Chapter 7:
Flow Controls – Introductory Concepts

Objectives

- Learn the definition of a fixed and variable orifice.
- Learn the basics of a compensated and restrictive flow control.
- Understand the operation of a priority/bypass flow control.
- Learn about pressure compensation characteristics.

Introduction

This chapter is an introductory chapter to proportional flow controls. It will introduce basic, non-electrical flow controls. This will act as a foundation in understanding the terminology associated with the construction and operation of the proportional flow valve. In addition, terminology to describe the performance will also be introduced. Other terms that are specific to proportional valves such as hysteresis, saturation, control range etc. can be found in Chapter 3.
Flow Control – Introductory Concepts

A flow control valve is one which specifically regulates the volume of oil passing through a hydraulic system.

The following sections describe two types of flow controls, non-pressure-compensated and pressure-compensated. The first two flow controls described are the fixed orifice and the variable orifice, or a needle valve. The third and fourth flow controls presented are pressure-compensated flow controls. All four are described in the following sections to give a basic understanding of how the proportional flow controls operate.

Fixed Orifice

A flow control valve is one that is used to meter the quantity of fluid passing through a hydraulic system. The simplest type of flow control, a fixed orifice, is shown below.

Since the hole or orifice is smaller in diameter than the tube, the oil flowing through the tube, downstream of the orifice, is restricted compared to the flow upstream.

The amount of oil flowing through the orifice is dependent on the area of the orifice, the pressure drop across the orifice and the viscosity or thickness of the oil. The relationship below can be used to determine the flow through an orifice.

\[
\text{Flow} = 31 \times \text{Orifice Area} \times \sqrt{\text{Pressure drop}}
\]

The equation above is a simplified version of one used in engineering fluid dynamics. The equation is based on one for an orifice as shown above, where the edges of the hole are sharp. The simplifications or assumptions that are built into this equation are:
- oil viscosity: 32 cSt
- the pressure is measured in psi
- the flow is measured in gpm
- the area is measured in inches squared
- the length of the orifice does not exceed the diameter

A centistoke or cSt is simply a measure of the oil viscosity as an inch is a measure of distance. The viscosity represents how thick the oil is. 32cSt was selected because this is the typical viscosity at which valves are tested when performance data is presented in a catalog.

The number 31 in the equation above takes into account the viscosity and the adjustment for non-sharp orifice.
Variable Orifice

A needle valve is similar to a fixed orifice in that it meters flow through a set area defined by the needle and seat. The difference is that the needle can move up or down to increase or decrease the size of the orifice. This is why it is known as a variable orifice. The needle valve can open or close the same way a faucet does, allowing more or less flow, depending on the open area. The flow through the needle valve can be determined by using the equation from the previous page.

While both the fixed and variable orifices control flow, there is one drawback to using them. If the pressure across the flow area changes, so does the flow. This occurs when the pressure in a hydraulic system changes as the load changes. For example, there is a difference in the hydraulic pressure required to lift an empty excavator bucket versus a full one.
Restrictive Compensated Flow Control

The previous section described a fixed orifice flow control where the flow varied when the pressure varied. In order to eliminate or at least minimize how pressure affects the flow, a valve known as a pressure compensated flow control can be used. A simple representation of a pressure compensated flow control is shown to the left. This particular type of flow control is known as a restrictive flow control because, typically, it restricts the downstream flow to a value lower than the supply or pump flow. Notice that this valve is made up of a fixed orifice and a variable orifice. The variable orifice is created by the spool moving up and down. As the spool moves up or down the flow area of the variable increases or decreases. This type of device is typically used to control flow into or out of a cylinder, thus controlling the speed of the cylinder extending or retracting.

The valve works by maintaining a constant difference between the inlet pressure $P_{in}$ and the pressure at the load, $P_{load}$. This is accomplished by the fixed orifice, variable orifice, and the spring working together. First the fixed orifice regulates the flow as mentioned in the previous section. That is, the flow across this orifice is still dependent on the area, pressure drop and viscosity. The flow across the variable orifice is also dependent on the pressure difference across the fixed orifice. When the pressure difference across the fixed orifice increases, the force acting on the spool increases. The equation and diagram to the left describe this force.

Initially, oil flows across the fixed orifice and the position of the spool remains unchanged. This is true as long as the pressure force ($P_{in}$) is less than the spring force. As the pressure force increases the spool begins to push against the spring. The spool will continue to move until the spring force equals the pressure force. (Note the spring force is based on the amount the spring is compressed, multiplied by the stiffness of the spring, or the rate.)
Priority / Bypass Compensated Flow Control

Another type of pressure compensated flow control is known as a priority/bypass flow control valve. It is known as a priority/bypass flow regulator because flow is regulated at the priority port like the previous valve and the excess is diverted (bypassed) to another portion of the circuit. As with the first type of flow control, it is also made up of a fixed and a variable orifice. These two orifices make up the priority portion of the flow control. A third orifice which is also variable, is the bypass portion of the valve. This type of valve is shown to the right.

This flow control has two advantages over the fixed orifice. First, it maintains a constant flow rate regardless of the pressure. Second, the excess system flow can be used in a secondary hydraulic circuit or it can be dumped to tank through the bypass line, thus reducing the amount of wasted energy.

As with the restrictive type flow control, the spool position remains unchanged until the pressure force exceeds the spring force. The spool will then move in response to the change in pressure at the priority port. When there is a small difference between the inlet pressure $P_{in}$ or $P_{by}$ and $P_{load}$, the variable orifice #2 is opened less compared to variable orifice #1. Conversely, when the inlet pressure and the bypass pressure begin to increase compared to the priority pressure, the variable orifice #1 begins to decrease. Yet, in either case, the flow rate at the priority port is maintained at a constant level. Further, this implies the flow at the bypass port is also compensated. That is, if the pump flow and the flow at the priority port remain fixed, the bypass flow will remain unchanged regardless of changes in pressure. Again, the spool will move when the pressure force exceeds the spring force. When this occurs, flow at the priority port will be restricted until the force due to $P_{load}$ plus the spring force equals the force due to the inlet pressure. In other words, the spool position is in equilibrium (held in place) when $F_{spring} = F_{inlet} - F_{load}$.

For a more in-depth review of force balance equations, refer to the HydraForce Solenoid Course Manual.
Compensation Characteristic Curves

The performance characteristic that represents the ability of the flow control to maintain a desired flow value, is the compensation characteristic. As the curves show, there is no set rule-of-thumb regarding a general trend for a pressure compensation characteristic. The characteristic can be flat or varying, depending on the differential pressure between the inlet and the work port of the flow control. It is also dependent on the spring force valve design in general, and the geometry of the valve components. Typically, when the flow is at the maximum operating level, the characteristic is a decreasing trend. This decreasing trend is known as **droop**. In this case the flow control does not fully compensate for the change in pressure.

![Diagram of Compensation Characteristic Curves]

**Saturation**

Saturation is indicated by the flat portion of the flow vs. current characteristic. Saturation occurs when there is no relative change in flow, even with a change in current. The saturation current of a normally closed valve is the level at which any increase in current does not increase the flow. The saturation current for a normally open valve is the level where the flow decreases to the expected leakage flow rate. Note: The maximum current may or may not be the same value at which saturation occurs. In other words, the saturation flow is typically at or above the maximum current required for most HydraForce flow control valves and directional control valves.

![Diagram of Saturation Characteristic]
Summary

In this chapter the following concepts were presented:

- An equation to determine flow through an orifice.
- Fixed and variable non-pressure compensated flow controls.
- Introduction to pressure compensated flow controls.
- Pressure compensation characteristic.
Review Questions

Use the following review questions as a measure of your understanding of the chapter material. Answers are provided in the appendix.

1. The pressure drop across an orifice is 100 psi. The area is 0.005in². Determine the flow.

2. What is the disadvantage of a fixed orifice?

3. What is one typical application for a restrictive style flow regulator?

4. What is the typical viscosity used when valves are tested for presentation of performance in the HydraForce catalog?

5. True or False. The general trend of the flow characteristic for a pressure compensated flow control is decreasing with increasing pressure.

6. How many orifices are active during the operation of a priority/bypass type of flow control?

7. Describe saturation.

8. Define flow range.