Chapter 10: Bidirectional Flow Controls

Objectives

- Learn about the patented, bidirectional flow control valves.
- Understand how the flow force affects the performance of the ZL70-36.
- Learn why there is a small pressure sense tube used in the ZL70-30.
- Understand the differences between the ZL70-33 and the ZL70-36 valves.

Introduction

This chapter introduces the proportional bidirectional flow control valve for which HydraForce has obtained two patents. The first patent protects the invention of the bidirectional, internally compensated flow control. This is a restrictive style two-port device. The second patent protects the invention of a unique, internally compensated flow control specifically designed for use with a single acting cylinder. In one direction the valve acts as a priority/bypass flow control and in the other it acts as a restrictive type. The operation, performance and forces acting on the valve components will be presented. The application of these valves will be presented in the following chapter.
The ZL70-30 is a bidirectional, normally closed internally compensated, proportional, restrictive type flow control. Like the PV70-31, the ZL70-31 is the normally open version of this valve. The cross section, model code structure and two symbols are shown below. The first symbol separates the compensating element and the variable metering orifice. The second symbol was created for ease in drawing of a hydraulic circuit. The performance, forces acting on the valve components and operation will be presented in the following sections.
Performance of ZL70-30

This section presents the two curves which describe the performance of the ZL70-30. These are the same type of graphs used to describe the performance of the restrictive type flow controls presented in the previous chapter. The first is the flow vs. current characteristic and the second is the pressure compensation characteristic.

The flow vs. current characteristic is shown below. While only one curve is shown on the graph, it actually represents the regulated flow regardless if port 2 or port 3 is the inlet port used. In other words, the regulated flow is symmetrical regardless of the inlet. The schematic below represents the hydraulic system used to test the valve for this characteristic. A relief valve was installed down stream of the regulated port and was set to open at 3000 psi while the inlet pressure was limited to 3500 psi. The PWM dither frequency of the controller which powered the ZL70-30 was set at 110 Hz.
As the graph on the previous page shows, the hysteresis is less than 6%. The flow range is 0 to 5.3 gpm. Saturation occurs at 90% of maximum current or 1260 mAmp for a 12V coil.

The next graph shows the compensation characteristic of the ZL70-30. The curves show that regardless of the change in pressure, the flow remains constant. This is true up to the curve which represents the flow at 70% of maximum current. Above this curve there is some change in flow as the load pressure increases. The flow decreases as the pressure increases or there is a droop in the characteristic. The compensation spring value represented by the bend in the curve is 190 psi. This curve and the previous curve show little difference in the characteristic with regard to direction of flow through the valve.
Forces Acting on the ZL70-30

The same forces that act on the PV70-30 also act on the components of the ZL70-30. These include the magnetic force, the metering spool spring force, compensating spool spring force and flow force. These are all indicated on the diagram below. All these forces act equally regardless of the direction of flow. The direction of the spring force and flow force change, depending on if the flow is from 2 to 3 or 3 to 2. This is shown in the two enlarged diagrams of the compensating spool below.

Where:

- $F_M$ = Magnetic force
- $F_{S1}$ = Metering spool spring force
- $F_{P1}$ = Compensator spool inlet port pressure force
- $F_{P2}$ = Compensator spool work port pressure force
- $F_F$ = Flow force
- $F_{S2}$ = Compensator spring force
Operation of ZL70-30

The diagrams that follow are used to describe the operation of the ZL70-30. The operation of the ZL70-30 is similar to that of the PV70-30. That is, power is applied to the coil, thus creating a magnetic force. The armature is attracted to the pole piece and pushes on the metering spool. Oil is then allowed to flow from port 2 to port 3 or port 3 to port 2. Port 1 is not connected externally from the valve to the hydraulic circuit.

The first diagram to the left shows the valve when no current has been applied. Notice the metering spool is in the neutral or the de-energized position. Also, note that the compensating spool has completely covered the cage cross holes at port 3. This is because there is no pressure at port 3 to balance the inlet pressure at port 2. The next diagram to the right shows oil flowing from port 2 to port 3. Here the coil has been energized. Notice that the compensating spool has moved back to its initial at-rest position. As with the PV70-30, this is because the compensating spring force is greater than the force developed by the difference in pressure between ports 2 and 3. This would only occur if the inlet flow was actually lower than the desired regulated flow selected by the current applied to the ZL coil.
Typically, the flow available from the pump is greater than the desired regulated flow from the ZL70-30. When this is true, the compensating spool moves to restrict flow at port 3 as shown in the diagram to the left.

The diagram below shows the oil flowing from port 3 to port 2. As in the previous diagram, the compensating spool is metering the flow of oil but in this case, the flow is restricted at port 2 rather than port 3.

The performance (linearity, hysteresis, stability and symmetrical flow) of the ZL70-30 not only depend on the damping chamber and tight fit between the parts but also on the small tube inserted into the metering spool. This tube, known as a pressure sense tube, balances the pressure on either side of the metering spool. This means that the pressure inside the actuator portion of the valve is equal to the pressure at the bottom edge of the metering spool. These two areas of the valve are indicated in the drawing to the left.
The following diagrams show how the pressure in the actuator would vary if the tube were not in place. In the two sets of diagrams following, the inlet is at port 2. Notice in both, that as the oil flows through the spool there is a decrease in pressure. In the diagram without the tube, the lower pressure is transmitted to the actuator side of the spool through the small hole in the center of the spool. In the assembly with the tube, the pressure at the bottom of the spool, $P_2$, is transmitted through the tube up to the actuator. Also shown below these pictures is a diagram of the forces acting on the spool. As the diagram to the left shows, the force acting on the bottom of the spool is greater than the force acting on the top of the spool. However, in the diagram to the right, the forces are balanced.
The next set of pictures depict what occurs when the direction of flow is reversed. The diagram to the left indicates that the pressure on the top of the spool is higher than the bottom and this causes the force on the top of the spool to be greater than the bottom. The picture to the right shows that the pressure and force are balanced because the tube transmits the pressure from the bottom of the spool to the top.
As shown on the previous page, if the tube was not present there would be a force imbalance acting on the metering spool. That is, there is a difference in the force on the actuator side of the spool versus the metering side. Not only would there be a force imbalance, but it also switches directions depending on the direction of the flow. If this were to occur when oil flows from port 3 to port 2, this pressure force would assist the magnetic force. This assistance in force is so great that the flow vs. current graph would not be a straight line, but would appear as a step instead. However, when the oil is flowing from port 2 to port 3, this force would work against the magnetic force. This is summarized in the two drawings below. This force imbalance would cause the flow vs. current characteristic to appear different based on which port was the inlet, as shown in the following graph.
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Regulated Flow vs. Current
for imbalanced pressure force

Flow: port 2 to 3
Flow: port 3 to 2

Flow (gpm)

0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0

10 20 30 40 50 60 70 80 90 100

% of max. current
Amps (12V coil)

Flow (lpm)
ZL70-33

The ZL70-33 is the first of two valves specifically designed to proportionally control the lift and lowering of a single acting cylinder. It is a normally closed, internally compensated, bidirectional, proportional flow control. It is interesting to note that the ZL70-33 acts as a priority/bypass flow regulator when the inlet is at port 1. When the inlet is at port 3 and port 1 is blocked, the ZL70-33 acts as a restrictive type flow regulator. The cross section, symbol and model code are shown below. A section describing the performance follows as well as the operation of the valve itself. Also included is a section listing the forces acting on the valve. However, the detailed description of the forces can be found in other parts of this manual. The operation of the valve when used in a lift/lower circuit can be found in the applications chapter. In addition, the cross section of the cavity needed for the ZL70-33 and the ZL70-36 is shown on the following page.
Cavity for ZL70-33

Shown below is a comparison of the cavity that must be used for the ZL70-33 and the ZL70-36. The diagram on the left is the standard HydraForce 10-size 3-way cavity. The diagram on the right is a long version of the 10-size 3-way cavity. The ZL70-33 and ZL70-36 must use this long cavity because they do not fit into the standard cavity. Further, the other types of PV and ZL valves must use the standard cavity as they will not function properly in the long cavity.
Performance of ZL70-33

This section discusses the performance characteristics that describe the operating limits of the ZL70-33. These are the flow vs. current characteristic and the pressure compensation characteristic. The flow vs. current characteristic as well as the hydraulic schematic that represent the circuit in which the valve was tested are shown below.

Regulated Flow vs. Current
Input flow 24.5 lpm/6.5 gpm; Port 2 connected to tank
1 to 3 ——— 207 bar/3000 psi at port 3
3 to 2 – – – – 240 bar/3500 psi at port 3
Dither: 110 Hz

Inlet Pressure = 3500 psi
Load Pressure = 3000 psi
PWM = 110 Hz
Unlike the ZL70-30, there is a sufficient difference in the maximum regulated flow depending on whether port 1 or port 3 is used as an inlet, therefore two graphs are required. The hysteresis in both graphs is less than 6%. The threshold current is 20% or 0.28 amp for a 12V coil. The saturation current for both is 100% of the maximum operating current or 1400 mAmp for a 12V coil. The maximum regulated flow when the inlet is at port 1 is 5.3 gpm. When the inlet is port 3 the maximum regulated flow is limited to 5.1 gpm. See the graph on the previous page.

The graph below shows the compensation characteristic of the ZL70-33. Three line types are used to represents a different characteristic depending on the direction of flow. The curve on the left which joins all the compensation curves represents the compensation value of the valve. That is, the compensating spool begins to regulate at 75psi. The solid line represents the flow of oil from port 1 to port 3. The load pressure at port 3 was varied from a minimum setting of the relief valve to 3500 psi while the pressure and flow at port 3 were recorded on the graph. These lines show that regardless of the change in pressure, the ZL70-33 maintains a constant flow.

The dashed line represents the performance of the valve when oil flows from port 3 to 2. The next line to review is the one which starts at approximately 250 psi and runs almost parallel to the vertical axis. This line represents the minimum pressure required at port 3 to open the flow path at port 2 between the compensating spool and cage. The dashed lines which project horizontally from this one represent how the valve compensates for changes in load pressure with oil flowing from port 3 to 2.
Forces Acting on ZL70-33

Detailed below are the forces acting on the ZL70-33 which are the same forces acting on the ZL70-30. These include the magnetic force, spring force and pressure forces. A detailed description of all these forces can be found in the previous sections of this manual.

Where:

- $F_M$ = Magnetic force
- $F_{S1}$ = Metering spool spring force
- $F_{P1}$ = Compensator spool inlet port pressure force
- $F_{P2}$ = Compensator spool work port pressure force
- $F_F$ = Flow force
- $F_{S2}$ = Compensator spring force

As with the PV70-30 there is a pressure sense tube in the metering spool to balance the forces acting on this spool, regardless of the direction of flow. If the tube was not present, the flow vs. current characteristic would differ between the two flow paths.
Operation of ZL70-33

The following section details the operation of the ZL70-33. This includes what occurs as oil flows from port 1 through port 3 as well as the operation when port 3 acts as the inlet. In the first diagram at left, pump flow has been turned on but the ZL70-33 coil has not been energized. Notice that the cross holes of the metering spool guide remain blocked and the oil flows from port 1 to port 2. In this mode the valve is bypassing the pump flow.

In the diagram to the left, the coil has been energized and the metering spool has unblocked the cross holes of the guide. The compensator has also moved to allow oil to flow out of port 3. Notice that some of the oil is still flowing out of port 2 as well. In this mode the valve is acting as a priority/bypass valve.
The diagram below shows the operation of the ZL70-33 with the inlet at port 1. \( I_{MAX} \) has been applied to the coil. This causes the metering spool to shift fully. The compensator has returned to the neutral position. This occurs because the inlet flow is less than or equal to the desired flow. The desired flow in this case is the flow at \( I_{MAX} \) or approximately 5.3 gpm. (This can be found on the flow vs. current characteristic graph given in the previous section.)
The following two drawings will be used to describe the operation of the ZL70-33 when oil is flowing from port 3 to port 2. No oil can flow from port 1 because there is a valve external to the ZL70-33 blocking the flow of oil. This will be explained further in the next chapter. In both drawings, current has been applied to the coil. The metering spool has moved to allow oil to flow through the center of the compensating spool. The difference between the pictures is the position of the compensating spool. In the picture to the left, the compensating spool is blocking the flow of oil. This shows that the differential pressure across the compensating spool has not exceeded 250 psi. 250 psi is the minimum pressure differential required for the ZL70-33 to regulate the flow of oil from port 3 to 2. This is shown on the pressure compensation characteristic curve. This was also depicted in the compensation characteristic shown in the performance of ZL70-33 section when the inlet is at port 3. In the drawing to the right, oil is flowing out of port 2. This occurs because the differential pressure across the compensator is greater than 250 psi.
The cross section, schematic and model code of the ZL70-36 are shown below. This valve is a normally closed, bidirectional, internally compensated proportional flow control. Like the ZL70-33, this valve was specifically designed to control the movement of a single acting cylinder. The performance, forces and operation will be described in the following sections.
Performance of ZL70-36

Two graphs are shown in this section to depict the performance of the ZL70-36. The first graph shows the flow vs. current characteristic and the second shows the compensation characteristic. The schematic representing the hydraulic test can be found in the performance section of the ZL70-33. In both of the flow vs. current curves below, the hysteresis is less than 6%. The threshold current is 20% of IMAX and the saturation when oil flows from port 1 to 3 or port 3 to 2 is 95% of IMAX and 100% of IMAX respectively. The maximum flow range is 0 to 5.5 gpm for the 1 to 3 direction but only 0 to 4.7 for the 3 to 2 direction.

![Regulated Flow vs. Current](image)

*Input flow 24.5 lpm/6.5 gpm; Port 2 connected to tank*

1 to 3 ——— 207 bar/3000 psi at port 3
3 to 2 ——— 240 bar/3500 psi at port 3

Dither: 110 Hz
The next graph represents the compensation characteristic for either oil flowing from port 1 to 3 or port 3 to 2. The line running almost parallel to the flow axis on the left can be used to determine the compensation value, which is 50 psi. Notice that unlike the ZL70-33, oil begins to flow immediately with the slightest change in pressure. This graph was made by setting the current to a specified level. Then the flow and load pressure were recorded while the inlet pressure was varied.
Forces Acting on ZL70-36

A cross section of the ZL70-36 with the forces labeled on the various components is shown below. These forces are the same as the ones listed on other proportional flow controls.

Where:
- $F_M$ = Magnetic force
- $F_{S1}$ = Metering spool spring force
- $F_{P1}$ = Compensator spool inlet port pressure force
- $F_{P2}$ = Compensator spool work port pressure force
- $F_F$ = Flow force
- $F_{S2}$ = Compensator spring force
The flow force acting on the compensating spool when the oil flows from port 3 to 2 affects the performance more than when the oil flows from port 1 to 3. In fact, the flow force has more influence on the compensating spool in the ZL70-36 than the ZL70-33. This is because the compensating spool spring force in the ZL70-36 is less than that of the ZL70-33. The following graphs show how the flow force differs depending on the direction of flow and how it affects performance.

The first graph shows how the spring force changes to match the pressure force. The various points labeled on the graph represent the position of the compensating spool in relation to the flow achieved when the current is varied. These points are also shown on the flow vs. current graph in the middle. Notice that point 1 on the force graph represents the highest spring force, but it also represents the lowest flow. This is because the metering spool is closed so the pressure at port 2 pushes up on the compensating spool and compresses the compensating spring. A pictorial view of the compensating spool in this position can be found in the first operational diagram of the following section. As the metering spool moves to uncover more of the metering spool guide cross holes, the compensating spool moves accordingly. A constant differential pressure is then maintained across the metering spool. As the compensating spool moves, the spring force decreases. This is shown in the decreasing slope of the line on the graphs. Notice the flow force is not shown on this graph. This is because the two different flow forces cancel each other out when the oil flows from port 1 to port 3.

The second force vs. spool position graph shows the changes in force as oil flows from port 3 to port 2. In this graph the flow force is shown. This is because the flow forces do not completely cancel. The beginning portion of this graph is similar to the previous. The difference is in the second half. As more flow passes through the valve, the flow force increases. Eventually, the flow force is so great that the flow cannot increase further. This is because the compensating spool is beginning to wash shut.

**Flow port 1 to 3**

**Flow port 3 to 2**

Where:
- \( F_S \) = spring force
- \( F_P \) = pressure force
- \( F_F \) = flow force
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Operation of ZL70-36

The following section describes the operation of the ZL70-36. The first two drawings show the operation when oil is flowing from port 1 to port 3. As with all the normally closed proportional valves, the flow of oil is blocked between the inlet and outlet until the threshold current is applied. The diagram to the left shows the condition where no power has been applied to the coil. Like the ZL70-33, all the oil is bypassed to tank.

The next drawing shows the metering spool has moved from the neutral position because current has been applied to the coil. The oil is now flowing to both the work port and bypass port. The compensating spool is metering the flow at port 3.
The next three diagrams show the operation of the ZL70-36 when oil is flowing from port 3 to port 2. The first diagram below shows that the metering spool is in the neutral position. The compensating spool has moved to completely cover the cage cross holes. This occurred because there is no pressure at port 2 to balance the pressure at port 3. Again, no oil is flowing because no power has been applied to the coil.
The diagram at left shows that the metering spool has moved and the cross-holes of the metering spool guide have been uncovered. Oil is now flowing from port 3 to port 2. The compensating spool is metering the flow of oil at port 2.

This last diagram shows that the oil is still flowing from port 3 to port 2. The difference between this picture and the one above is that the compensating spool is no longer metering flow at port 2. This is because the pressure difference between port 3 and port 2 does not exceed the pressure compensating spring force. However, unlike the ZL70-33, oil continues to flow. This is because the compensating spool is free to float in the ZL70-36. The compensating spool in the ZL70-33 is held in place by the compensating spring.
Summary

In this chapter the following concepts were presented:

• The patent covering the invention of the bidirectional flow control.

• The performance and operation of the restrictive style, bidirectional ZL70-30.

• How the pressure sense tube improves the performance of the ZL70-30.

• Why the flow force affects the maximum flow through the ZL70-36 more than the ZL70-30.

• The various compensating values for the ZL70 type valves.

• The operation of the ZL70-33 and the ZL70-36 and how the valves change from priority/bypass type to a restrictive type valve depending on the direction of flow.
Review Questions

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

1. What is the basic premise of the patents covering the bidirectional flow control?
2. Why is the pressure sense tube used in the ZL70-30?
3. What are the differences in the forces acting on the compensating spool of the ZL70-30 when the flow changes direction?
4. What is the compensating pressure of the ZL70-30?
5. True or False. The ZL70-30 is a restrictive type flow control.
6. What is the minimum pressure required at port 3 of the ZL70-33 to move the compensating spool so that oil can flow?
7. What is the compensating value of the ZL70-33 when oil flows from port 1 to 3?
8. What is the compensating value of the ZL70-36 when oil flows from port 1 to 3 or from port 3 to 2?
9. What are some of the main differences between the performance of the ZL70-33 and the ZL70-36?
10. True or False. The ZL70-36 can either be a restrictive type flow control or a priority bypass type flow control, depending on the direction of flow.
Notes: