Lesson 5: Directional Control Valves

Basic Hydraulic Systems

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

Introduction

Directional control valves are used to direct oil into separate circuits of a hydraulic system. The maximum flow capacity and the pressure drop through the valve are the first considerations. Directional control valves may be interfaced with manual, hydraulic, pneumatic and electronic controls. These factors are mostly determined during the initial system design.

Objectives

Upon completion of this lesson the student will:

1. State the function of the manual spool type control valve, the rotary type control valve and the solenoid actuated control valve.
2. State the function of the simple check valve, the pilot operated check valve and the shuttle valve
3. Identify the ISO symbols for the various directional control valves.

Directional Control Valve

The directional control valve is use to direct the supply oil to the actuator in a hydraulic system.

The valve body is drilled, honed and sometime the bore is heat treated. The inlet and outlet ports are drilled and threaded. The valve spool is machined from high grade steel. Some valve spools are heat treated, ground to size and polished. Other valve spools are chrome plated, ground to size and polished. The valve body and valve spool are then mated in assembly to the design specifications. When assembled, the valve spool is the only part that moves.

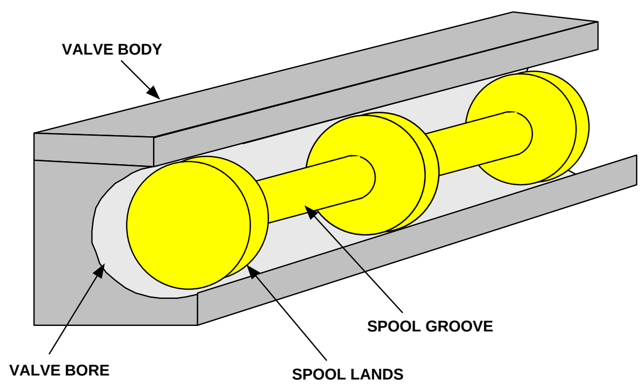

Fig. 3.5.1 Valve Spool

Valve Spool

The valve spool (Figure 3.5.1) consist of lands and groves. The spool lands block the oil flow through the valve body. The spool groves allow oil to flow around the spool and through the valve body.

The position of the spool when not activated is called the "normal" position.

When an "open center" valve is in the normal position, the supply oil flows through the valve and back to the tank. When a "close center" valve is in the normal position, the supply oil is blocked by the valve spool.

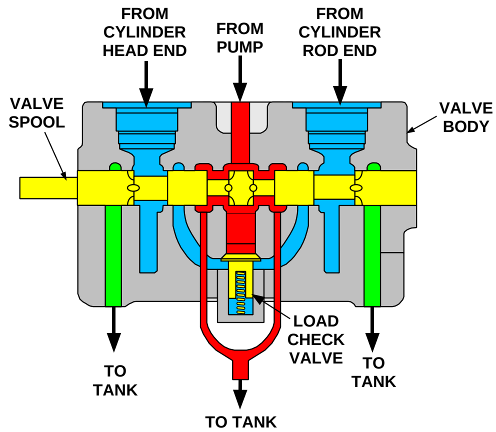

Fig. 3.5.2 Directional Control Valve in HOLD

Open Center Directional Control Valve in HOLD Position

Figure 3.5.2 shows a cutaway diagram of a typical open center directional control valve in the HOLD position.

In the HOLD position, the pump oil flows into the valve body, around the valve spool and returns to the tank. The pump oil also flows to the load check valve. The passage behind the load check is filled with blocked oil. The blocked oil and the load check valve spring keep the load check valve closed. The valve spool also blocks the oil in the line to the rod end and the head end of the cylinder.

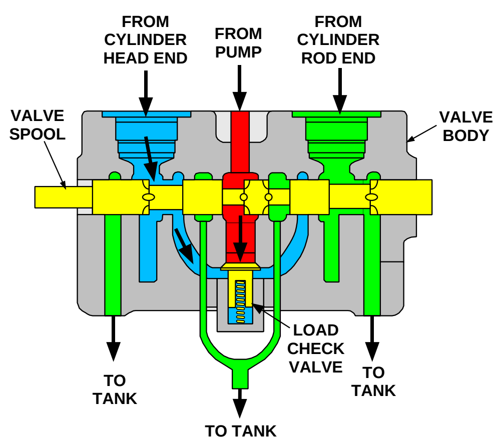

Fig. 3.5.3 Directional Control Valve RAISED

Open Center Directional Control Valve in RAISE Position

Figure 3.5.3, shows the valve spool at the instant the spool is moved to the RAISE position.

When the valve spool is moved to the RAISE position, the valve spool blocks the pump oil flow to the tank. However, pump oil flow is open to the load check valve. The valve spool also connects the cylinder head end to the oil behind the load check valve and the cylinder rod end to the tank passage. The load check valve prevents .

the oil in the head end of the cylinder from flowing into the pump oil passage. The blocked pump oil flow causes an increase in the oil pressure

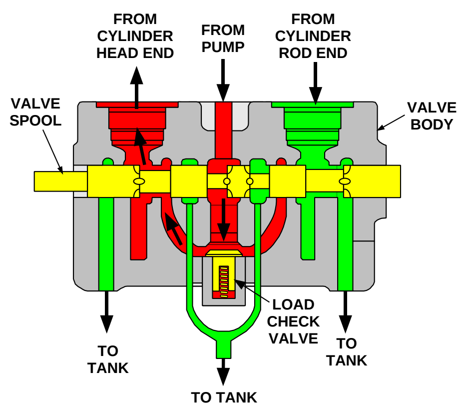

Fig. 3.5.4 Raise Position

Open Center Directional Control Valve, RAISE Position

In Figure 3.5.4, the increase in pump oil pressure overcomes the pressure behind the load check valve (unseats the load check valve). The pump oil flows pass the load check valve and around the valve spool to the head end of the cylinder.

The oil in the rod end of the cylinder flows pass the valve spool to the tank.

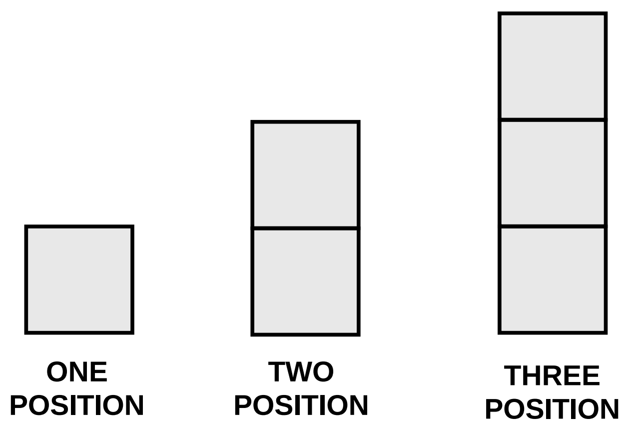

Fig. 3.5.5 ISO Symbols

Directional Control Valve ISO Symbols

Basic Envelope

The basic valve ISO symbol in Figure 3.5.5 consists of one or more basic envelopes. The number of envelopes used represents the number of positions that the valve can be shifted.

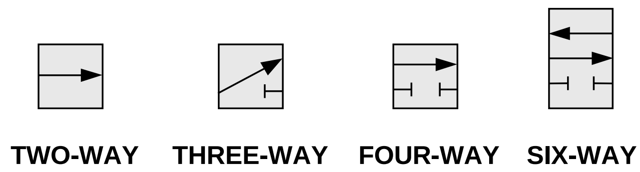

Fig. 3.5.6 Valve Port

Valve Port

Shown in Figure 3.5.6 are the valve ports for attaching working lines. A valve with two ports is commonly referred to as a two-way valve. This is not to be confused with a two-position valve shown in Figure 3.5.5. Valves may have as many positions and ports as needed. However, most valve positions are in the range of one to three and valve ports in the range of two to six.

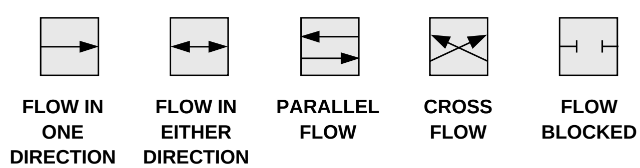

Fig. 3.5.7 Flow Path

Flow Path

In Figure 3.5.7, the lines and arrows inside the envelopes are used basically to represent the flow paths and directions between ports.

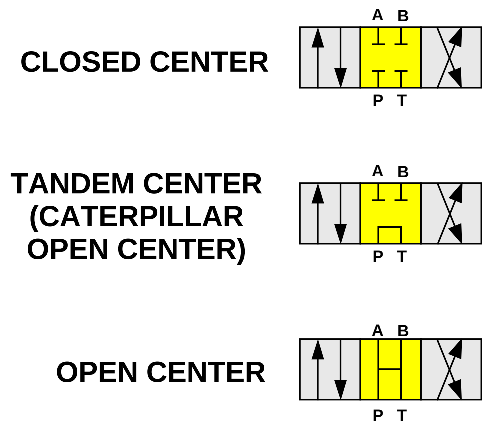

Fig. 3.5.8 Three Position Valve

Three Position Valve

Figure 3.5.8 shows three ISO symbols of the three position valve. In the three position valve, the center position is the NEUTRAL or HOLD position. When the valve is not doing work, the valve is placed in the HOLD position.

Depending on the design of the spool, the center position serves several purposes.

The ISO symbol at the top represents a closed center valve. When in the HOLD position, the close center spool blocks all oil flow.

The ISO symbol in the middle represents a tandem center valve. When in the HOLD position, the tandem center valve blocks oil flow at A and B but connects the pump to the tank.

The ISO symbol on the bottom represents an open center valve. When in the HOLD position, the open center valve connects all ports to the tank.

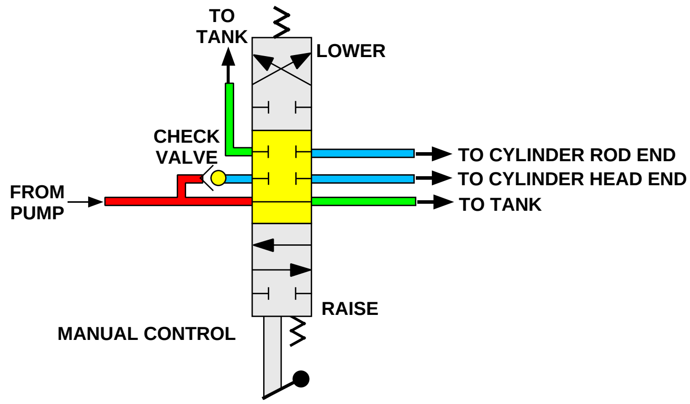

Fig. 3.5.9 Six Way Valve

Three Position, Six Way, Open Center, Manual Controlled Valve

Figure 3.5.9, shows a three position, six way, open center, manual controlled valve in the HOLD position. The pump oil flows around the valve spool to the tank. The oil in the cylinder is blocked at the control valve spool.

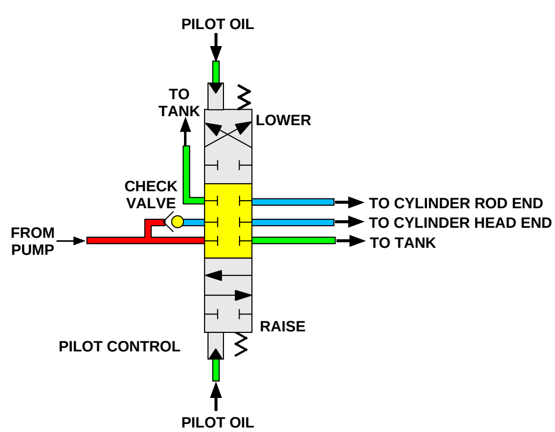

Fig. 3.5.10 Six Way Valve

Six Way Valve

Three Position, Six Way, Close Center, Pilot Controlled Valve

Figure 3.5.10 shows a three position, six way, close center, pilot controlled valve. In the HOLD position, all oil flow is blocked at the control valve spool.

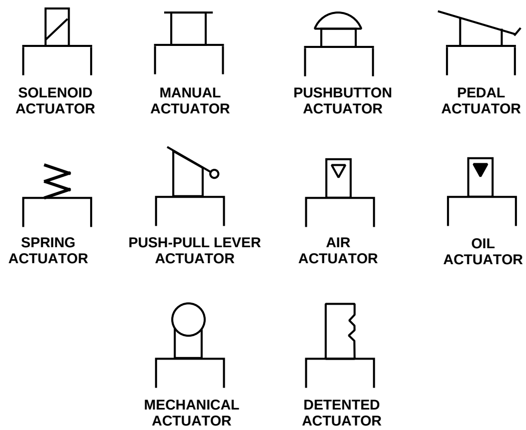

Fig. 3.5.11 Directional Control Valve Actuator

Directional Control Valve Actuator

Figure 3.5.11 shows the ISO symbols for various directional control valve actuators.

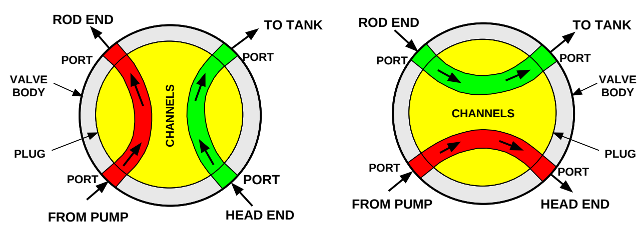

Fig. 3.5.12 Rotary Valve

Rotary Valve

The rotary valve (Figure 3.5.12) consists of a round stem with passages or channels. The channels in the stem connect with the ports in the valve body. Instead of shifting to the right or to the left, the valve rotates.

In the diagram on the left, the valve connects the pump to the rod end of the cylinder. The oil in head end flows to the tank. When the valve is rotated 90 degrees, the pump is connected to the head end and the oil in the rod end flows to the tank.

The rotary valve shown is a four-way valve. However, rotary valves may also be two-way or three-way. The rotary valve is used in low pressure operations.

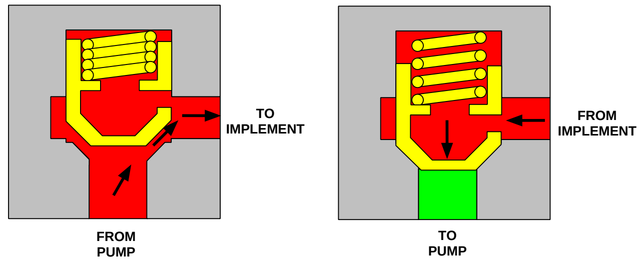

Fig. 3.5.13 Check Valve

Check Valve

The purpose of a check valve is to readily permit oil flow in one direction, but prevent (check) oil flow in the opposite direction. The check valve is sometimes called a "one way" check valve.

Most check valves consist of a spring and a tapered seat valve as in Figure 3.5.13 above. However, a round ball is sometimes used instead of the tapered seat valve. In some circuits, the check valve may be free floating (has no spring).

In the valve on the left, when the pump oil pressure overcomes the oil pressure in back of the check valve plus the check valve slight spring force, the check valve opens and allows the oil to flow to the implement.

In the valve on the right, when the pressure of the pump oil is less than the oil pressure in the implement, the check valve closes and prevents implement oil flow back through the valve.

Pilot Operated Check Valve

The pilot operated check valve differs from the simple check valve in that the pilot operated check valve allows oil flow through the valve in the reverse direction.

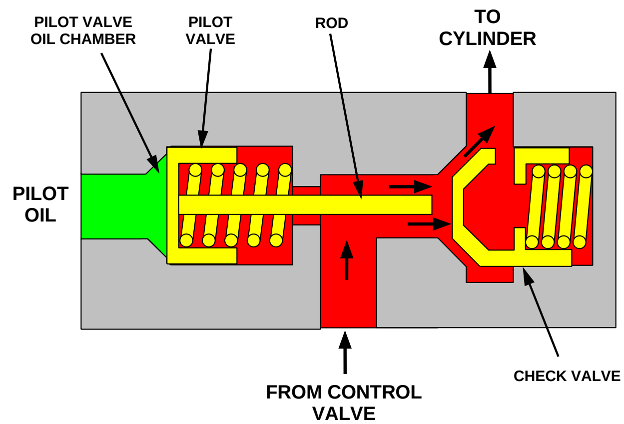

Fig. 3.5.14 Forward Flow

Forward Flow

Figure 3.5.14 shows a pilot operated check valve. The pilot operated check valve consist of a check valve, a pilot valve and a rod. The pilot operated check valve allows free flow from the control valve to the cylinder.

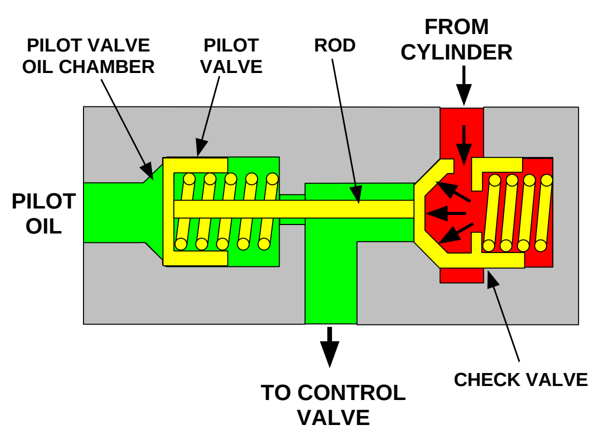

Fig. 3.5.15 Flow Blocked

Flow Blocked

When oil flow from the control valve cease, the check valve seats as shown on the right of Figure 3.5.15. The oil flow from the cylinder to the control valve is blocked at the check valve.

The pilot operated check valve is most often used in operations where load drift is a problem. The pilot operated check valve allows load drift to be held to a very close tolerance.

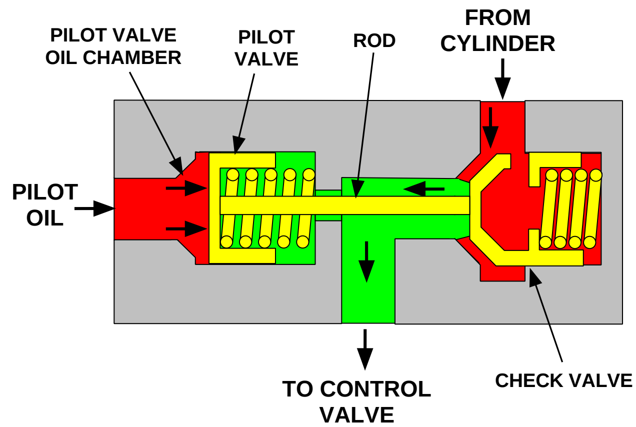

Fig. 3.5.16 Reverse Flow

Reverse Flow

The valve in Figure 3.5.16, shows oil flow from the cylinder to the control valve.

When flow is required, pilot oil is sent to the pilot valve oil chamber. Pilot oil pressure moves the pilot valve and rod to the right and unseats the check valve. The cylinder oil flows through the check valve to the control valve and then to the tank.

The pressure ratio between the load pressure and the pilot pressure is designed into the valve. The valve used on the Explorer training unit has a pressure ratio of 3:1. The pressure needed to open the check valve is equal to one-third of the load pressure. A load pressure of 4134 kPa (600 psi) requires a pilot pressure of 1378 kPa (200 psi) to open the check valve.

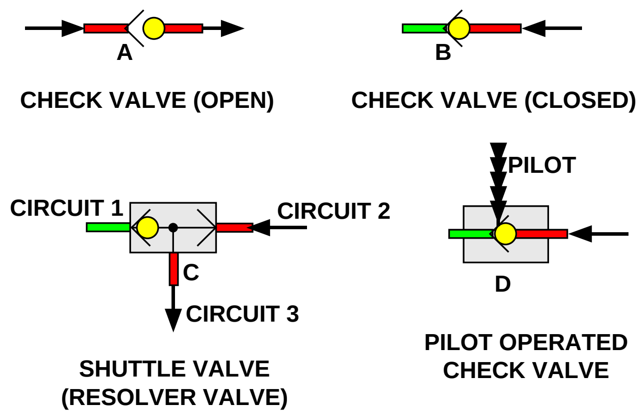

Fig. 3.5.17 Check Valve ISO Symbols

Check Valve ISO Symbols

In Figure 3.5.17, symbols A and B represents the simple check valve in the OPEN and CLOSE positions.

Symbol C represent the shuttle valve. The shuttle (resolver) valve allows two separate circuits to supply oil to a third circuit while keeping the two separate circuits isolated from each other.

Symbol D represents the pilot operated check valve.

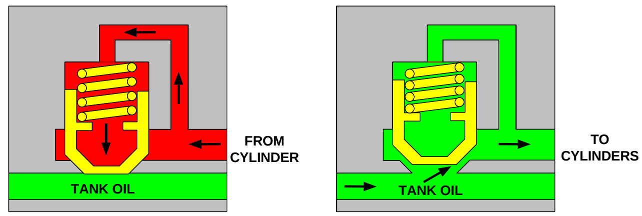

Fig. 3.5.18 Make-up Valve

Make-up Valve

The make-up valve in Figure 3.5.18, looks similar to the check valve. The makeup valve is normally positioned in the circuit between the implement and the tank. During normal operations, the pump or cylinder oil fills the area behind the make-up valve. The pressure in the cylinder keeps the valve CLOSED. When the cylinder pressure is approximately 14 kPa (2 psi) lower than the tank pressure, the make-up valve will OPEN. The tank oil bypasses the pump and flows directly through the make-up valve to the cylinder.

The make-up valve is used to prevent cavitation. For example, when a loader bucket is RAISED and the operator moves the control to the FULLY LOWER position, the gravitational force on the bucket is transmitted through the cylinder piston to the return oil. The increased pressure on the return oil increases the flow from the cylinder. When the cylinder piston displaces the return oil faster than the pump can send oil to displace the piston, a vacuum is formed in the cylinder and lines. A vacuum can cause the cylinder and lines to cavitate. When the pressure in the cylinder and lines decreases to 14 kPa (2 psi) less than tank pressure, the make-up valve opens and allows tank oil to flow through the make-up valve to the lines and cylinder. This procedure prevents cavitation in the cylinder and lines.

Makeup Valve ISO Symbol

The operation (function) of the make-up valve and the check valve is the same. Therefore, the ISO symbol for the make-up valve is the same as the ISO symbol for the check valve.

SOLENOID ACTUATED CONTROL VALVES

Solenoid Actuator

In a solenoid actuator, an electro-magnetic field moves an armature which moves a push pin. The push pin moves the valve spool.

The two most popular solenoid actuators are the air gap and the wet armature.

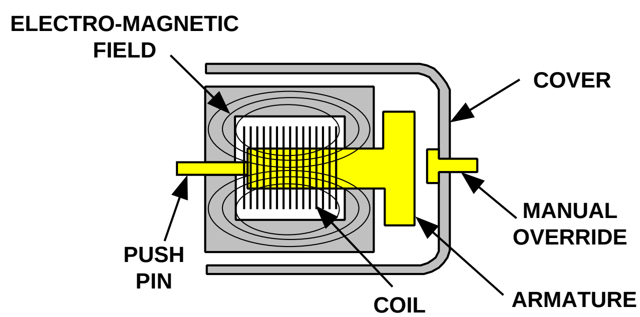

Fig. 3.5.19 Air Gap Solenoid

Air Gap Solenoid

An air gap solenoid is shown in Figure 3.5.19. When the coil is energized, an electro-magnetic field is created. Such a field develops whenever electricity flows through a wire. When the wire is straight, the field is relatively weak. When the wire is wound into a coil, the electro-magnetic field becomes much stronger. The field takes a circular shape around the coil. The higher the number of turns in the coil, the stronger the field.

When the flow of electricity through the coil remains constant, the electro-magnetic field acts very much like the field of a permanent bar magnet. The electro-magnetic field attracts the armature. The armature moves a push pin and the push pin moves the valve spool in the control valve.

The air gap solenoid is protected by a cover. The air gap solenoid also has a "manual override" feature. The manual override allows the valve to be activated when the solenoid is defective or disabled. A small metal pin is located in the cover. The pin is positioned directly in line with the armature. When the pin is pushed into the cover, the pin mechanically moves the armature. The armature moves the push pin which shifts the spool.

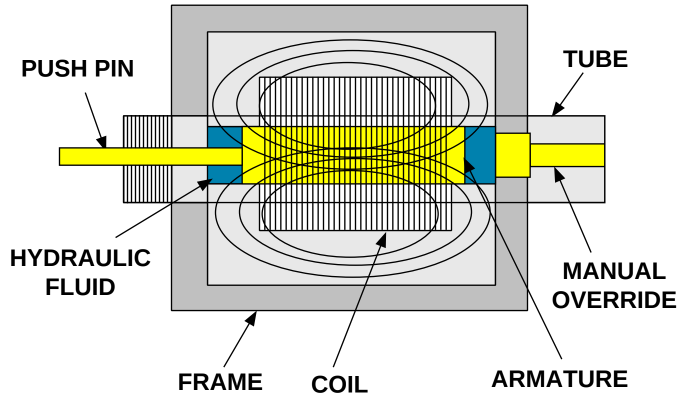

Fig. 3.5.20 Wet Armature Solenoid

Wet Armature Solenoid

The wet armature solenoid (Figure 3.5.20) is a relatively new arrival on the hydraulic scene.

The wet armature solenoid consist of a rectangular frame, coil, tube, armature, push pin and manual override. The coil and rectangular frame is encapsulated in plastic. The tube fits into a hole that runs through the coil center and two sides of the frame. The armature is housed within the tube and is bathed with hydraulic fluid from the directional valve. The hydraulic fluid is a better conductor of the electro-magnetic field than air. Therefore, the wet armature solenoid works with greater force than the air gap solenoid.

When the coil is energized, an electro-magnetic field is created. The electro-magnetic field moves the armature. The armature moves a push pin and the push pin moves the valve spool in the control valve.

In the wet armature solenoid, the manual override is located on the end of the tube which houses the armature and the push pin. The manual override is used to check movement of the directional valve spool. If the solenoid fails because the spool jammed, the spool movement can be checked by pushing in the manual override. The manual override may also be used to cycle the actuator without energizing the complete electrical control system.

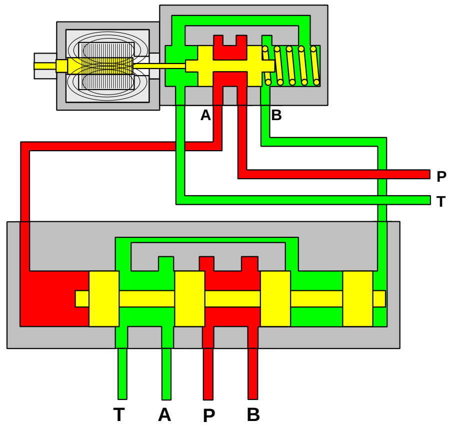

Fig. 3.5.21 Two Position 4-Way Directional Control Valve

Solenoid Controlled, Spring Offset, Pilot Operated, Two Position, 4-way Directional Control Valve

Figure 3.5.21, shows a Solenoid Controlled, Spring Offset, Pilot Operated, Two Position, 4-way Directional Control Valve.

The solenoid controlled, spring offset, pilot operated, two position, directional control valve is not frequently equipped with two solenoids. The second solenoid is considered an unnecessary expense and an additional solenoid to worry about in the system.

The solenoid is used to shift the pilot valve spool. The pilot valve spool is returned to its original position by a spring. When a system is designed for large oil flow, a large directional valve is required. A substantial force is needed to shift the large valve spool. The solenoid needed to generate that amount of force would be quite large. In valves of this type, a small solenoid controlled pilot valve is positioned on top of the larger main valve spool. When shifting is required, pressurized oil flows from the small solenoid controlled pilot valve to either side of the larger valve spool.

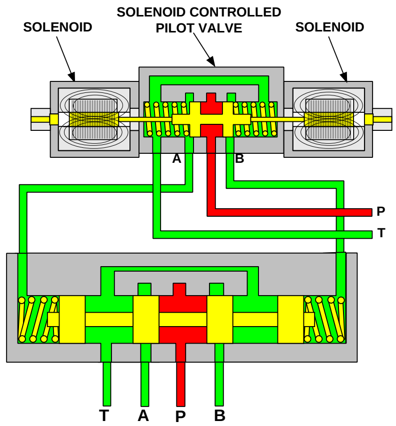

Fig. 3.5.22 Three Position 4-way Directional Control Valve

Solenoid Controlled, Pilot Operated, Three Position, 4-way Directional Control Valve

Figure 3.5.22 shows a Solenoid Controlled, Pilot Operated, Three Position, 4-way Directional Control Valve.

The pilot valve is controlled by two solenoid valves. The pilot valve also has a spring located at each end of the valve spool. When neither solenoid is energized, the pilot valve spool springs hold the pilot valve spool in the CENTER position. When the pilot valve is in the CENTER position, pilot oil flow to the larger control valve is blocked. The springs in the three position directional control valve return the control spool to the center position.

Spring centering is the most common means of centering a directional control valve spool. The directional control valve has a spring located at each end of the valve spool. When pilot oil pressure is applied to either end of the directional valve spool, the valve spool moves and compresses the spring on the opposite end. When the pilot oil pressure is removed, the spring returns the directional control spool to the center position.

Solenoid Failure

Most solenoid actuator failures occur when valves are stuck. The stuck valve spool prevents the armature from closing properly. The most likely cause of a stuck valve spool is contamination. Contaminant such as silt, metal chips, and other particles may become lodged between the spool and bore causing the spool to stick. Also, oxidized oil particles can create a gooey varnish which clogs the clearance between the spool and bore walls and cause the spool to stick to the bore. Silt, metal chips, and other contaminating particles can be removed by installing a filter. The varnish build-up can be removed by washing the valve in lacquer thinner. The proper oil and filter change intervals can help to eliminate most of this type problems.

When the valve is stuck and the solenoid is energized, the solenoid coil receives a constant high flow of current that generates excessive heat. The solenoid is not designed to dissipate the excessive heat and the coil burns out. Overheating problems most often occur during periods of high ambient (environmental) temperatures, or system low voltage.

Problems with solenoid failure due to high ambient temperatures may be controlled by increasing the air flow across the solenoid. The temperature of the hydraulic oil can be lowered to allow more heat to be drawn from the solenoid through the hydraulic system. Sometimes, a different valve design may be required when operating during very hot weather. Some arrangement must be made to allow the system to operate at a lower temperature.

When the voltage to the coil is too low, the electro-magnetic field is not sufficiently strong to attract the armature. Just as when the spool is stuck, the current continues flowing through the coil. The constant flow of current generates the excessive heat.

Other factors also affect the proper operation and life expectancy of the solenoid actuator. The solenoid actuator may fail when cycled excessively, when short-circuited, or when operated with an incorrect electrical supply (wrong frequency, wrong voltage).

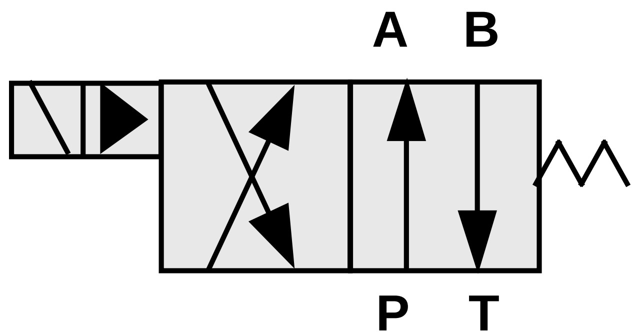

Fig. 3.5.23 Two Position, 4-way Pilot Valve

Spring Offset, Solenoid Controlled, Two Position, 4-Way Pilot Valve

In the ISO symbol in Figure 3.5.23, the spring offset pilot valve is shown in its normal position. The pump oil flows to A and the oil in B flows to the tank.

When the solenoid is energized, the solenoid moves the valve against the spring. The pump oil then flows to B and the oil in A flows to the tank.

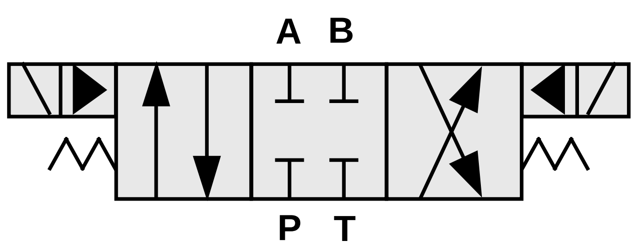

Fig. 3.5.24 Three Position, 4-way Control Valve

Solenoid Controlled Pilot Operated, Spring Centered, Three Position, 4-Way, Closed-Centered Control Valve

In the ISO symbol in Figure 3.5.24, the solenoid controlled pilot operated, spring centered, three position, 4-way, closed-centered control valve is shown in its normal position. All four ways are blocked at the valve. When the solenoid on the right is energized, the pump oil flows to B and the oil in A flows to the tank. When the solenoid on the left is energized, the pump oil flows to A and the oil in B flows to the tank.

NOTES

Name ___________________________

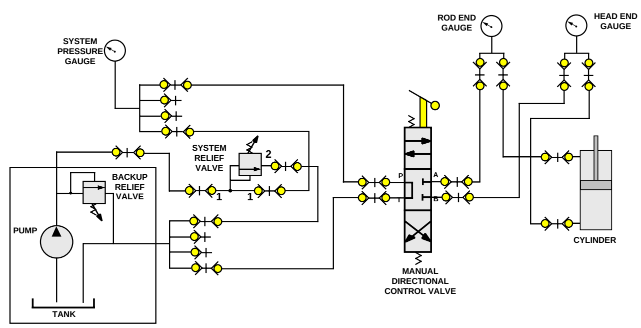

Fig. 3.5.25 Circuit

LAB 3.5.1: DIRECTIONAL CONTROL VALVE

Purpose

To install and operate a directional control valve in a simple circuit.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Mount the manual valve to the horizontal component mounting rack.

   To mount the valve, first loosen the wing nuts about half way. Slide the carriage bolts into the grooves on the mounting rack. Move the valve to where you can operate the lever comfortably. Tighten the wing nuts so that the valve is securely in place.

2. Construct the circuit in Figure 3.5.25.

4. Adjust system pressure to 5856 kPa (850 psi).

3. Turn ON the training unit.

5. With the control lever in the NEUTRAL position, read the pressure gauges. Record the pressure readings below.

   System pressure gauge: ____________________________

   Rod End pressure gauge: __________

   Head End pressure gauge: ____________

LAB 3.5.1: DIRECTIONAL CONTROL VALVE (continued)

6. Retract the cylinder rod until the rod stops moving. Continue to hold the control lever in the retract position and read the pressure gauges. Record the pressure readings below.

   System pressure gauge: ___________

   Rod End pressure gauge: ___________

   Head End pressure gauge: _________

7. Extend the cylinder rod until the rod stops moving. Continue to hold the control lever in the rod extend position and read pressure gauges. Record the pressure readings below.

   System pressure gauge: ___________

   Rod End pressure gauge: ___________

   Head End pressure gauge: ___________

8. State the differences in the three sets of readings.

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9. Turn OFF the training unit and disconnect the hoses.

Name ___________________________

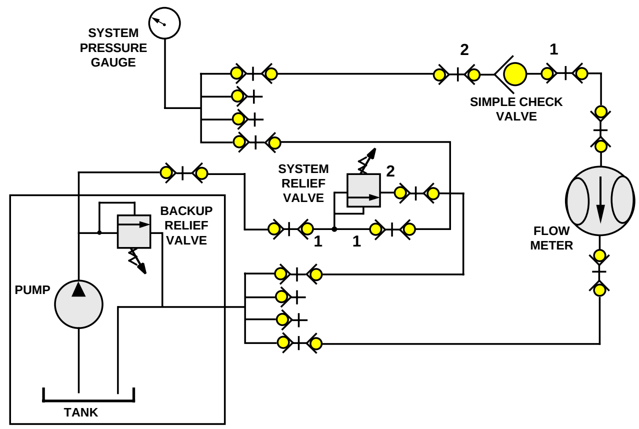

Fig. 3.5.26 Circuit

LAB 3.5.2: CHECK VALVE

Purpose

To install and operate a check valve in a simple circuit.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Construct the circuit given in Figure 3.5.26.
2. Adjust system pressure to 5856 kPa (850 psi).
3. Turn ON the training unit.
4. Read the system pressure gauge and the flow meter (Reading 1).
5. Record the pressure and flow in the chart in Figure 3.5.27.

READINGS	PRESSURE GAUGE	FLOW METER
1		
2		

Fig. 3.5.27

6. Turn OFF the training unit.

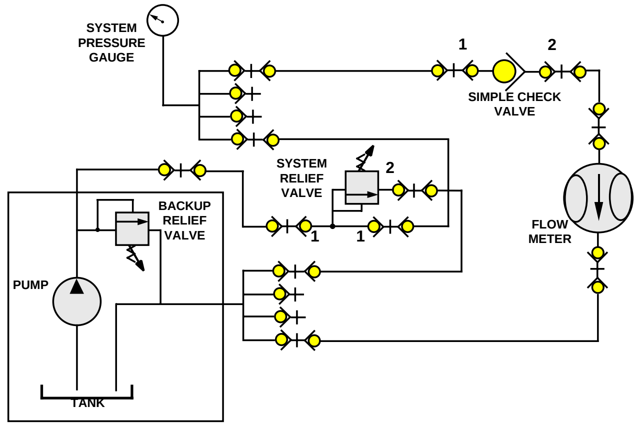

Fig. 3.5.28 Circuit

LAB 3.5.2: CHECK VALVE (continued)

7. Reverse the check valve as in Figure 3.5.28.
8. Turn ON the training unit.
9. Read the system pressure gauge and the flow meter (Reading 2).
10. Record the pressure and flow in the chart in Figure 3.5.27.
11. Turn OFF the training unit and disconnect the hoses.

Explain the difference between reading 1 and reading 2.

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Name ____________________________

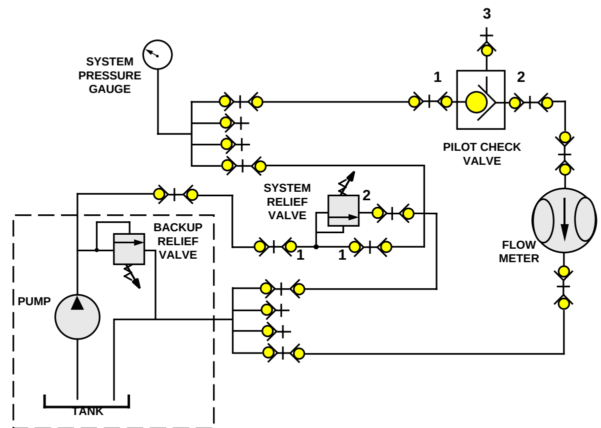

Fig. 3.5.29 Circuit

LAB 3.5.3: PILOT OPERATED CHECK VALVE CIRCUIT

Purpose

To install and operate a pilot operated check valve in a simple circuit.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Construct the circuit shown in Figure 3.5.29
2. Turn ON the training unit.
3. Adjust system pressure to 5856 kPa (850 psi).
4. Read the pressure gauge and flow meter (Reading 1).
5. Record the information on the chart in Figure 3.5.30.

READING	FLOW RATE	SYSTEM PRESSURE	OPENING PRESSURE
1			
2			
3			
4			

Fig. 3.5.30 Chart

6. Turn OFF the training unit.

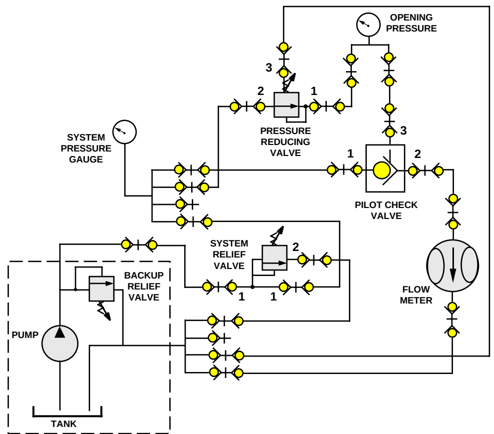

Fig. 3.5.31 Circuit

LAB 3.5.3: PILOT OPERATED CHECK VALVE CIRCUIT (Continued)

7. Reconstruct the circuit as shown in Figure 3.5.31.
8. Turn the adjustment on the pressure reducing valve fully counter-clock wise.
9. Turn ON the training unit.
10. Set system pressure to 2067 kPa (300 psi).
11. Slowly turn the adjustment on the pressure reducing valve clockwise until flow is seen through the flow meter.
12. Read the pressure gauges and the flow meter (Reading 2).
13. Record the information on the chart in Figure 3.5.30.
14. Turn OFF the training unit for two minutes.
15. Turn the pressure reducing valve adjustment one turn counter-clockwise.
16. Turn ON the training unit.
17. Adjust the system pressure to 4134 kPa (600 psi).
18. Read the pressure gauges and the flow meter (Reading 3).
19. Record the information on the chart in Figure 3.5.30.
20. Slowly turn the adjustment on the pressure reducing valve clockwise until flow is seen through the flow meter.
21. Read the pressure gauges and the flow meter (Reading 4).
22. Record the information on the chart in Figure 3.5.30.
23. Turn OFF the training unit and disconnect the hoses.

LAB 3.5.3: PILOT OPERATED CHECK VALVE CIRCUIT (Continued)

Questions:

1. Does the pilot check valve opening pressure equal to approximately one third the system pressure?

   ________ Yes ________ No

2. Explain the difference between the non-pilot check valve and the pilot check valve.

   ____

   ____

   ____

   ____

   ____

   ____

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Name ________________________

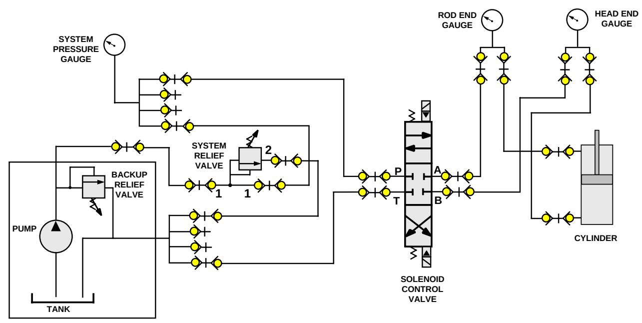

Fig. 3.5.32 Circuit

LAB 3.5.4 SOLENOID ACTUATED DIRECTIONAL CONTROL VALVE

Purpose

To install and operate a solenoid actuated control valve in a simple circuit.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Construct the circuit in Figure 3.5.32.
2. Adjust system pressure to 5856 kPa (850 psi)..
3. Turn ON the training unit.
4. With the control valve in the NEUTRAL position, read the pressure gauges. Record the pressure readings below.

   System pressure gauge: _______________

   Rod End pressure gauge: _______________

   Head End pressure gauge: ______________

5. Depress and hold the switch to retract the cylinder rod. Read the pressure gauge and record the pressure readings below.

   System pressure gauge: ___________________

   Rod End pressure gauge: ___________________

   Head End pressure gauge: ______________________

LAB 3.5.4 SOLENOID ACTUATED DIRECTIONAL CONTROL VALVE (continued)

6. Depress and hold the switch to extend the cylinder rod. Read the pressure gauges and record the pressure readings below.

   System pressure gauge: ________________

   Rod End pressure gauge: ________________

   Head End pressure gauge: __________________

7. Disconnect the pump electrical power supply and move the solenoid actuated control valve to reduce the pressure in the hoses.
8. Turn OFF the training unit and connect the pump electrical power supply. Disconnect the hoses.

Questions:

1. State the differences in the three sets of readings.

   ____
   ____
   ____
   ____
   ____
   ____

2. What happens inside the valve when the rod extending solenoid is activated?

   ____
   ____
   ____
   ____

3. What happens inside the valve when both solenoids are deactivated?

   ____
   ____
   ____

4. How could you tell the valve spool moved without looking at the gauges?

   ____
   ____
   ____

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