Lesson 6: Flow Control Valves

Basic Hydraulic Systems

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

Introduction

Flow control consists of controlling the volume of oil flow in or out of a circuit. Controlling flow in a hydraulic circuit can be accomplished in several ways.

The most common way is by installing an orifice. When an orifice is installed, the orifice presents a higher than normal restriction to the pump flow. The higher restriction increases the oil pressure. The increase in oil pressure causes some of the oil to take another path. The path may be through another circuit or it may be over a relief valve.

Also discussed are non-compensated and compensated flow control valves.

Objectives

Upon completion of this lesson the student will:

1. State the function of the orifice, the needle valve, the flow control valve, the pressure compensated flow control valve, and the quick-drop valves.
2. Identify the ISO symbols for the various flow control valves.

Orifice

An orifice is a small opening in the oil flow path. Flow through an orifice is affected by several factors. Three of the most common are:

1. The temperature of the oil.
2. The size of the orifice.
3. The pressure differential across the orifice.

Temperature

The oil viscosity changes with changes in temperature. Viscosity is a measurement of the oil's resistance to flow at a specific temperature. Hydraulic oil becomes thinner and flows more readily as the temperature increases.

Orifice Size

The size of the orifice controls the flow rate through the orifice. A common example is a hole in a garden hose. A small pin hole will leak in the form of a drip or a fine spray. A larger hole will leak in the form of a stream. The hole, whether small or large, meters a flow of water to the outside of the hose. The amount of water metered depend on the size of the hole (orifice).

The orifice size may be fixed or variable.

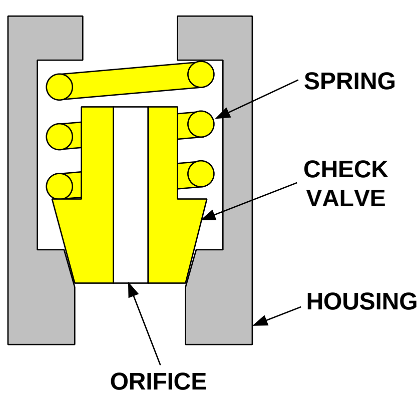

Fig. 3.6.1 Check Valve With Fixed Orifice

Check Valve With A Fixed Orifice

Figure 3.6.1 shows an example of a check valve with a fixed orifice that is commonly used in construction equipment. The fixed orifice is a hole through the center of the check valve. When oil flow is in the normal direction, the valve opens and allows oil to flow around the valve as well as through the orifice. When oil attempts to flow in the reverse direction, the valve closes. All reverse flowing oil must flow through the orifice which controls the flow rate.

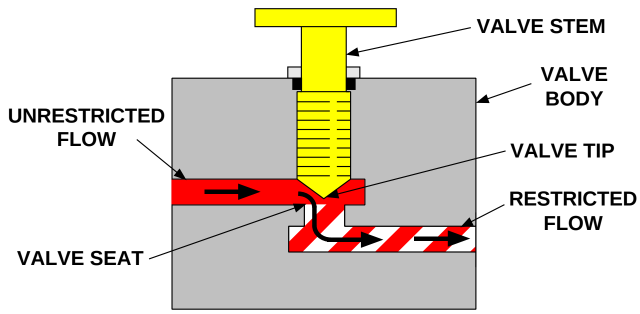

Fig. 3.6.2 Variable Orifice

Variable Orifice

Figure 3.6.2 shows a variable orifice in the form of a needle valve. In the needle valve, the size of the orifice is changed by the positioning of the valve tip in relation to the valve seat.

The oil flow through the needle valve must make a 90° turn and pass between the valve tip and the valve seat. The needle valve is one of the most frequently used variable orifices.

When the valve stem is turned counter-clockwise, the orifice becomes larger and the flow increases through the valve.

When the valve stem is turned clockwise, the orifice becomes smaller and the flow decreases through the valve.

The schematic in Figures 3.6.3 and 3.6.4 consist of a positive displacement pump, a relief valve and a variable orifice. The relief valve is set at 3445 kPa (500 psi) and limits maximum pressure in the system. The orifice may be adjusted to any flow between zero and 5 gpm.

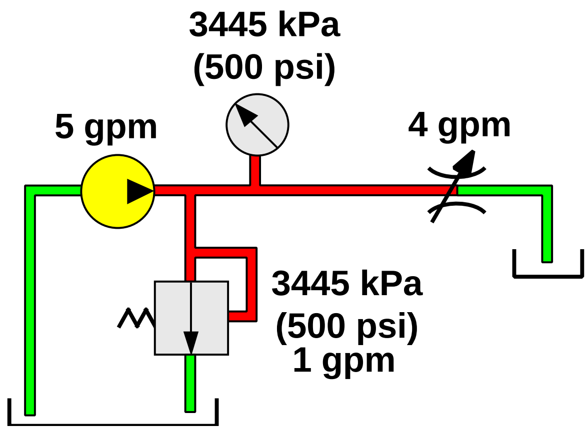

Fig. 3.6.3 Variable Orifice 4 gpm

In Figure 3.6.3, the variable orifice allows a flow of 4 gpm through the orifice at a pressure of 3445 kPa (500 psi). Any increase in flow through the orifice requires a pressure greater than 3445 kPa (500 psi). When the pressure exceeds 3445 kPa (500 psi), the relief valve opens and the excessive oil (1 gpm) flows through the relief valve.

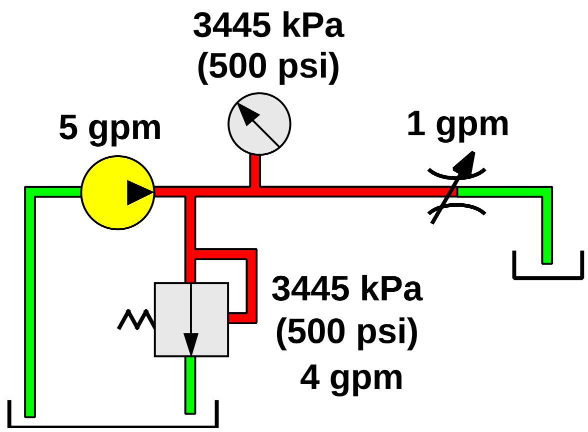

Fig. 3.6.4 Variable Orifice 1 gpm

In Figure 3.6.4, the variable orifice allows a flow of 1 gpm through the orifice at a pressure of 3445 kPa (500 psi). Any increase in flow through the orifice requires a pressure greater than 3445 kPa (500 psi). When the pressure exceeds 3445 kPa (500 psi), the relief valve opens and the excessive oil (4 gpm) flows through the relief valve.

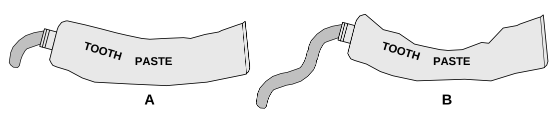

Fig. 3.6.5 Pressure Differential

Pressure Differential

Flow through an orifice is affected by the pressure differential across the orifice. The greater the pressure differential across the orifice, the greater the flow through the orifice.

In Figure 3.6.5, pressure differential is illustrated using the two tubes of tooth paste. When the tube of toothpaste is gently squeezed as in A, the pressure difference between the inside of the tube and the outside of the tube is small. Therefore, only a small amount of tooth paste is forced out.

When the tube is squeezed with greater force as in B, the pressure difference between the inside of the tube and the outside of the tube increases and a larger amount of toothpaste is forced out.

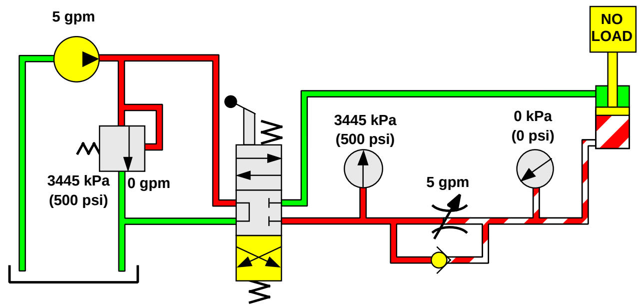

Fig. 3.6.6 Non-Compensated Flow Control Valve Schematic

Non-Compensated Flow Control Valve

The schematic in Figure 3.6.6 consists of a positive displacement pump, a relief valve, a cylinder, a non-compensated flow control valve, two pressure gauges and a three position, four-way, tandem centered, lever operated directional control valve.

The non-compensated flow control valve consists of a variable orifice and a check valve. When oil flows into the cylinder head end, the check valve seats. The variable orifice controls oil flow into the head end. When oil flows out of the cylinder head end, the check valve opens, the oil follows the path of least resistance and flows unrestricted through the check valve.

In a non-compensated flow control circuit, any change in the pressure differential across the orifice will produce a corresponding change in the flow through the orifice.

The relief valve is set at 3445 kPa (500 psi). The orifice is adjusted to a flow of 5 gpm at 3445 kPa (500 psi) with no load on the cylinder. The pressure differential across the orifice is 3445 kPa (500 psi). Total pump oil flows through the orifice to the cylinder.

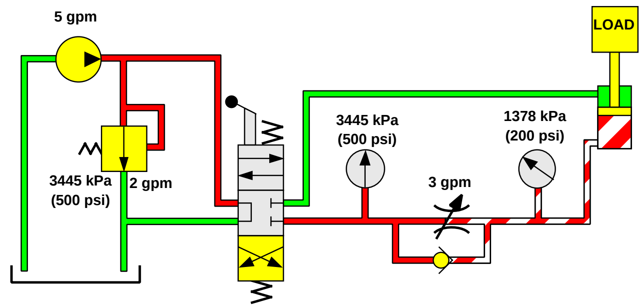

Fig. 3.6.7 Load and Pressure Increases

Load Increase

In Figure 3.6.7, the cylinder load is increased. The cylinder pressure required to overcome the resistance of the load is 1378 kPa (200 psi). The 1378 kPa (200 psi) is subtracted from the available 3445 kPa (500 psi) upstream of the orifice. This reduces the pressure differential across the orifice to 2067 kPa (300 psi). The 2067 kPa (300 psi) causes the flow through the orifice to decrease to 3 gpm. Any attempt to increase the flow through the orifice will cause the system pressure to increase above the relief valve maximum setting of 3445 kPa (500 psi). The remaining 2 gpm causes the system pressure to increase above 3445 kPa (500 psi). The relief valve opens and 2 gpm flows across the relief valve to the tank.

A decrease in the flow through the orifice causes a corresponding decrease in the speed of the cylinder.

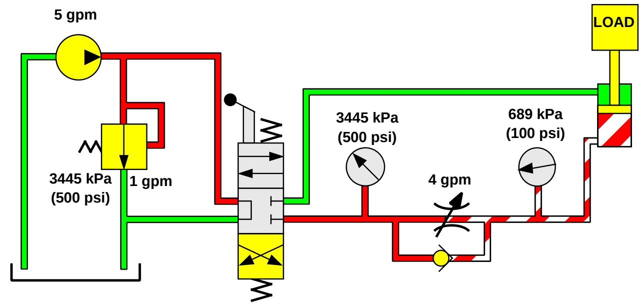

Fig. 3.6.8 Load and Pressure Decreases

Load Decrease

In Figure 3.6.8, the cylinder load is decreased. The pressure required to overcome the resistance of the load decreases to 689 kPa (100 psi). The 689 kPa (100 psi) is subtracted from the available 3445 kPa (500 psi) upstream of the orifice. The new pressure differential across the orifice is 2756 kPa (400 psi). The 2756 kPa (400 psi) causes the flow through the orifice to increase to 4 gpm. Any attempt to increase the flow through the orifice above 4 gpm will cause the system pressure to increase above the relief valve maximum setting of 3445 kPa (500 psi). The remaining 1 gpm causes the system pressure to increase above 3445 kPa (500 psi). The relief valve opens and 1 gpm flows across the relief valve to the tank.

An increase in the flow causes a corresponding increase in the speed of the cylinder.

In Figures 3.6.7 and 3.6.8, increasing the relief valve pressure setting to 4823 kPa (700 psi) allows the pump to send the maximum flow of 5 gpm through the orifice as long as the cylinder load pressure is less than 1378 kPa (200 psi). Therefore, the speed of the cylinder will remain constant as the pressure changes between 1378 kPa (200 psi) and 689 kPa (100 psi).

Compensated Flow Control Circuits

In a compensated flow control circuit, the pressure differential across the orifice is not affected by a change in the load. The constant pressure differential across the orifice will produce a constant flow through the orifice.

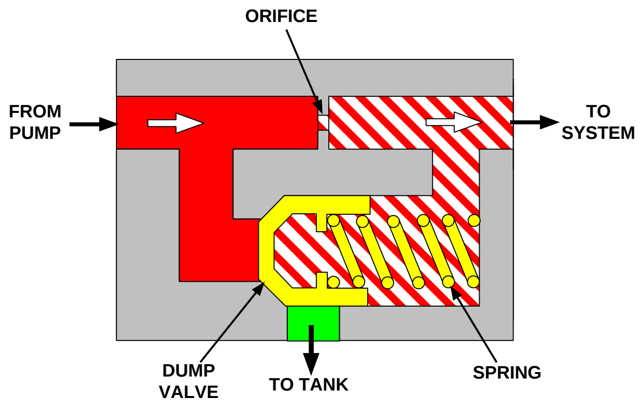

Fig. 3.6.9 By-pass Pressure Compensated Flow Control Valve

By-pass Pressure Compensated Flow Control Valve

Figure 3.6.9 shows a illustration of a by-pass type pressure compensated flow control valve. The by-pass type pressure compensated flow control valve automatically adjusts to flow and load changes.

Flow Change

The amount of flow through the valve depends on the size of the orifice. Any change in oil flow through the orifice creates a change in pressure on the upstream side of the orifice. The same pressure change acts against the dump valve and spring.

When the pump flow is within the design flow of the orifice, the force of the upstream oil pressure acting on the dump valve is less than the combined force of the downstream oil pressure and the spring. The dump valve remains closed and all of the pump oil flows through the orifice.

When the pump flow is more than the design flow of the orifice, the force of the upstream oil pressure acting on the dump valve is greater than the combined force of the downstream oil pressure and the spring. The dump valve opens and the excess oil flows through the dump valve to the tank.

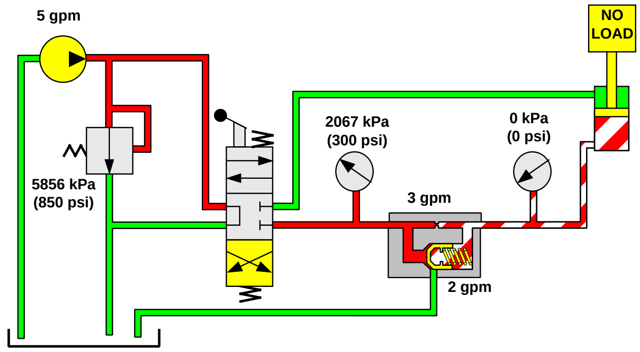

Fig. 3.6.10 By-pass Pressure Compensated Flow Control Valve

No Load Pressure

Figure 3.6.10 shows the by-pass pressure compensated flow control valve in a simple lifting circuit.

When the control valve is moved to the RAISE position, pump oil is directed to the flow control valve. The flow control valve requires a pressure differential of 1378 kPa (300 psi) to send 3 gpm through the orifice. To send more than 3 gpm through the orifice, requires an increase in the pressure differential. An increase in the pressure differential of more than 1378 kPa (300 psi) opens the dump valve. The excessive oil flows through the dump valve to the tank.

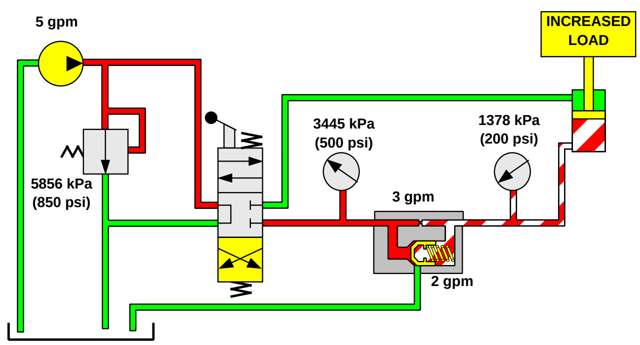

Fig. 3.6.11 By-pass Pressure Compensated Flow Control Valve

Load Pressure Increases

When the load pressure increases, the pressure increases at the orifice and in the dump valve spring chamber.

The increase in pressure at the orifice lowers the pressure differential across the orifice and attempts to reduce the oil flow through the orifice. However, at the same instance, the pressure is increased in the dump valve spring chamber. The additional pressure closes the dump valve and blocks oil flow to the tank. The blocked oil causes the pressure on the pump side of the orifice to increase. The pressure increases until the pressure differential across the orifice reaches 1378 kPa (300 psi). A pressure differential of 1378 kPa (300 psi) sends 3 gpm through the orifice and 2 gpm across the dump valve.

This allows the flow control valve to respond instantly to any increases or decreases in the load pressure.

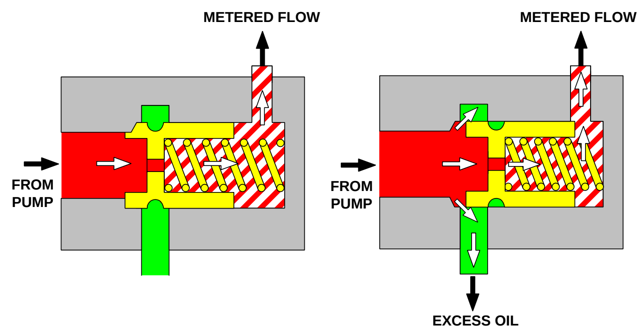

Fig. 3.6.12 Bypass Pressure Compensated Flow Control Valve

Combine Orifice and Dump Valve

The more common type of flow control valve is shown in Figure 3.6.12. This valve combines the action of the orifice and dump valve in one moving part. The pressure compensating operation is the same as the by-pass pressure compensated flow control valve.

The graphic on the left shows flow through the valve that is either at the flow rating or less than the flow rating of the valve.

The graphic on the right shows that flow is beginning to exceed the flow rating of the valve, the pressure differential resulting from the flow across the orifice becomes great enough to begin compressing the spring and start dumping the excess oil as shown.

If the flow through the valve increases, the action of the orifice will cause the spring to compress still more, and more flow will be dumped. The controlled (metered) flow remains fairly constant as flow to the valve increases or decreases.

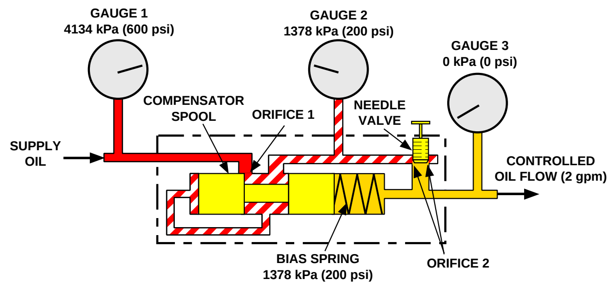

Fig. 3.6.13 Restrictor Type Pressure Compensated Flow Control Valve

Restrictor Type Pressure Compensated Flow Control Valve

Figure 3.6.13 shows an illustration of a restrictor type pressure compensated flow control valve. The controlled oil flow is set by adjusting the needle valve.

The compensator spool and bias spring work like a pressure reducing valve. The supply oil pressure is reduced to the pressure that sends the correct oil flow pass the needle valve.

When the system is off, the spring moves the compensator spool

to the left.

At start up, the compensator spool is open to full oil flow and pressure. When the oil flow becomes greater than the setting of the needle valve, the needle valve restricts oil flow and causes the oil pressure to increase as shown on gauge 2. The increase in oil pressure is also sensed on the left side of the compensator spool. When the force of the pressure on the left side of the compensator spool overcomes the force of the spring, the compensator spool moves to the right.

Although the supply pressure may continue to increase as shown on gauge 1, orifice 1 reduces the oil pressure at the needle valve to the force of the spring. The controlled oil flow pressure is 0 kPa (0 psi), the pressure differential across the needle valve is 1378 kPa (200 psi) which equals the force of the spring.

The needle valve is adjusted to allow 2 gpm through orifice 2 when the pressure differential across the needle valve is 1378 kPa (200 psi).

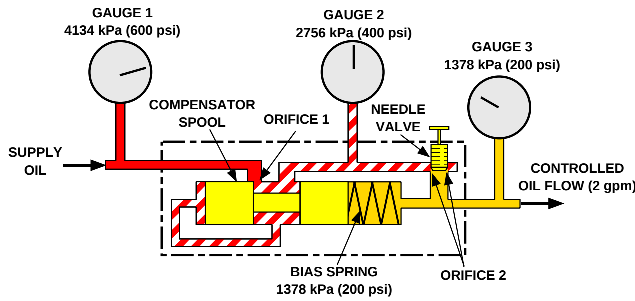

Fig. 3.6.14 Controlled Oil Pressure

Controlled Oil Pressure

In Figure 3.6.14, the controlled oil pressure is 1378 kPa (200 psi) as shown on gauge 3. The oil pressure in the valve spring chamber is also 1378 kPa (200 psi). The force of the spring chamber oil pressure is added to the force of the spring. The combined forces move the compensator spool to the left. When the compensator spool moves to the left, orifice 1 opens. Orifice 1 allows the oil pressure to increase at the upstream side of the needle valve.

The increase in oil pressure is also sensed on the left side of the compensator spool. The increase in pressure moves the compensator spool to the right against the combined force of the spring and controlled oil pressure. The compensator spool moves to a new position that allows 2756 kPa (400 psi) through orifice 1. The increase in gauge 2 pressure to 2756 kPa (400 psi) on the upstream side of the needle valve maintains a pressure differential of 1378 kPa (200 psi) across the needle valve (gauge 2 minus gauge 3).

The pressure differential of 1378 kPa (200 psi) across the needle valve sends 2 gpm through orifice 2.

The pressure compensated flow control valves offer more precise cylinder speed control than non-pressure compensated valves. The pressure compensated valves automatically adjust to keep the flow rate constant as load conditions vary.

The pressure compensated valves are usually installed when cylinder operating loads are 6890 kPa (1000 psi) and over.

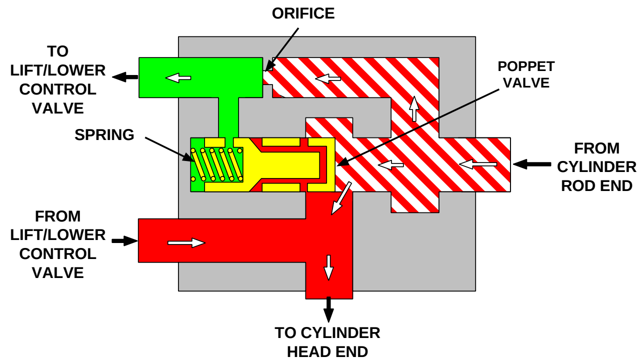

Fig. 3.6.15 Quick-Drop Valve

Quick-Drop Valve "Quick-Drop Mode"

Figure 3.6.15 shows an illustration of a quick-drop valve. The quick-drop valve is commonly installed on the dozer lift cylinder. When activated, the quick-drop valve allows the dozer blade to rapidly drop to the ground.

When the dozer blade is raised and the operator moves the lift/lower control to the QUICK-DROP position, the lift/lower control valve allows the lift cylinder rod end oil to flow to the tank. The gravitational forces acting on the dozer blade pulls the rod out of the cylinder and causes the piston to move independent of the force of the pump oil pressure. This action greatly increases the oil flow through the quick-drop valve orifice and creates a vacuum in the head end of the lift cylinder. The increase in oil flow through the orifice causes the pressure up stream of the orifice to increase. The increased oil pressure opens the poppet valve. The open poppet valve connects the passage from the cylinder rod end to the passage to the cylinder head end. The oil from the rod end of the cylinder flows through the open poppet valve, joins the oil from the control valve and flows to the head end of the cylinder.

A small amount of oil flows through the orifice to the lift/lower control valve and to the tank.

When the blade strikes the ground, the movement of the rod out of the cylinder cease. This causes a rapid decrease in the oil flow through the orifice. The pressure caused by flow through the orifice decreases and the spring closes the poppet valve. All oil flow to the head end, now comes from the lift/lower control valve.

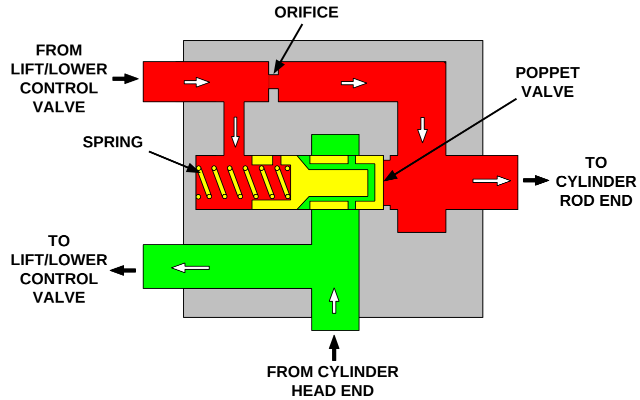

Fig. 3.6.16 Quick-Drop Valve

Quick-Drop Valve "Blade RAISE Mode"

Figure 3.6.16 shows the quick-drop valve when the blade is being raised.

When the operator moves the lift/lower control to the blade RAISE position, pump oil flows from the lift/lower control valve, through the orifice and to the rod end of the lift cylinder. The orifice creates a restriction to the oil flow which increases the upstream pressure. The higher pressure oil flows through the passage to the spring chamber behind the poppet valve. The pressurized oil assists the spring and holds the valve closed when pressure is applied to the rod end of the cylinder.

Oil from the head end flows through the quick-drop valve and the control valve to the tank.

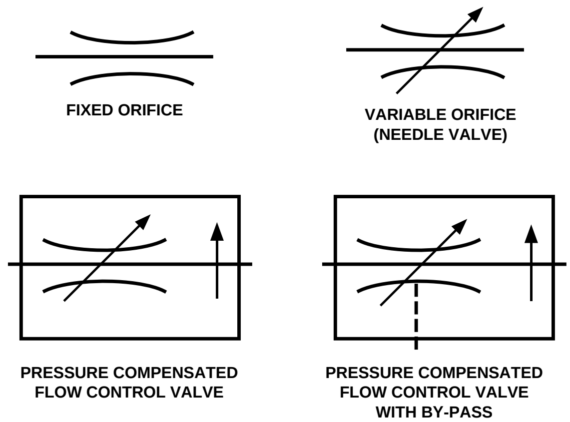

Fig. 3.6.17 Flow Control ISO Symbols

ISO Symbols

Figure 3.6.17 shows the ISO symbols for the basic flow control components.

The non-pressure compensated flow control ISO symbols are the fixed orifice and the variable orifice.

The pressure compensated flow control devices are the pressure compensated flow control valve and the pressure compensated flow control valve with by-pass.

The ISO symbol does not give any information on the actual physical structure of the component.

NOTES

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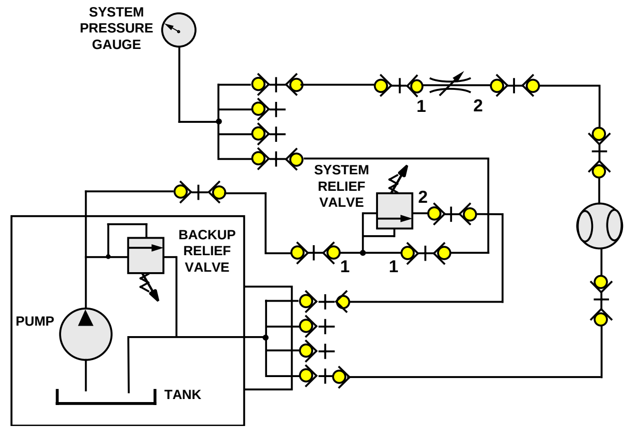

Fig. 3.6.18 Hydraulic Circuit

LAB 3.6.1: NEEDLE VALVE

Purpose

To install and operate a needle valve in simple hydraulic circuits.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Build the circuit shown in Figure 3.6.18.
2. Turn the needle valve adjustment knob clockwise until the valve closes completely.
3. Adjust system pressure to 5856 kPa (850 psi).
4. Turn ON the training unit.
5. Monitor the pressure gauge and flow meter. Record the readings in the "Chart 1" (Figure 3.6.19). The pressure gauge and flow meter readings will change with changes in hose length and oil temperature.
6. Open the needle valve one-half (1/2) turn at a time. Monitor the pressure gauge and flow meter. Record the readings in the "Chart 1" (Figure 3.6.19).
7. Continue to open the needle valve 1/2 turn at a time. Monitor the pressure gauge and flow meter. Record the readings in the "Chart 1" (Figure 3.6.19) until the valve is fully open.
8. Turn OFF the training unit and close the needle valve (turn clockwise).

LAB 3.6.1: NEEDLE VALVE (continued)

CHART 1

Number of Turns	Pressure kPa (PSI)	Flow Rate (GPM)
0	5856 kPa (850 psi)	0
1/2		
1		
1 1/2		
2		
2 1/2		
3		
3 1/2		

CHART 2

Number of Turns	Pressure kPa (PSI)	Flow Rate (GPM)
0	5856 kPa (850 psi)	
1/2		
1		
1 1/2		
2		
2 1/2		
3		
3 1/2		

Fig 3.6.19

9. Reverse the hoses to the top and bottom of the needle valve.
10. Turn ON the training unit.
11. Monitor the pressure gauge and flow meter. Record the readings in the "Chart 2" (Figure 3.6.19).
12. Continue to open the needle valve 1/2 turn at a time. Monitor the pressure gauge and flow meter. Record the readings in the "Chart 2" (Figure 3.6.19) until the valve is fully open.
13. Compare the two sets of data and explain what you have found.

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13. Turn OFF the training unit.

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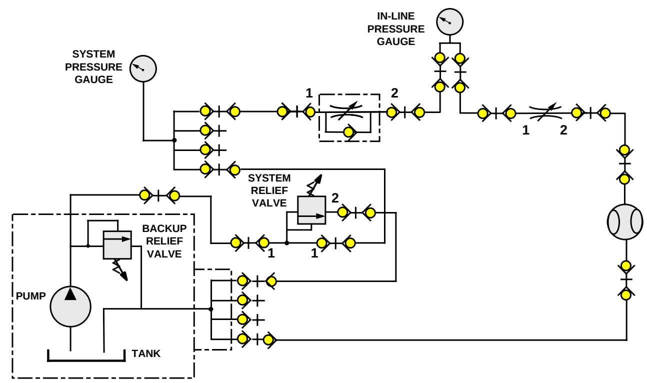

Fig. 3.6.20 Pressure Reducing Valve Circuit

LAB 3.6.2: NON-PRESSURE COMPENSATED FLOW CONTROL VALVE

Purpose

To install and operate in a hydraulic circuit a non-pressure compensated flow control valve with reverse flow check.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Build the circuit in Figure 3.6.20.
2. Adjust system pressure to 5856 kPa (850 psi).
3. Open the flow control valve and the needle valve fully counter-clock wise.
4. Turn on the training unit.
5. Monitor the gauges and flow meter. The flow meter should read 0.9 gpm.
6. Record the pressure gauges and the flow meter readings in the chart (Figure 3.6.21).
7. Adjust the flow control valve so that the flow meter reading is .5 gpm.
8. Monitor the gauges and flow meter. Record the data on the chart (Figure 3.6.21).
9. Adjust the needle valve so that the load on the system is 1378 kPa (200 psi). Pressure is shown on the in-line pressure gauge.
10. Monitor the flow meter and pressure gauges. Record the data on the chart (Figure 3.6.21).
11. Increase the load pressure in increments of 345 kPa (50 psi) up to 2756 kPa (400 psi). After each increase, record the flow meter and pressure gauges readings on the chart (Figure 3.6.21).

LAB 3.6.2: NON-PRESSURE COMPENSATED FLOW CONTROL VALVE (continued)

Test	System Pressure kPa (PSI)	In-Line Pressure kPa (PSI)	Flow Rate (GPM)
1			
2			
3			
4			
5			
6			
7			

Fig. 3.6.21

13. Turn OFF the training unit and review the complete set of data. The pressure gauge and flow meter readings will change with changes in hose length and oil temperature.
14. How does changing the load affect the flow rate as indicated on the flow meter?

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15. Based on your experience, what would happen in you switched the hoses on the ports to the flow control valve? Think about the effect of the change on flow control.

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16. Disconnect hoses from training unit.

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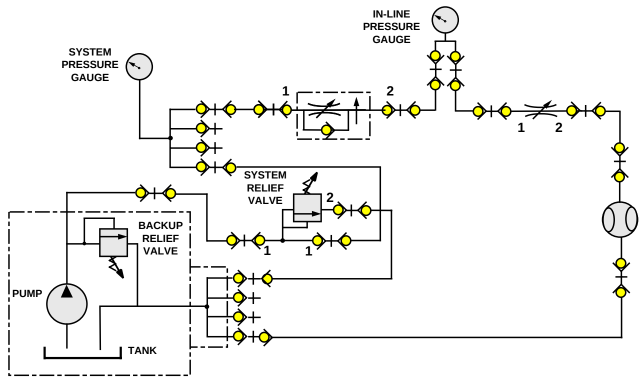

Fig. 3.6.22 Hydraulic Circuit

LAB 3.6.3: PRESSURE COMPENSATED FLOW CONTROL VALVE WITH REVERSE FLOW CHECK

Purpose

To install and operate in a hydraulic circuit a pressure compensated flow control valve with reverse flow check.

Materials needed

1. Basic Hydraulic Training Unit

Procedure

1. Build the circuit shown in Figure 3.6.22.
2. Adjust system pressure to 5856 kPa (850 psi).
3. Open the flow control valve and the needle valve fully counter-clock wise.
4. Turn on the training unit.
5. Monitor the gauges and flow meter. The flow meter should read 0.9 gpm.
6. Record the pressure gauges and the flow meter readings in the chart (Figure 3.6.23).
7 Adjust the flow control valve so that the flow meter reading is .5 gpm.
8. Monitor the gauges and flow meter. Record the data on the chart (Figure 3.6.23).
9. Adjust the needle valve so that the load on the system is 1378 kPa (200 psi). Pressure is shown in-line pressure gauge.
10. Monitor the flow meter and pressure gauges. Record the data on the chart (Figure 3.6.23).
11. Increase the load pressure in increments of 345 kPa (50 psi) up to 2756 kPa (400 psi). After each increase, record the flow meter and pressure gauges readings on the chart (Figure 3.6.23).

LAB 3.6.3: REVERSE FLOW CHECK (continued)

Test	System Pressure kPa (PSI)	In-Line Pressure kPa (PSI)	Flow Rate (GPM)
1			
2			
3			
4			
5			
6			
7			

Fig. 3.6.23

12. Turn OFF the training unit and review the complete set of data.
13. How does changing the load affect the flow rate as indicated on the flow meter?

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14. Based on your experience, what would happen in you switched the hoses on the ports to the flow control valve? Think about the effect of the change on flow control.

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15. When the system was throttled to .5 GPM, the pump still pumped 0.9 GPM. Based on your previous experiences and knowledge of the system, what is the flow path of the 0.4 GPM not used by the system?

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16. Disconnect hoses from training unit.