Chapter 4: Direct-Acting Pressure Controls

Objectives

The objectives for this chapter are as follows:

- Learn about direct acting proportional pressure control valves.
- Become familiar with the operation of the manual override in the TS valves.
- Become familiar with the bleeding screw feature available on the TS valves.
- Recognize the difference between the force motor and linear proportional actuator.
- Understand the performance graphs associated with proportional pressure controls.
- Recognize the differences between the TS38-20 and the TS38-21 valves.
- Learn about the EHPR08-33.

Introduction

In this chapter, we will look at design, construction and operating parameters of the direct acting pressure control valves available from HydraForce. The discussion begins with two different types of direct acting relief valves. One of which increases pressure as current is increased and the other where the control pressure decreases as current is increased. The final valve that we will look at is a direct acting pressure reducing and relieving valve.
TS38-20

The TS38-20 is a direct acting pressure relief valve which is used to control the pressure of the hydraulic system. It is considered a direct acting valve because the poppet is the main hydraulic controlling element and directly controls the pressure. In addition, it can be used to control the pressure applied to a cylinder, motor or another valve.

The cross section shown below is that of the TS38-20 valve. The following sections describe how the valve works, the forces acting on the components and the various operating parameters. Also included is a section on the manual override operation and bleeder screw operation. Note the TS38-20 is available without the manual override option.
Performance of TS38-20

The following graphs illustrate typical performance of the TS38-20A with and without current applied. Graph 1 shows the pressure drop through the valve when no current is applied and the flow varies. Graph 2 shows the pressure dependency on the input of current. Graph 3 shows the relation between flow and pressure with fixed levels of current applied to the coil.

The graph above shows three sets of lines or pressure drop curves. Each set is designated by a letter, either A, B or C which indicates the pressure range. The pressure drop for A is higher than that for C because the seat for A is smaller than the one for C. A smaller seat or orifice means that the flow restriction is higher, increasing the pressure drop. There are two lines (solid and dashed) for each pressure control range. Two lines are shown because the pressure drop through the valve is dependant on the way the valve is mounted (positioned relative to the ground). A diagram of mounting positions is shown on the following page. If the valve is mounted vertically (nut side up), the weight of the plunger pushes down on the poppet. Pressure is required to push the poppet off its seat before oil can flow. This is reflected in the small offset shown between the solid and dashed lines.
The following diagram shows three positions in which valves may be mounted. The picture on the left shows the valve mounted parallel or horizontal to the ground. In this case, the cylindrical part of the coil and valve are laying on their side. The center picture shows the axis of the valve is perpendicular to the ground and is mounted with the nut furthest from the ground. The picture on the right also shows the valve mounted vertically with the nut side facing down.
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Shown above is the pressure vs. current graph for the TS38-20. Several pieces of information can be extracted from this graph. These include: threshold current, pressure range and hysteresis.

Notice in Graph 2 the threshold current is zero. This occurs because there is no force initially opposing the magnetic force developed by the current. A force which would initially work against the magnetic force is the spring. Since there is no spring opposing the plunger, there is no threshold current required. The spring shown in the manual override portion of the valve will be discussed later in this chapter. Recall that threshold current is defined as the current level which produces a change in the output, in this case a change in pressure. Graph 2 shows that there is an immediate change in pressure with the smallest amount of current.

Recall from Chapter 3 that the pressure range is the pressure between the threshold current and maximum current. There are three pressure ranges for the TS38-20: A: 0-3000 psi, B: 0-2000 psi and C: 0-1000 psi.

The hysteresis shown in the curves above is less than 3.3%. Recall that hysteresis is a measurement of how far apart the increasing and decreasing lines are from one another for a particular pressure range. Looking at 50% current for the A pressure range, shows there is a difference of 100 psi between the two curves, with a range of 3000 psi. This produces a hysteresis of 3.33% ((100 psi / 3000 psi) x 100). As mentioned in Chapter 2, the use of dither decreases hysteresis. If dither or PWM is not used in this case, the hysteresis is 7% or less.
The following graph describes the pressure rise of the TS38-20. This graph shows how the pressure increases as the flow increases when a fixed level of current is applied to the coil. Pressure increases because of the pressure drop through the valve.
Forces of TS38-20

The operation of this valve, as in all other valves discussed in this manual, is dependant on balancing the forces acting on the hydraulic components. Since forces such as viscous and mechanical friction, along with residual magnetic force or hysteresis have already been reviewed in Chapter 3, the remainder of the manual will focus on the dominant forces. These include the spring force, pressure force, magnetic force and flow force. Not all these forces are present or exist to a significant degree in all valves. The two main forces that will be covered on the TS38-20 are the magnetic force and the pressure force.

Magnetic Force

The type of solenoid actuator used in the TS38-20 is known as a flat face actuator or force motor. The part of the valve that makes up the actuator is shown below.

The actuator is termed flat face because of the flat surface between the two elements. The term force motor comes from the relation of the actuator elements to elements found in a common electrical motor. These elements are the winding, armature and pole piece. The armature and pole piece make up what is known as a stator in a motor. The stator is the part of the motor that becomes magnetic when the coil is turned on. A motor spins or rotates. The motor generates torque which is work that can be used to spin another device attached to the motor. In the case of a flat face actuator, it generates force that can move something in a straight line. In other words, the actuator is an electric motor that generates force instead of torque. Thus the term ‘force motor’.
The graphs below show the force vs. air gap as well as the force vs. current characteristic. The graph on the left shows the force decreasing as the air gap increases. Because of this continual change in force, valves with this type of actuator typically use only a limited amount of air gap or stroke. The graph on the right shows how the force from the actuator increases proportionally with the increase in current.

If the change in air gap was not limited to a small amount (approximately 0.005 inches, or the difference between $X_1$ and $X_2$) a different force would result for the same amount of current. Compare the force vs. current graphs for air gap $X_1$ and $X_2$. Notice that these differ only a small amount. Therefore, if the armature is at $X_1$ and the same amount of force is required as the $X_2$ graph, the current only needs to be increased slightly. However, if the armature was at $X_1$ and the same force was required as the $X_3$ graph, the current would need to be increased greatly.
Pressure Force

The pressure at the inlet acts on or pushes on the poppet, as shown in the diagram to the below. The type of poppet used in the TS38-20 is known as a differential area poppet. This means that the pressure is acting on two different areas. Differential area poppets are used because there is a limitation on the amount of magnetic force which the actuator can develop. For the poppet shown, the pressure force is found as follows:

\[\text{Force} = \text{Pressure} \times \text{Area} \text{ or } F = P \times A\]

The total pressure force is, \(F_P\), is based on the difference between \(F_1\) and \(F_2\) where:

\[F_1 = \text{Force acting on seat of poppet} = P \times A_1\]
\[F_2 = \text{Force acting on stem of poppet} = P \times A_2\]

\[F_P = F_1 - F_2 = (P \times A_1) - (P \times A_2) = P(A_1-A_2)\]
Operation of TS38-20

When current is applied to this valve, pressure builds in the system. An example of a system which could use this valve is shown on the following page. In this circuit, as the pressure increases, the torque developed by the motor increases. If the current is held at a certain level, the pressure and torque also remain at that level. When no current is applied, the pressure in the system is simply the pressure drop through the valve.

Where:
- $F_M$ = the magnetic force
- $F_P$ = the pressure force
The graph below describes the pressure and flow of the hydraulic circuit below as well as the current applied to the coil. In addition, the diagram of the poppet on the previous page is related to the graph. From points A-B, there is no current applied to the coil. The pressure measured in the system is the pressure drop due to the flow through the valve. When current is applied (B-C portion of graph), the magnetic force (\(F_M\)) or attraction between the pole piece and plunger builds. As a result, the poppet is pushed on its seat. This blocks the flow from the inlet of the valve to the tank. The pressure at port 1 builds until the pressure force (\(F_P\)) equals or exceeds the magnetic force. Oil then begins to relieve to tank so that the magnetic force and pressure force remain in balance (C-D portion of the graph).
Manual Override Operation

The manual override is to be used only in case of loss of electrical power to the solenoid or a failure of the solenoid itself. In other words, it is to be used in emergency situations. The manual override in the TS38-20 is known as a screw style. The TS38-20X is a version of the same valve with no manual override. Initially, the spring is free to float between the plunger and the manual override screw. As the screw is turned, it eventually comes in contact with the spring and it begins to compress the spring. The force applied to the opposing parts, in this case the plunger, increases linearly. The increase in force is directly related to the amount the spring is compressed. That is, force is equal to the distance of compression multiplied by the rate of the spring \((F = D \times R)\). The rate is a measure of how stiff the spring is. The stiffer the spring is, the greater the force. The spring force replaces the magnetic force. The number of times the adjusting screw is turned is superimposed on the pressure vs. current graph to the right.
It is important to note that if the manual override screw is not fully backed out (turned full counter clockwise), then the amount the spring is compressed will add to the force developed by the solenoid. The lower graph illustrates this concept. Note that the pressure starts at 500 psi when no current is applied. This offset is due to the fact that the manual override screw is turned clockwise 1/2 to 1 turn. Since the spring force is added to the magnetic force, the manual override must be turned full counterclockwise during normal operation of the valve. If this is not done, the maximum pressure controlled by the TS38-20 may exceed the rating of the rest of the hydraulic system.

While the manual override should typically be used only in an emergency, it could also be used to set the minimum pressure. As noted in the graphs on the previous page, if the manual override is turned in approximately 1/2 turn, the minimum pressure setting of the TS38-20A will be between 200-400 psi, even when no current is applied. For every 1/2 turn from that point, the pressure will increase approximately 500 psi. In order to protect the other hydraulic components in the system, Imax from the controller would need to be limited to a level with the rating of these components. Another method which could be used to set the minimum pressure would be through the use of the I_min control. In this case, current would need to be applied to the coil to reach that minimum current.
The TS38-21 is a direct acting, single stage pressure control valve. Like the TS38-20, it can be used to directly control the pressure in a hydraulic circuit. However, because of its limited flow capability (0.3 gpm), it is typically used as a pilot element for larger spools. A cross section of it is shown in the diagram below. It works opposite to the way the TS38-20 valve works, meaning, as current is increased, the pressure decreases. The performance, forces and operation of the TS38-21 will be presented in the following sections.
Performance of TS38-21

The first graph shown below is the pressure vs. current graph. Notice that the pressure at no current is high and as current is applied, the pressure decreases until approximately 89% of maximum current, at which point the pressure levels off. This will be further discussed in the operation of the valve.

The pressure range for this valve is 3000 to 150 psi. The hysteresis shown above is 30% with 200Hz PWM or dither current applied to the coil. The threshold current is zero, even though there is a spring opposing the armature. This too will be further discussed in the operation section.

Graph two shown below depicts the change in pressure as the flow increases. This change in pressure is a direct result of the pressure drop through the valve as shown in Graph 3.
Forces of TS38-21

The three dominant forces which will be reviewed are:
\[ F_M = \text{Magnetic Force} \]
\[ F_S = \text{Spring Force} \]
\[ F_P = \text{Pressure Force} \]

The magnetic force which is present in the TS38-21 is from a force motor or flat face actuator, as described in the TS38-20. The spring force opposes the armature (magnetic) force and at the same time, holds the poppet on its seat. The pressure force pushes the poppet up against the spring. These two forces will be described below.

### Spring Force

The type of spring inside the TS38-21 as well as the other valves in this manual is known as a compression spring. It is called this because the force of the spring increases as it is compressed. In the TS38-21, the spring is compressed between the adjuster in the pole piece and the plunger. The adjuster in the pole piece is used to consistently set the initial or installed force of the spring. This setting is only done in the factory. The following equation describes the spring force.

\[ \text{Force} = \text{Rate} \times \text{Amount compressed} \]

The rate is a constant describing how stiff or difficult it is to compress the spring. The stiffer the rating, the higher the force is for a given amount of compression.

### Pressure Force

The pressure force acting on the poppet is similar to that of the TS38-20. However, in this case, the pressure acts directly on one area only rather than two. For this valve the pressure is described by the following equation:

\[ \text{Force} = \text{Pressure} \times \text{Area} \]
Operation of TS38-21

The two graphs below will be used in describing the operation of the TS38-21.

When no current is applied to the coil of the TS38-21, the valve acts as a mechanical relief valve. That is, it works like the relief valve described in Chapter 3. The pressure pushes up against the ball which in turn pushes on the plunger and spring. When the pressure force balances the spring force, the crack pressure is reached. If flow continues to increase, pressure across the valve begins to rise. This can be seen in graph on the left.

If current is applied to the coil, the magnetic force begins to build. As the magnetic force increases, it works against the spring force. Since the spring force is now acting against the poppet and the armature, the pressure begins to decrease. As the current is increased, the pressure continues to decrease until the magnetic force exceeds the spring and the pressure in the system drops to 150 psi.
The three diagrams above further clarify the operation of the TS38-21. In the diagram on the left, pressure is pushing on the poppet. No flow is passing through the valve however, because the spring force is greater than the pressure force. In the center diagram, current is applied to the coil, creating the magnetic force. The magnetic force assists the pressure force and oil begins to flow. In the third diagram, the magnetic force is even greater. More oil is allowed to flow, which results in a decrease in pressure.

The lowest value to which the pressure can be decreased is 150 psi, regardless of the current that is applied to the coil. The reason for this is that the shim between the plunger and the pole piece limits the movement of the plunger. This also limits the movement of the poppet. Because the poppet is still close to the seat, the pressure drop through the valve is 150 psi with a flow of 0.3 gpm or the minimum setting of the valve.
EHPR08-33

The cross section of the EHPR08-33 is shown below. It is a direct acting pressure reducing/relieving valve, used to control pressure at the work port (the port at which the load is connected), regardless of the inlet pressure. This is true as long as the inlet pressure is always greater than the control pressure. Direct acting means that there is one hydraulic component (the spool), within the valve controlling hydraulic pressure. This valve can be used to directly control pressure to a clutch. However, because the maximum operating flow is relatively small (1 gpm) for clutch applications, it is typically used to control pilot pressure applied to spools in larger valves. The performance, forces acting on the valve and operation of the valve will be discussed in the sections which follow.
Performance of EHPR08-33

The following graphs illustrate typical performance of the EHPR08-33. Graph 1 shows the pressure vs. current performance. Graph 2 shows both the pressure rise performance when the valve works in the relieving mode and the pressure droop when the valve works in the reducing mode.

The graph above shows the pressure vs. current performance. Not only does it show how the pressure varies with current, it also gives other performance characteristics such as the threshold current. As the graph shows, the threshold current is 28% of the maximum current or 0.34 mAmp for a 12V coil.

The graph also shows the pressure range which is 0-375 psi for the EHPR08-33. Unlike the TS38-20, there is only one pressure range available.

Another performance characteristic depicted by the curve is the hysteresis. The hysteresis for the EHPR08-33 is less than 3% when dither or PWM is applied to the coil. If smooth DC current is applied to the coil, the hysteresis is 10%. (This is not shown in the graph.)
The following graph shows the pressure rise and droop of the valve. The portion on the right shows the pressure droop or how the desired control pressure decreases as the flow increases. Pressure droop occurs when the flow is increased and the current is held fixed, while the valve is reducing pressure. For example, the “46% of maximum current” line shows that when there is no flow through the valve, the control pressure is 94 psi. When there is 1 gpm, the control pressure is approximately 75 psi.

The pressure rise is also shown on this graph, and is associated with the relieving mode of the valve. The change in the work pressure is a result of the pressure drop in the valve. The graph shows the pressure rises by approximately 20 psi for a change in flow from 0 to 1.0 gpm.
 Forces of EHPR08-33

The forces acting on the valve components which will be considered in the following section are:

- \( F_P \) = Pressure Force
- \( F_M \) = Magnetic Force
- \( F_F \) = Flow Force
- \( F_S \) = Spring Force

These four forces and the way they act on the EHPR08-33 will be described in the following section. The spring force is the same as was described for the TS38-21 and will therefore not be discussed in this section.

Pressure Force

When the coil is energized, the spool moves down, connecting the inlet to the work port. The oil flows from the inlet to the work port and pushes up on the bottom of the spool. This area, multiplied by the pressure, gives the pressure force \((P \times A = F)\).
Magnetic Force

The type of actuator used in the EHPR08-33 is a linear proportional solenoid actuator. It is called this because the force builds proportionally to the current. In addition, it is called linear because the armature moves in a straight line as opposed to a rotary actuator which turns like a wheel. The following graphs show how the force varies with the movement of the plunger or change in air gap and how the force varies with current.

Both graphs show that the force remains constant regardless of the position of the armature. This allows the stroke of the hydraulic element, which the armature controls, to be much greater as compared to the flat face actuator. The drawback to this increased stroke is a decrease in force for the same size coil.
Flow Force

In addition to the magnetic force, pressure force and spring force, a fourth force which acts on the spool would be the flow force. This force increases as the flow from port 2 to port 1 increases. As a result, the magnetic force is opposing two forces. In order for the forces acting on the spool to remain in balance, the pressure force needs to decrease. This is shown in the droop of the pressure in the reducing pressure vs. flow graph.

If $F_{\text{Flow}}$ Then $F_{\text{Pressure}}$

$F_{\text{magnetic}} = F_{\text{pressure}} + F_{\text{flow}}$

This is true as long as the current to the coil or magnetic force remains unchanged.

Summary of Forces

The force can be summarized by the following equation: $F_M = F_S + F_F + F_P$

The interaction between the forces can be seen in the two graphs below. The graph on the left shows two curves representing the performance of the valve as current is varied. One curve gives the pressure when there is no flow or the oil is dead-headed (maintaining the pressure in a fixed volume of oil) at the work port. The other curve on this graph depicts the performance when oil flows out of the work port.

The graph above-right shows how the pressure droops from the no flow (deadheaded) condition to full flow. There are two curves on this graph as well. Each represents a fixed current level. Again, the pressure droop is caused by the fact that the magnetic force is held constant and the flow force is increasing as flow increases.
Operation of EHPR08-33

Refer to the graphs on the previous page as well as the diagrams below for the following section.

The first diagram shows the spool in transition. This is the point where all ports are blocked. In this case, the current was just applied to the coil, causing the plunger to move down against the spool, compressing the spring. This is shown in the pressure vs. current graph as the flat part just before the threshold current is reached, or $F_M \leq F_s + F_p$. The next picture shows when the spool has been pushed down by the armature and opens a small passage between the inlet and the work port. Oil flows downstream of the work port. If no more oil is needed downstream of the workport, the system is considered to be dead-headed. The spool then moves between allowing oil from the inlet to the work port (reducing) and the work port to the tank (relieving). The relieving mode is shown in the diagram on the right.
Summary

In this chapter the following concepts were presented:

- What a direct acting proportional valve is.
- The function of the TS38-20 as well as how it works and the forces acting on it.
- The positions in which valves can be mounted.
- The manual override option is and how it works.
- The bleeder screw and how it is used.
- The performance, forces and operation of the TS38-20.
- The performance, forces and operation of the EHPR08-33.
- What a force motor or flat face actuator is.
- The force vs. air gap characteristic of a linear proportional actuator.
- Why pressure droop and pressure rise occurs when using pressure reducing/relieving valves.
Review Questions

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

1. Why is it important to assure that the manual override of the TS38-20 turned fully counterclockwise when power is applied to the coil? 

2. Why is the stroke of the TS38-20 limited to 0.005 inches?

3. Describe the spring force.

4. What type of actuator is used in the EHPR08-33?

5. Does the force in the EHPR08-33 remain constant as the air gap changes?

6. What is the hysteresis of the TS38-20 with PWM?

7. What is the pressure range of the TS38-21?

8. What is the typical application for the TS38-21?

9. What causes the pressure droop in the EHPR08-33?

10. Why is the EHPR08-33 typically used to pilot larger spool valves?
Notes: