to and from the top side of the motor

b. ____________________ Provides the surface area for oil to exert pressure against

c. ____________________ Contains the lower oil inlet port

d. ____________________ Actuates the detent assembly at the appropriate times

e. ____________________ Prevents oil leaks between the top and bottom sides of the piston

f. ____________________ Keeps the reciprocator valve assembly properly positioned during the upstroke and down stroke phases

g. ____________________ Provides the surface against which the motor piston seals

h. ____________________ Transfers mechanical force from the motor piston to the pump

i. ____________________ Contains the upper oil inlet port and the oil return port

j. ____________________ Contains the detent assembly

k. ____________________ Holds the motor assembly together

Answers to Progress Check

1. The correct answers are:

   [1] Tie rods

   [2] Upper oil manifold

   [3] Control valve

   [4] Valve stop

   [5] Trip rod

   [6] Detent spring

   [7] Motor piston

   [8] Piston seals

   [9] Motor cylinder

   [10] Displacement rod

   [11] Lower oil manifold

2. The correct answers are:

   a. The <u>reciprocator valve assembly</u> controls the flow of oil to and from the top side of the motor.

   b. The <u>motor piston</u> provides the surface area for oil to exert pressure against.

   c. The <u>lower oil manifold</u> contains the lower oil inlet port.

   d. The <u>trip rod assembly</u> actuates the detent assembly at the appropriate times.

   e. The <u>piston seal</u> prevents oil leaks between the top and bottom sides of the piston.

   f. The <u>detent assembly</u> keeps the reciprocator valve assembly properly positioned during the upstroke and down stroke phases.

   g. The <u>motor cylinder</u> provides the surface against which the motor piston seals.

   h. The <u>displacement rod</u> transfers mechanical force from the motor piston to the pump.

   i. The <u>upper oil manifold</u> contains the upper oil inlet port and the oil return port.

   j. The <u>valve stop</u> contains the detent assembly.

   k. <u>Tie rods</u> hold the motor assembly together.

How Differential Hydraulic Motors Work

To aid in your understanding, discussion of the hydraulic motor's operating cycle is divided into: upstroke, top changeover, down stroke, and bottom changeover.

1. The oil inlet port in the upper oil manifold to the top side of the motor piston is closed.
2. The oil return port in the upper oil manifold to the reservoir is open.
3. The oil inlet port in the lower oil manifold to the bottom side of the motor piston is open. Pressurized hydraulic oil enters the motor through this lower oil inlet port.
4. The pressurized hydraulic oil pushes the motor piston up.
5. The oil above the motor piston is pushed out of the motor and back to the reservoir through the oil return port. During upstroke, twice as much oil exits from the motor through the oil return port as enters the motor through the lower oil inlet port.
6. The displacement rod moves upward with the motor piston, pulling up the displacement rod of the pump.

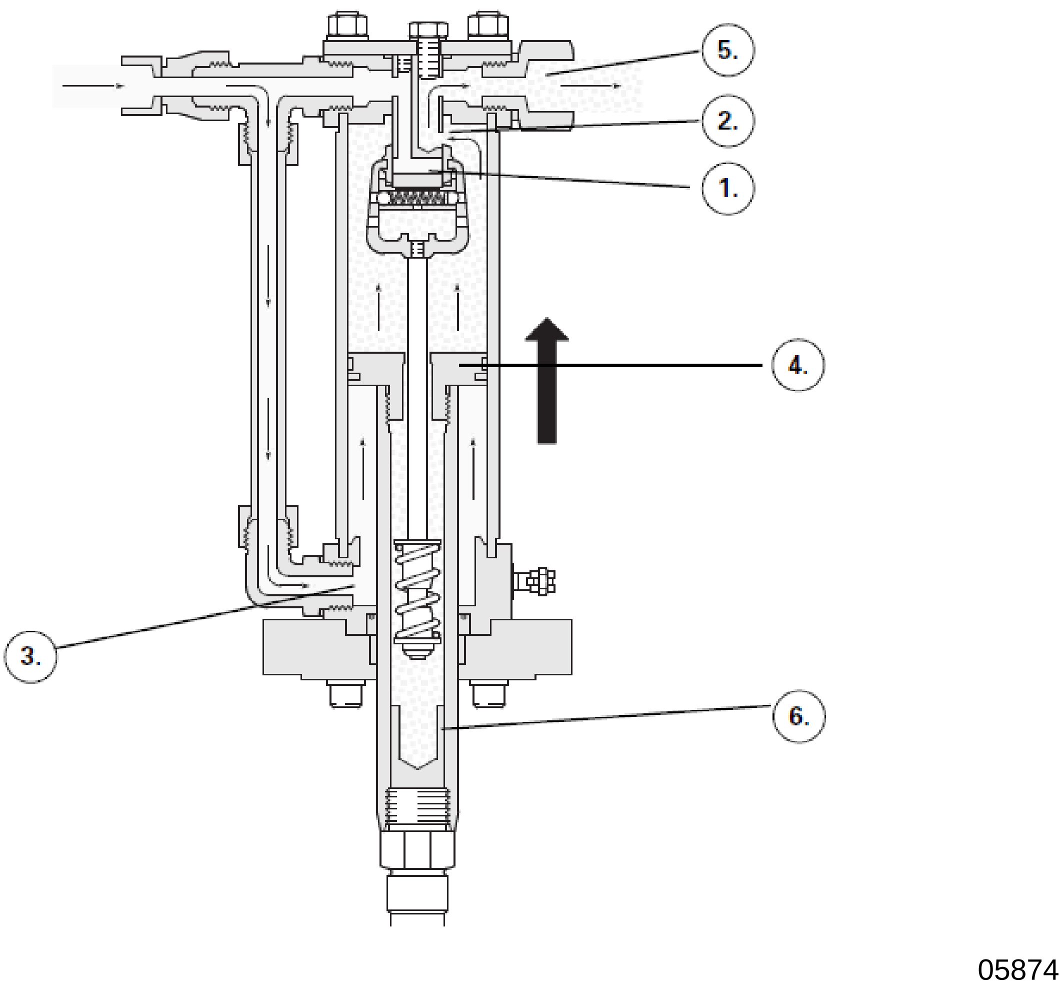

Figure 9 Upstroke

During top changeover, the motor components work as shown in Figure 10:

1. The bottom of the inner part of the displacement rod contacts the trip rod spring.
2. The motor piston continues to travel upward, compressing the trip rod spring until the force on the trip rod spring exceeds the force on the detent spring.
3. When the detent spring force is exceeded, the reciprocator valve assembly quickly moves upward.
4. The upper oil inlet port to the top side of the motor piston opens.
5. The oil return port in the upper oil manifold to the reservoir closes. No hydraulic oil can exit the motor.
6. The lower oil inlet port to the bottom side of the motor piston remains open.

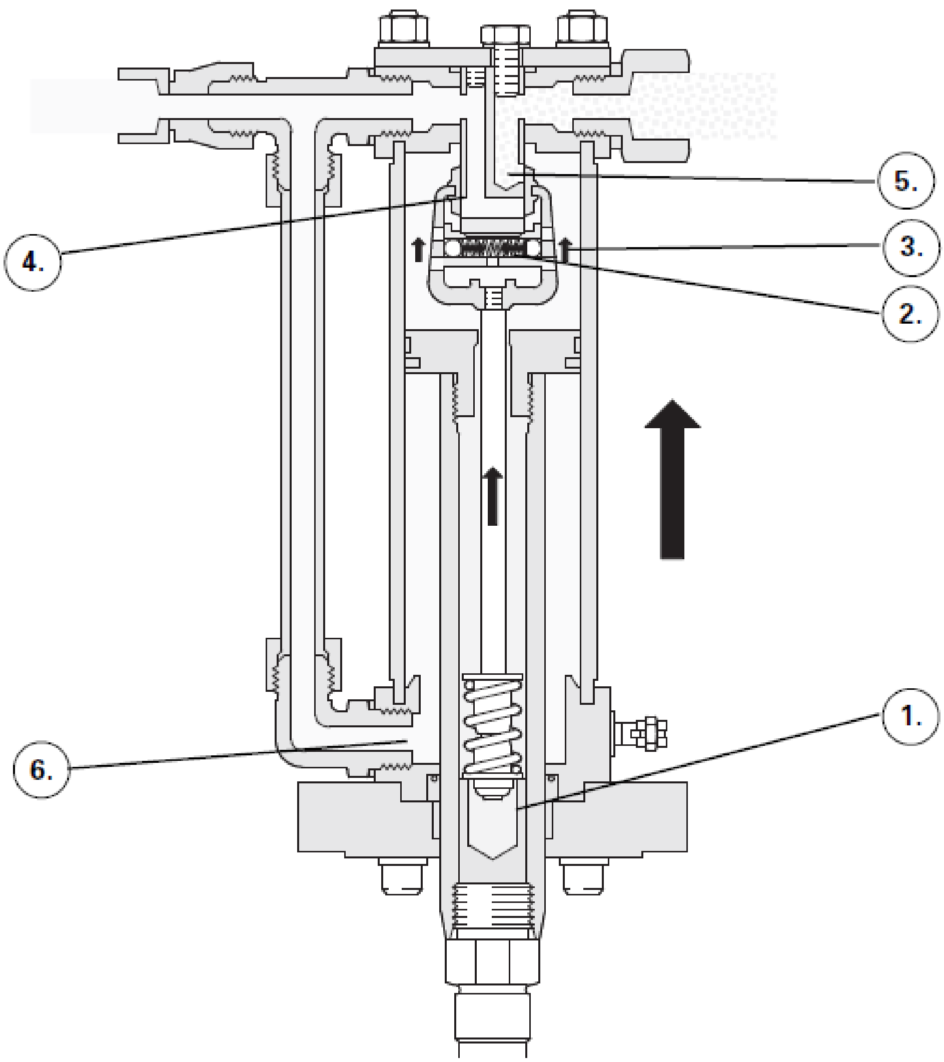

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Figure 10 Top changeover

During down stroke, the motor components work as shown in Figure 11:

1. Hydraulic oil enters the motor through both the upper and lower oil inlet ports, pressurizing both sides of the motor piston.
2. Because the surface area on the top side of the motor piston is twice as great as the surface area on the bottom, the force above the piston is twice as great as the force underneath it. Therefore, the motor piston moves downward.
3. Since the oil return port to the reservoir is closed, all the oil below the motor piston is forced out through the lower oil inlet port and up to the top side of the motor piston.
4. The displacement rod moves downward with the motor piston, pushing the displacement rod of the pump down.

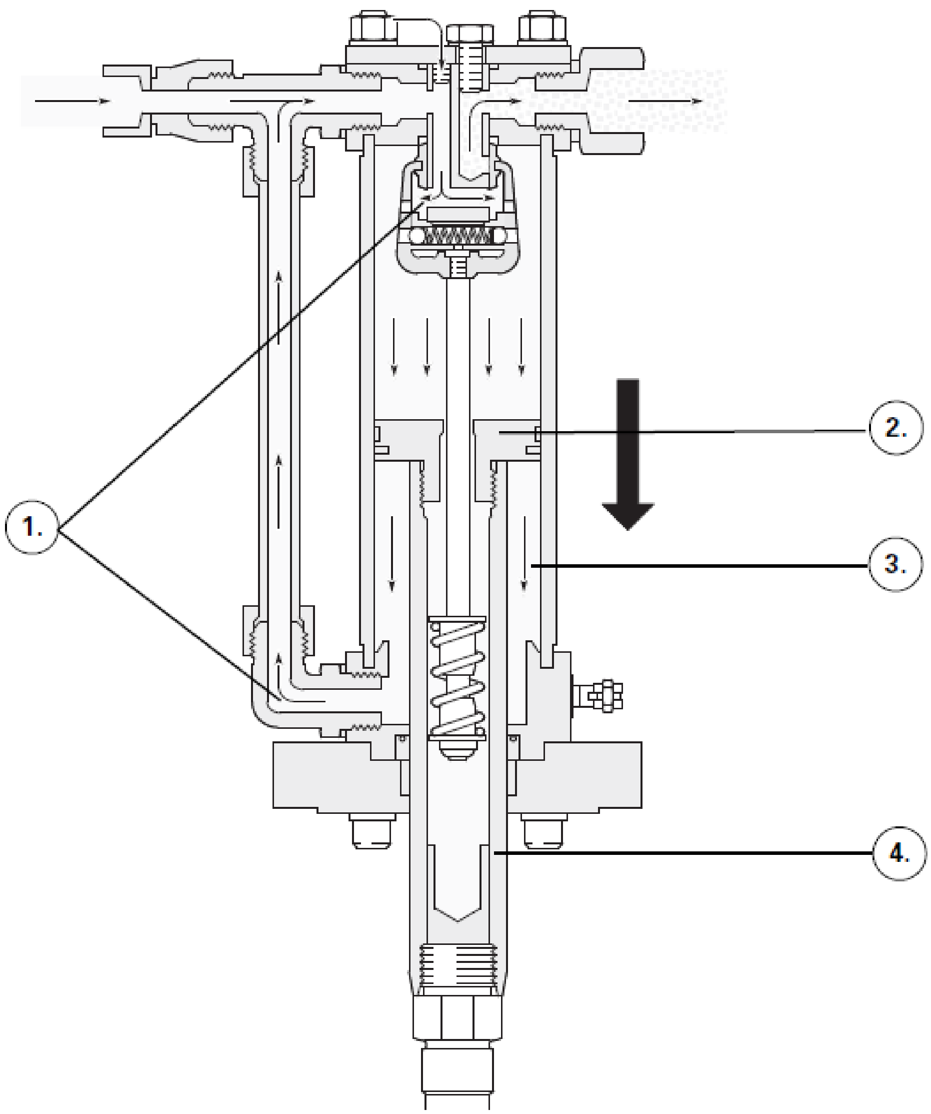

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Figure 11 Down stroke

During bottom changeover, the motor components work as shown in Figure 12:

1. The motor piston contacts the trip rod spring.
2. The motor piston continues to travel downward, compressing the trip rod spring until the force on the trip rod spring exceeds the force on the detent spring.
3. When the detent spring force is exceeded, the reciprocator valve assembly quickly moves downward.
4. The upper oil inlet port to the top side of the motor piston closes.
5. The oil return port in the upper oil manifold to the reservoir opens.
6. The lower oil inlet port to the bottom side of the motor piston remains open. Pressurized hydraulic oil enters the motor here.
7. Hydraulic oil will now exit the motor at twice the rate that it enters. Since pressurized hydraulic oil is entering only through the lower oil inlet port to the bottom side of the motor piston, it will push the piston upward.

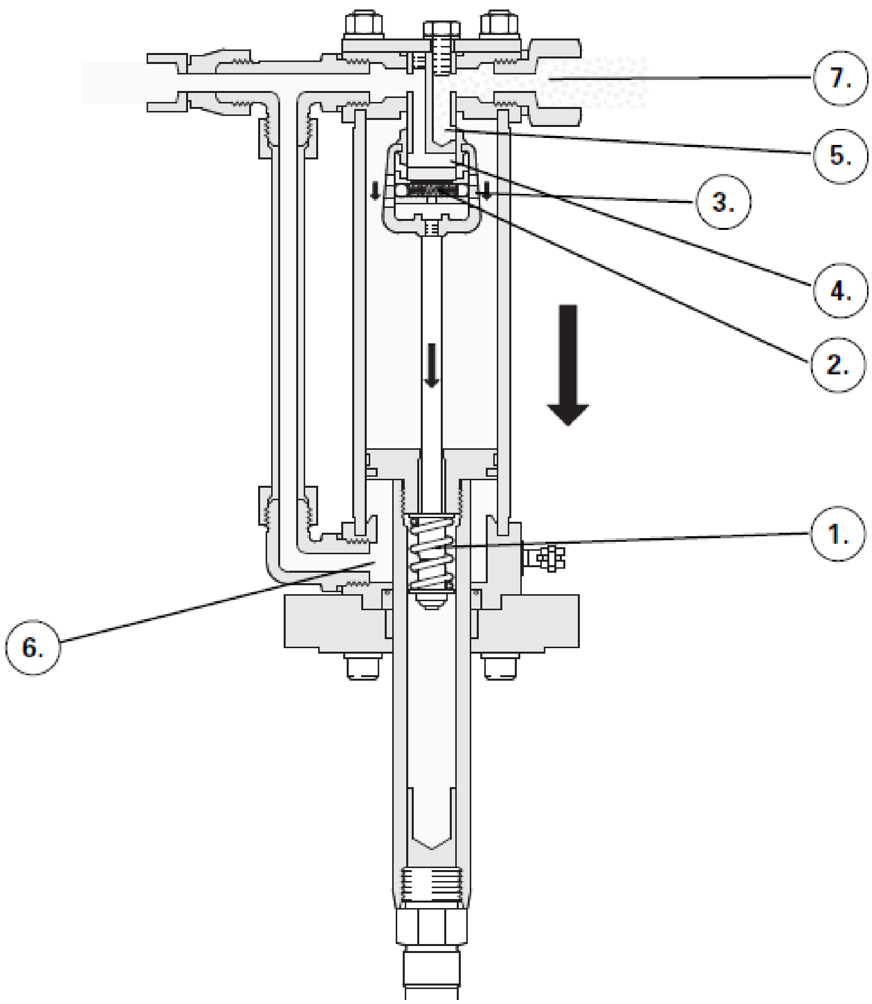

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Figure 12 Bottom changeover

Progress Check

Directions: After answering the following questions, compare your answers with those proved in the answer key following this progress check. If you respond to any items incorrectly, return to the text and review the appropriate topics.

Fill in the blanks to answer the following questions about the upstroke, down stroke, and changeover phases of the differential hydraulic motor's operating cycle. Refer to the graphics for help.

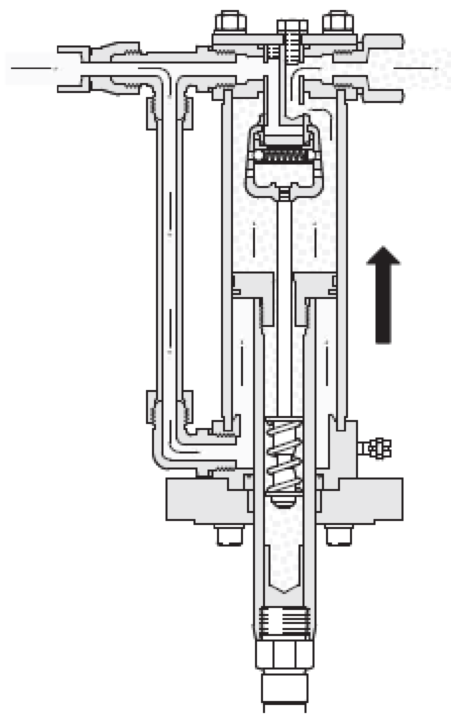

Figure 9 Upstroke

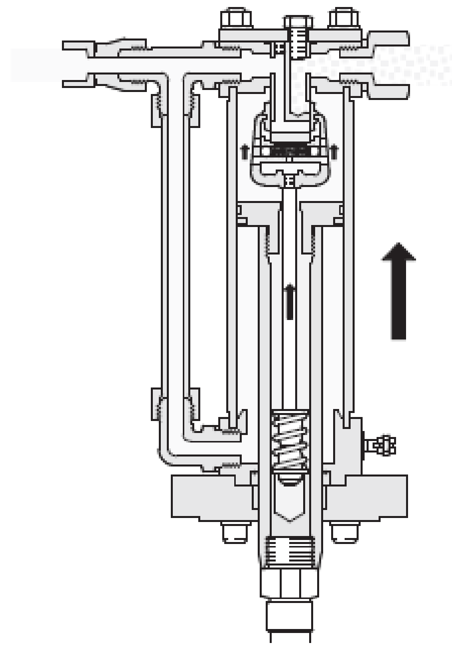

Figure 10 Top changeover

1. During upstroke:
    a. The upper oil inlet port is _____________________.
    b. The lower oil inlet port is_____________________.
    c. The oil return port is _____________________.
    d. The _____________________ moves up, forcing the oil above to exit via the _____________________.
    e. The _____________________ moves up, pulling the _____________________ of the pump up.
2. During top changeover:

a. The displacement rod contacts the ______________________.

b. The upward movement of the ______________________ compresses the ______________________ until detent spring force is exceeded.

c. The ______________________ then moves quickly upward, opening the ______________________ and closing the ______________________.

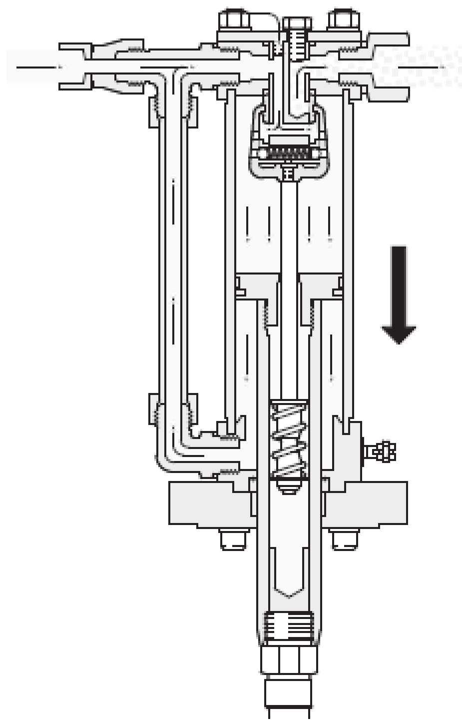

Figure 11 Down stroke

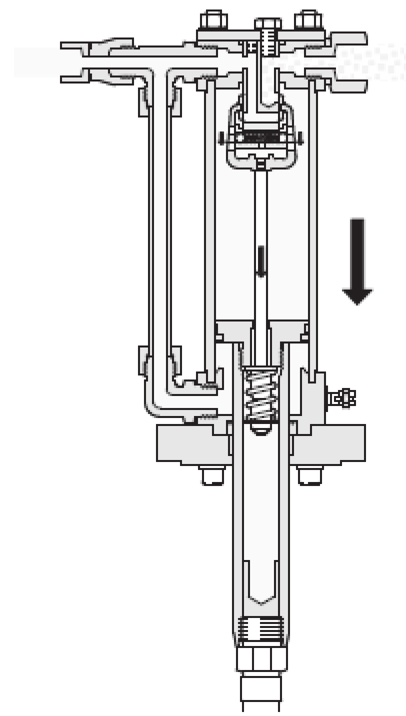

Figure 12 Bottom changeover

3. During down stroke:

   a. The ______________________ moves downward, forcing the oil below to exit via the ______________________ and re-enter via the ______________________.

   b. The ______________________ moves down, pushing the ______________________ of the pump down.

4. During bottom changeover:

   a. The ______________________ contacts the trip rod spring.

   b. The downward movement of the ______________________ compresses the ______________________ until detent spring force is exceeded.

5. The ______________________ then moves quickly downward, closing the ______________________ and opening the ______________________.

Answers to Progress Check

1. The correct answers are:

   During upstroke:

   a. The upper oil inlet port is closed.
   b. The lower oil inlet port is open.
   c. The oil return port is open.
   d. The motor piston moves up, forcing the oil above to exit via the oil return port.
   e. The motor displacement rod moves up, pulling the fluid displacement rod of the pump up.

2. The correct answers are:

   During top changeover:

   a. The displacement rod contacts the trip rod spring.
   b. The upward movement of the motor piston compresses the trip rod spring until detent spring force is exceeded.
   c. The reciprocator valve assembly then moves quickly upward, opening the upper oil inlet port and closing the oil return port.

3. The correct answers are:

   During down stroke:

   a. The motor piston moves downward, forcing the oil below to exit via the lower oil inlet port and re-enter via the upper oil inlet port.
   b. The motor displacement rod moves down, pushing the fluid displacement rod of the pump down.

4. The correct answers are:

   During bottom changeover:

   a. The motor piston contacts the trip rod spring.
   b. The downward movement of the motor piston compresses the trip rod spring until detent spring force is exceeded.
   c. The reciprocator valve assembly then moves quickly downward, closing the upper oil inlet port and opening the oil return port.

Hydraulic Systems: Advantages, Limitations, and Uses

Advantages and Limitations

The main advantages of a hydraulic fluid handling system are:

- Efficiency
- Reliable and effective operation
- A relatively low investment cost for the power supply
- A relatively small physical space requirement

Hydraulic power supplies are theoretically about five times more efficient than air compressors. A great deal of energy is required to compress air before it can perform work. Hydraulic oil is nearly incompressible, so energy is not consumed compressing it before it performs work. The efficiency advantage of a hydraulic system is greater in continuous duty applications than in intermittent applications. However, in intermittent applications, although the power supply continues to operate in bypass mode, it does so with much lower energy consumption than in continuous duty applications. Figure 13 shows an example of a hydraulic system's efficiency advantage.

Air-Powered	**Hydraulic-Powered**
Performance: 3 gpm at 800 psi (5.5 MPa, 55 bar)	Performance: 3 gpm at 800 psi (5.5 MPa, 55 bar)
Pump: 10:1 President	Pump: 1:1 Dyna-Star
Input energy: 32 scfm at 80 psi (.55 MPa, 5.5 bar)	Input energy: 3 gpm hydraulic oil at 800 psi (5.5 MPa, 55 bar)
Compressor: 4 hp electric Rule of thumb: hp = scfm / 4	Hydraulic power supply: 1.7 hp electric Rule of thumb: hp = psi x gpm / 1714 x .85

Figure 13 Air and hydraulics performance comparison chart

In addition to being more efficient, hydraulic systems provide greater reliability than air systems. Components last longer because they operate in oil. Also, because they operate in a closed loop, hydraulic systems have fewer moving parts and less contamination than air systems which develop rust, scale, and fluid contaminants due to condensed moisture in the compressed air supply.

Hydraulic systems do not have icing problems as air systems do. Therefore, they are the preferred choice for cold weather operations.

Hydraulic systems operate more effectively than air systems in these ways:

- Pumps driven by hydraulic motors can maintain a higher fluid pressure and flow than equivalent air-driven pumps. This can affect production rates for certain types of applications.
- Hydraulic motors change over more quickly than air motors so there is less pulsation in pumped fluids.
- Hydraulic systems do not exhaust to the atmosphere. They are quieter than air systems and emit no air-borne contamination.

The initial investment cost for a hydraulic power source can be significantly less than that for a comparable air power source. Since hydraulic systems are about five times more efficient than air systems, a 5 hp hydraulic power supply unit will perform at the same output as a 25 hp air compressor.

Hydraulic power supplies are smaller than air compressors and pressure tanks with equivalent output performance, so hydraulic systems usually require less physical space than air systems. Therefore, they may be preferred for truck-mounted or gas engine-powered operations. The limitations of a hydraulic system include:

- Expense
- System design constraints
- Potential for contamination

Hydraulic motors cost more than air motors and they require twice as much plumbing. Air motors need only supply lines, while hydraulic motors need both supply and return lines.

For proper system operation, hydraulic oil must be kept cool, usually below 140 degrees Fahrenheit. The capacity of the power supply reservoir must be large enough to keep hydraulic oil at or below recommended operating temperatures. Otherwise, additional oil cooling equipment, usually a case drain cooler on the return line side of the system, must be used.

Also, return line size must be relatively large to prevent downstream pressure spikes and to ensure that oil goes through the return oil filter rather than the filter bypass valve.

In addition to being kept cool, hydraulic oil must be kept clean for proper system operation. Although hydraulic systems are closed loop systems, they are not entirely free from contamination. Contaminants come from outside the hydraulic system and from within:

- Contaminants from outside the system include lint, dirt, and moisture. These contaminants may cling to system components or enter the reservoir if the filter cap is not cleaned at proper intervals.
- Contaminants from inside the system include particles formed due to wear of metal and seals and packings components and sludge and acids formed when extreme heat and pressure cause chemical reactions in the hydraulic fluid.

Figure 14 summarizes the main advantages and limitations of hydraulic fluid handling systems.

Hydraulic Fluid Handling Systems

Advantages	**Limitations**
Efficiency • Are theoretically about five times more efficient than air systems • Efficiency advantage is greatest in continuous duty applications	Expense • Hydraulic motors cost more than air motors • Hydraulic motors require twice as much plumbing as air motors
Reliable and effective operation • Components last longer than air system components • Have fewer moving parts and less contamination than air systems • Do not have problems with icing • Can maintain higher fluid pressure and flow than equivalent air systems • Cause less pulsation than air systems • Are quieter than air systems • Do not emit air-borne contamination	System design constraints • Power supply reservoir must be large enough to keep hydraulic oil at or below recommended operating temperature • Return line size must be relatively large Potential for contamination from outside or inside system
Relatively low investment cost for power supply Relatively small physical space requirement	

Figure 14 Advantages and limitations of hydraulic fluid handling systems

Typical Applications

As you've no doubt gathered from the information provided in ***Advantages and Limitations,*** hydraulic systems are preferred when energy efficiency, motor reliability, air motor icing, or insufficient air compressor capacity are concerns. In short, the most likely market opportunities for selling hydraulics include situations in which:

- The customer has continuous duty applications
- The customer will use the system in an environment where the temperature is below freezing
- The customer does not have an air compressor or has:
    - High volume delivery demands that occur on an intermittent basis
    - An air compressor without the capacity to handle delivery demands

The specific types of applications that a hydraulic system can handle are a function of the type of pump used to deliver the fluid. Differential hydraulic motors drive the same types of pumps that air motors do: two-check, four-check, and priming piston pumps.