Objectives

After studying this chapter, you will be able to:

✓ List the two different types of pre-spool-compensated LSPC systems.
✓ Explain the operation of a fixed-displacement LSPC hydraulic system.
✓ Define load sensing.
✓ Explain the operation of a signal network.
✓ Describe the operation of a signal network.
✓ Explain the two different meanings of pressure compensation in an LSPC system.
✓ List examples of fixed-displacement LSPC systems in mobile machinery.
✓ Explain the similarities between unloading valves and flow control valves; and pressure relief valves and pressure compensator valves within LSPC systems.
✓ Explain the operation of a variable-displacement LSPC hydraulic system.
✓ Describe examples of relief valves and the absence of relief valves in LSPC systems.
✓ Explain the benefit and operation of torque-limiting controls.
✓ Describe the application of jammer solenoids in variable-displacement LSPC systems.
✓ Explain what equipment is needed to add power beyond in an LSPC system.

Introduction to Load-Sensing Pressure-Compensating (LSPC) Hydraulic Systems

The previous chapter focused on pressure-compensating hydraulic systems, which use a variable-displacement hydraulic pump that maintains high pressure and practically no flow anytime the DCVs are in a neutral position. LSPC systems use closed-center DCVs and one of two hydraulic pump designs:

• Variable-displacement with variable flow.
• Fixed-displacement with constant flow.

In order to fully understand LSPC systems, it is helpful to break the system into two separate operations: load sensing and pressure compensation. This chapter will begin by explaining load sensing and pressure compensation separately in order to build a foundation to better understand the principles of load-sensing pressure-compensating (LSPC) systems.

Load-Sensing System

In Figure 18-1, a closed-center DCV valve is used with a fixed-displacement pump. In this scenario, anytime the DCV is in a neutral position, maximum hydraulic horsepower will be generated by constantly flowing oil over the main system relief valve at a high system pressure. As a result, the system will generate unnecessary heat, pressure, and noise. This is one reason this style of hydraulic system is not used in machinery today.

A load-sensing (LS) hydraulic system is designed to operate at a prescribed pressure value above the highest working pressure. See Figure 18-2. Two items have been inserted into the previous closed-center system schematic in order to convert the hydraulic system into a LS hydraulic system: an unloading valve and a shuttle valve. The term unloading valve means that the valve dumps the hydraulic pump’s flow to the reservoir at a set low-pressure value anytime the closed-center DCV is in the neutral position. In this case, the unloading valve's spring value is set at 300 psi (21 bar).

When the DCV is actuated, the shuttle valve senses the load's working pressure and sends that signal pressure to the unloading valve. If the cylinder requires 1000 psi (69 bar) to extend, the shuttle valve sends that 1000 psi (69 bar) signal pressure to work in conjunction with the unloading valve's spring pressure. The combination of the spring pressure and signal pressure causes the system to operate at 1300 psi (90 bar). The difference between pump outlet pressure and signal pressure is known as differential pressure or margin pressure. Margin pressure as it relates to variable-displacement LSPC systems is explained later in this chapter.

Note

The unloading valve’s spring can be called the differential spring, margin spring, standby spring, low-pressure standby spring, or the dump valve spring.
At least one gear pump supplier, Concentric (formerly Haldex), manufactures a LS gear pump that places the unloading valve inside the pump housing. They advertise that this design has the pump directly controlling the flows and pressures, which will reduce valving losses and circuit inefficiencies.

Some individuals might be tempted to call the hydraulic system in Figure 18-2 an open-center hydraulic system. When the DCV is in the neutral position, the fixed-displacement pump delivers a maximum amount of flow at a relatively low pressure of 300 psi (21 bar). Technically, the DCV is closed center and the DCV sends a signal to an unloading valve. The hydraulic system is therefore more accurately described as a constant flow closed-center LS hydraulic system. This style of hydraulic system still wastes hydraulic horsepower when the DCV is in the neutral position. In this case, if the gear pump is delivering a constant 30 gpm (113.5 lpm) of flow at 300 psi (21 bar), the system will consume a certain amount of engine horsepower:

$$30 \text{ gpm (113.5 lpm)} \times 300 \text{ psi (21 bar)} \times 0.000583 = 5.2 \text{ hp}$$

This style of hydraulic system is still found in mobile machinery and examples of machines using this design are listed later in this chapter.

Figure 18-2. A fixed-displacement pump can be used in a load-sensing application by adding a shuttle valve and an unloading valve. The unloading valve keeps the pump operating at a set low system pressure when the DCV is in a neutral position.

Fixed-Displacement Pump Standby Mode

Figure 18-3 illustrates a cross-sectional drawing of an unloading valve that is used in a fixed-displacement LS hydraulic system. The spool valve has a cross-drilled passageway, which enables pump pressure to act on the left-hand side of the spool. Pump pressure opposes the margin spring. When the DCV is in the neutral position, signal pressure will equal zero. Chapter 25 will explain that some steering circuits will have a residual steering signal pressure that will cause the standby pressure to be a little higher than the margin spring value.

Pump pressure will build to achieve the margin spring value—300 psi (21 bar) in this example—causing the spool to shift to the right, compressing the margin spring. As the spool shifts to the right, it opens the passageway allowing the pump’s constant flow of oil to be dumped to the reservoir at the margin spring value of 300 psi (21 bar). While the DCV is in neutral, the system is in the standby mode, also called low-pressure standby. LS systems normally operate at a pressure between 300 to 500 psi (21 to 34 bar) while in the standby mode. Standby mode as it relates to variable-displacement LSPC systems will be explained later in this chapter.

Fixed-Displacement Pump Working Mode

When a DCV is actuated, its shuttle valve directs the hydraulic cylinder’s working pressure, also known as signal pressure, to the unloading valve so that the signal pressure can work in conjunction with the margin spring. See Figure 18-4.

Anytime an actuator is moving, the hydraulic system is in the working mode. While in the working mode, hydraulic pump outlet pressure will equal the
signal pressure plus the margin pressure. For example, if the cylinder requires 1000 psi (69 bar) to extend, and the margin pressure equals 250 psi (17 bar), the pump outlet pressure will equal 1250 psi (86 bar).

**Differential Spring Value**

A margin spring has a static spring pressure value, known as standby pressure, and a dynamic spring pressure value, known as margin pressure. The standby pressure is usually a higher value than the margin pressure. Some service literature will only specify adjusting the standby pressure, while other literature will specify only adjusting the margin pressure. Some service manuals will provide specifications for adjusting both the standby and the margin pressure. This topic will be discussed in more detail later in this chapter.

Referring to Figure 18-4, the function of the LS system's working mode is the heart of LS hydraulics. The system builds only the necessary pressure to do the work, plus the set pressure value of the margin spring.

**Stall Pressure**

When the cylinder reaches its end of travel, the LS system will be in its final mode, called the stall mode. It is also called the high-pressure cutoff mode or high-pressure standby mode. In this mode, the hydraulic pump cannot build enough pressure to overcome both the signal pressure and the margin spring. As a result, the margin spool remains closed, blocking off pump flow, which causes the system pressure to climb to the highest system pressure value. In a fixed-displacement system, a high-pressure relief valve is used to set the pump's stall pressure.

LS systems can also use variable-displacement pumps. Systems using variable-displacement LS pumps are even more efficient than fixed-displacement LS systems. In variable-displacement LS systems, the unloading valve becomes the flow control valve or the margin spool. These systems are described later in the chapter.

**Signal Network**

LS hydraulic systems require a group of shuttle valves to sense actuator working pressure. As mentioned in Chapter 9, a shuttle valve is a T-shaped valve that determines the higher pressure of two inlet pressures and sends the higher pressure to a new destination within the system. See Figure 18-5. That destination can be another shuttle valve, a pump compensator assembly, or an unloading valve.

**Primary Shuttle Valve**

Shuttle valves can be designated as primary or secondary shuttle valves. A primary shuttle valve chooses an actuator's higher working pressure. This means the primary shuttle determines if the double-acting cylinder is extending or retracting based on the higher working pressure and sends the appropriate signal pressure to a secondary shuttle valve, as shown in Figure 18-6.

**Secondary Shuttle Valve**

A secondary shuttle valve is used to choose the higher working pressure between two different DCVs' working pressures. A series of secondary shuttle valves is used to send the highest working pressure to the margin spool. The group of primary shuttle valves and secondary shuttle valves makes up the hydraulic system's signal network.
For example, refer to Figure 18-7 and consider the following actuator requirements:
- DCV 3 requires 1500 psi (103 bar) to retract its cylinder.
- DCV 2 requires 1000 psi (69 bar) to extend its cylinder.
- DCV 1 requires 500 psi (34 bar) to extend its cylinder.

The following sequence of events would occur if the operator requested the previous actions from the cylinders:

1. The primary shuttle inside DCV 3 would direct 1500 psi (103 bar) to DCV 2 secondary shuttle.
2. The primary shuttle in DCV 2 would direct 1000 psi (69 bar) of signal pressure to the DCV 2 secondary shuttle.
3. The secondary shuttle in DCV 2 would choose the higher working pressure of 1500 psi (103 bar) and send it to the secondary shuttle located in DCV 1.
4. The primary shuttle in DCV 1 would direct 500 psi (34 bar) to the secondary shuttle inside DCV 1.
5. The secondary shuttle in DCV 1 would choose 1500 psi (103 bar) and send the 1500 psi (103 bar) to the unloading valve.
6. The unloading valve would maintain a system pressure of 1500 psi (103 bar), plus the value of margin pressure, 300 psi (21 bar).

Note that DCV 3 in Figure 18-7 does not contain a secondary shuttle valve. The last DCV does not have to distinguish the difference in signal pressure of a downstream valve that does not exist. However, if a customer wanted to add another DCV (such as DCV 4, power beyond, or a three-point hitch), a secondary shuttle valve must be installed inside DCV 3.

The signal network must have an orifice that allows the network to have a controlled drain back to the reservoir. If the signal network has no controlled drain back to tank it can cause one of two problems, depending on whether the system uses a variable-displacement pump or a fixed-displacement pump. In a fixed-displacement LS hydraulic system, a plugged LS network orifice will cause the signal network to hydrostatically lock, resulting in the unloading valve blocking system oil flow. When the unloading valve blocks off the fixed-displacement pump, the constant flow of oil must dump across the main system relief at high pressure. In a variable-displacement LS hydraulic system, a plugged orifice in the LS network will cause the variable-displacement pump to achieve high-pressure standby. This mode will be discussed later in the chapter.

Note
In John Deere agricultural machines, the shuttle valves are called **dime valves** because they resemble the shape of a dime, as shown in Figure 18-8. The shuttle valves are called **isolators** in John Deere construction machines. Caterpillar calls their shuttle valves **resolver**s because the shuttle valves resolve which pressure is the higher pressure.
Figure 18-7. The initial secondary shuttle valve in a signal network sequence chooses the higher working pressure between its DCV and the working pressure it receives from the downstream DCV(s). It sends the higher signal pressure to the unloading valve, which maintains system pressure at 1800 psi (124 bar).

Figure 18-8. Due to their appearance, shuttle valves are also known as dime valves in John Deere agricultural equipment. A problem with an upstream secondary shuttle valve in DCV 1 can cause problems for downstream DCVs.
Diagnosing Secondary Shuttle Valves

Shuttle valves can cause malfunctions in hydraulic systems if they become stuck in one position. If a technician is faced with a downstream DCV that will not flow oil, it is possible that an upstream secondary shuttle valve is at fault. For example, in Figure 18-8, if the secondary shuttle valve in DCV 1 is stuck in the lifted position, it would cause problems downstream for DCV 2 and DCV 3. Initially, a technician might think that DCV 2 and DCV 3 are suspect because those are the valves having trouble flowing oil. However, the problematic shuttle valve is actually located upstream in DCV 1.

Load-Sensing System with Single-Acting Actuator

Figure 18-9 illustrates an LS system with one single-acting actuator, a unidirectional hydraulic motor. Note that neither a primary shuttle valve nor a secondary shuttle valve is necessary. Primary shuttles are required for choosing the higher working pressure of a double-acting actuator, for example choosing between the working pressures at the rod end and cap end of a double-acting cylinder. A single-acting actuator only has one possible working pressure. In this example, it is the hydraulic motor’s forward rotation. If the hydraulic system contained multiple single-acting actuators, secondary shuttles would be required to choose the highest system working pressure among the multiple actuators so it could be directed to the unloading valve.

Pressure-Compensating System

Most LS hydraulic systems are also pressure compensating (PC). The combination of LS and PC can be called any one of the following names, depending on the manufacturer:

- LSPC—Load-sensing pressure compensation system (Caterpillar).
- PCLS—Pressure compensation load-sensing system (John Deere’s construction division).
- PFC—Pressure and flow compensated system (Case IH, Eaton, and John Deere’s agricultural division).
- CCLS—Closed-center load-sensing system (New Holland Agriculture and AGCO).

The most problematic of the five descriptors is PFC. Although Case IH, John Deere agricultural equipment, and Eaton have all used PFC to describe a load-sensing pressure-compensating hydraulic system, there is another type of PFC hydraulic system known as positive flow control which is completely different than an LSPC system. Positive flow control hydraulic systems will be explained in Chapter 20. LSPC is the term adopted for this textbook. The term pressure compensation, in the context of an LSPC system, can have two different meanings.

Pressure-Compensating Hydraulic Pump

The first PC description is based on the pressure compensator valve located inside a variable-displacement pump, which was the focus of Chapter 17. The pump’s PC spool operates in the same manner as described in Chapter 17. Within an LS PC variable-displacement pump, the PC spool has the responsibility to destroke the pump when a hydraulic cylinder reaches its end of travel. The PC spool maintains that constant high pressure until the DCV is returned to the neutral position.

Pressure-Compensated DCV

The second description for pressure compensation in an LSPC system focuses on a pressure compensator valve inside the DCV, which was briefly mentioned in Chapter 8. The valve is also called a flow compensator valve. It is essentially a pressure-reducing valve that senses working pressure. The valve uses this signal pressure to compensate the DCV’s flow.

Without the compensator valve, anytime the system’s flow or pressure changes, the operator would have to readjust the position of the DCV spool to attempt to maintain the same implement speed. In this context, pressure compensation is used to maintain a constant actuator speed (cylinder or hydraulic motor) based on a fixed position (opening) of the DCV spool.

The PC valve can be placed before the DCV spool, which is known as pre-spool compensation or upstream compensation. Pre-spool compensation is the focus of this chapter. When the pressure compensator valve is placed after the DCV spool, it can be called many different terms. Two of the most common terms are post-spool compensation or downstream compensation, which is the focus of Chapter 19.

Consider an agricultural tractor that is using a DCV for operating a planter’s fan motor. The hydraulic motor is used to develop either a precise positive air pressure or a precise vacuum pressure. The farmer must dial-in the speed of the hydraulic motor to achieve a specific air pressure or vacuum, otherwise the seeding mechanism will not plant accurately.

In this example, assume that planter motor operation needs precisely 4 gpm (15 lpm) at 1000 psi (69 bar). The challenge is that, as the operator uses other hydraulic functions, such as raising or lowering the three-point hitch for draft
control or steering the tractor along a line of trees, the hydraulic system flow and pressures will vary. As the flow and pressures vary, the planter’s hydraulic motor speed will be negatively affected. As a result, the speed of the planter’s hydraulic motor will fluctuate, causing seed population problems. Inserting a compensator valve in-line prior to the DCV spool can alleviate this concern.

Most planter motors are unidirectional. However, the schematic in Figure 18-10 shows a bidirectional hydraulic motor to illustrate how the primary shuttle is used to direct signal pressure of a double-acting actuator to the compensator valve.

Pre-spool compensation has the following attributes:
- The compensator valve must sense the actuator’s working pressure. Therefore, a primary shuttle valve is used to send the actuator’s signal pressure to the compensator valve.
- The compensator’s spring value establishes the pressure drop across the DCV spool.
- The DCV spool must be closed center.

The pressures in Figure 18-10 will equal the following values:
- Working pressure/signal pressure: 1000 psi (determined by the load on the actuator)
- Pump outlet pressure: 300 psi (unloading spring) + 1000 psi (working pressure) = 1300 psi
- Pressure drop across the compensator valve: 1300 psi – (1000 psi + 40 psi spring) = 260 psi

Pre-spool pressure compensation places the compensator valve prior to the DCV spool. The compensator valve senses the actuator’s working pressure through the use of a shuttle valve to maintain a fixed implement speed.

Figure 18-10. Pre-spool pressure compensation places the compensator valve prior to the DCV spool. The compensator valve senses the actuator’s working pressure through the use of a shuttle valve to maintain a fixed implement speed.

Pressure supplied to the DCV spool:
- 1000 psi + 40 psi = 1040 psi
- Pressure drop across the DCV spool equals the value of the PC spring:
  - 1040 psi – 1000 psi = 40 psi

The addition of the shuttle valve and the pressure compensator valve provides precise flow to the actuator. As the hydraulic system’s flow and pressure changes, the pressure compensator valve will automatically compensate and adjust the flow so that the actuator remains at the same speed.

There is a limit to pressure compensation. If the engine-driven pump is slowed and is no longer delivering minimum flow as requested by the operator, the pressure compensator valve cannot magically magnify oil flow that is not there.

The shuttle valve and the pressure compensator valve also help alleviate an additional problem. As oil flows through a spool valve, oil velocities create forces that affect the position of the spool valve. See Figure 18-11.

The addition of the compensator valve results in a smaller pressure drop across the DCV spool, which minimizes the negative effect of flow forces. If the DCV spool is manually operated, the PC valve will help by lowering the amount of effort the operator must use to actuate the spool valve and the effort required to maintain the position of the spool valve.

Figure 18-11. Oil flowing through a DCV spool creates forces, causing a resistance when attempting to open and close the spool valve. High-pressure pump flow is directed to extend the cylinder as the spool is opened. The shuttle valve and PC valve work in unison to keep the pressure drop across the DCV spool relatively low, 60 psi. Decreasing the size of the orifice between the pump input oil and cylinder extend oil ports by closing the spool increases these flow forces.
Chapter 18
Load-Sensing Pressure-Compensating (LSPC) Hydraulic Systems 431

Note
Some personnel will label constant-flow LSPC systems (for example, Figure 18-6) as an open-center hydraulic system. They would point out that the system uses a fixed-displacement pump that delivers a constant flow at a relatively low pressure anytime the DCVs are in a neutral position. However, this system uses closed-center DCVs; has pressure compensator valves installed in series prior to the DCV spool; and uses an unloading valve that enables the hydraulic system to operate at a preset value above the actuator working pressure. Technically, the DCVs in this system are identical to the DCVs used in a variable flow LSPC system.

One drawback to a fixed-displacement LSPC system is that the pump produces a constant flow when the DCVs are in a neutral position. Even though the flow is at a relatively low pressure, this still results in wasted power. Variable-displacement LSPC hydraulic systems can reduce the hydraulic pump’s horsepower consumption to only a fraction, sometimes as little as 0.15 hp.

Examples of LSPC with Fixed-Displacement Hydraulic Pumps
LSPC systems that use a fixed-displacement pump are not as popular as LSPC variable-displacement pump systems. Some manufacturers use fixed-displacement LSPC systems in their economy model tractors and variable-displacement LSPC systems in their premium model tractors. A fixed-displacement LSPC system was used on older machines such as the Case IH 9390 Steiger 4WD tractor equipped with the high-flow hydraulic system, Caterpillar 926H and 927H track-type tractors, and Caterpillar 926A, 936A, 936E wheel loaders. Some examples of newer machines using this system design are Caterpillar D3K–D5K Series I and II track-type tractors and John Deere 6030, 7030, and 6M economy model tractors.

Case IH 9390 High Flow Steiger
The Case IH 9390 High Flow tractor contained two separate LSPC systems, one with a fixed-displacement pump and one with a variable-displacement pump. The tractor was designed so that DCVs 3 and 4 used the fixed-displacement 30 gpm steering gear pump, while DCVs 1 and 2 used the variable-displacement 30 gpm piston pump. The fixed-displacement gear pump contained an unloading valve that received a load-sensing signal pressure from DCV 3 and DCV 4. DCV 1 and DCV 2 sent a LS signal to the variable-displacement LSPC pump. Variable-displacement LSPC systems are discussed later in this chapter.

Caterpillar D3K–D5K Series I and II Dozers
The Caterpillar D3K–D5K dozers used a fixed-displacement pump and LSPC DCVs to control the implement hydraulic system. The unloading valve dumped the gear pump’s constant flow at a low pressure value when the DCVs were in a neutral position. The DCVs sent a signal pressure to enable the unloading valve to build the pressure required for the DCVs to operate.

John Deere Base Model 6030 and 7030 Tractors
John Deere manufactured late-model tractors that used a fixed-displacement LSPC system. These were the 6030 and 7030 base models, produced from 2008 to 2011. The premium models used a variable-displacement LSPC system.

The base model 6030 and 7030 tractors used two pumps. The first was a low-pressure transmission pump (254 psi) and the second was a high-pressure hydraulic pump (2973 psi) for steering, brakes, and DCVs. The high-pressure circuit consisted of a gear pump that used a priority valve. Deere labeled the priority circuits as one and three. The priority-one circuit included steering and brakes. After priority-one hydraulic requirements had been met, oil was routed to the priority-three circuit, which included the three-point hitch, selective control valves (SCVs), independent control valves (ICVs), and power beyond. The service literature omitted reference to a priority-two circuit. The SCVs were essentially DCVs located at the rear of the machine, and ICVs were mid-mounted DCVs used for loader control functions. When all of the DCVs were in a neutral position, a pressure-regulating valve dumped oil to the reservoir at approximately 217 psi (15 bar). When a DCV was actuated, a load-sensing signal pressure was sent to the pressure-regulating valve, which enabled the system to build the necessary pressure to operate the actuator.

The John Deere 6M series tractors replaced the 6030 series. The 6M series tractor also uses a fixed-displacement LSPC hydraulic system. Note that the 6R uses a variable-displacement LSPC system.

LSPC Systems with Variable-Displacement Hydraulic Pumps
LSPC variable-displacement systems gained popularity in the off-highway industry in the late 1970s and early 1980s.

- Massey Ferguson introduced LSPC in 1978 on the MF60 loader backhoe.
- In 1979, Case introduced the 90 series Case tractors with LSPC.
- In 1981, International Harvester introduced the 88 series with a system called Power Priority Hydraulics, which was an LSPC system.
- In the mid 1970s, Caterpillar introduced the G Series motor graders that used load-sensing hydraulics.

Many late-model machines use LSPC variable-displacement systems, including many of the agricultural tractors that retail for $150,000 or more. Case IH started using LSPC in their 2100 series Axial Flow® combines in 1995 and still use LSPC variable-displacement systems in their late-model combines. Caterpillar has used these systems in numerous machines in the past, but today many of their machines use proportional priority pressure compensated (PPPC), negative flow control (NFC), or positive flow control (PFC) systems.
Relating Constant-Flow LSPC to Variable-Flow LSPC

Referring back to Figure 18-6, if the high-pressure relief and the unloading valve were relocated to the compensator assembly inside a variable-displacement pump and relabeled as the pressure cutoff spool and the flow control spool respectively, the fixed-displacement LSPC system could be converted to an LSPC system that uses a variable-displacement pump. This LSPC system, Figure 18-12, is commonly used in thousands of old and new machines today.

A compensator assembly used on an inline axial variable-displacement LSPC piston pump is shown in Figure 18-13. The compensator assembly has two control spools. The smaller of the two spools is the flow control spool. The larger one is the pressure compensator spool. The flow control spool must receive the working pressure from the signal line, which is connected via the flat-face O-ring elbow fitting.

LSPC Variable-Displacement Hydraulic Pump Symbols

LSPC variable-displacement pump symbols can be depicted in different styles (or formats). Two simplified symbols used to represent the pump in a basic hydraulic system are shown in Figure 18-14. These two symbols are commonly found in older schematics. Newer schematic symbols used to depict LSPC variable-displacement pumps sometimes show the pump’s individual pressure compensator spool and load-sensing (flow control) spool in greater detail. See Figure 18-15.

LSPC Variable-Displacement Pump Modes of Operation

An LSPC variable-displacement piston pump will operate in one of three modes depending on the status of the DCV and the actuator:

- Low-pressure standby.
- Working mode.
- Stall mode.

Low-Pressure Standby

Low-pressure standby is the mode of operation when the DCVs are in the neutral position. For example, when the tractor is started and no DCVs have been actuated, the pump flow is destroked in the low-pressure standby mode. Refer to Figure 18-16.

The oil flow from the hydraulic piston pump is low, 0.5 to 1 gpm (1.9 to 3.8 lpm), which is the minimum amount of oil needed to maintain the minimal leakage inside the pump. The pump operates at a relatively low pressure, 300–500 psi (21–34 bar). With practically no flow of oil and a low system pressure, the pump uses very little horsepower while in the standby mode.

\[
\text{Power} = \frac{\text{Pressure} \times \text{Flow}}{1714} = \frac{300 \times 0.5}{1714} = 0.15 \text{ hp}
\]

The flow control spool establishes the low-pressure standby pressure setting. On older machines, the flow control spool is usually the smaller of the two spools. This spool must sense the actuator’s working pressure from the signal network.
Note

The flow control spool can also be called the low-pressure standby spool, flow compensator spool, or the margin spool. In a fixed displacement LSPC system, the unloading valve takes the place of the flow control spool.

When the DCVs are in the neutral position, pump flow deadheads at the DCV, and pump pressure begins to build. The pressure increases to the value of the flow control spool’s spring value. This spring is adjustable, and is commonly adjusted to a value between 300–500 psi (21–34 bar) for the low-pressure standby mode.

If the low-pressure standby is set at 300 psi (21 bar) and the DCVs are in the neutral position, pump pressure increases until it reaches 300 psi (21 bar). At this point, pump pressure overcomes the flow control spring value, causing the flow control spool to shift. Once the spool shifts, oil pressure is sent to the control piston, which destroys the pump.

As the control piston pushes the pump’s swash plate back to a neutral position, the control piston meters a small amount of oil into the pump’s case through an orifice that becomes exposed as the control piston is extended. While in the standby mode, the swash plate will never reach a complete neutral angle, but will maintain a minimal amount of flow to overcome leakage and maintain the standby pressure. The orifice effectively stops the swash plate from returning to a completely neutral angle. As the oil dumps through the orifice, the oil pressure can push no further on the swash plate. The oil is commonly routed through a case drain back to the reservoir.
If the variable-displacement pump uses a bias piston instead of a bias spring, the control piston will have a larger surface area, and it might be called the large piston. The control piston must be larger than the bias piston in this style pump because pump output pressure acts on both piston surfaces anytime the pump compensator is trying to destroy the pump. In this situation, the control piston’s larger surface area must produce a stronger force to overcome the bias piston’s force.

**Working Mode**

Whenever the operator actuates a DCV to request oil flow, the pump generates oil flow to perform some work. The DCV must be a load-sensing valve, meaning that as the oil is routed to the cylinder, the load-sensing DCV must also send a signal pressure to the pump’s compensator so the pump can meet the system’s demands. See the schematic in Figure 18-17.

**Margin Pressure**

Caterpillar and John Deere construction equipment use the term margin pressure to describe a differential pressure. Stated another way, while in the working mode, the difference between the hydraulic pump's output pressure and the highest system working pressure is margin pressure. Chapter 19 expands on the margin pressure definition as it relates to flow sharing or post-spool compensation.

Both the low-pressure standby value and margin pressure value are changed by adjusting one flow control spring value, which is the smaller spool in Figure 18-16. It has the responsibility of setting the pump's reaction.

Two methods are used for adjusting the spool. The first method is a static adjustment made with the DCVs in the neutral position. The second, or dynamic, method is to operate a hydraulic actuator slowly while measuring the margin pressure. Both adjustments alter the pump’s reaction. As more spring tension is placed on the spool, the pump’s reaction time is shortened.

The flow control spool’s spring setting is usually one adjustment that can make a substantial improvement to an LSPC hydraulic system. However, there are negative effects to adjusting the flow compensator spring value too high. As the spool’s spring pressure increases, system efficiency normally increases minimally. As an example, consider an LSPC system that is operating at 300 psi (21 bar) in low-pressure standby and presume the system is flowing approximately 1 gpm. The hydraulic horsepower could be determined with the following equation:

\[ 300 \text{ psi} \times 1 \text{ gpm} \times 0.000583 = 0.17 \text{ hp} \]

If the standby pressure was adjusted up to 500 psi, it would increase the hydraulic horsepower to the following value:

\[ 500 \text{ psi} \times 1 \text{ gpm} \times 0.000583 = 0.29 \text{ hp} \]

In addition, if the spool spring is adjusted too high, the machine can become too sensitive and overly reactive. For example, a loader backhoe operator complains that the tractor’s hydraulic system is sluggish. The technician servicing the machine is in a hurry and adjusts the low-pressure standby value from 200 psi (14 bar) to 650 psi (45 bar) before going home for the day. The next day, the operator tries to slowly operate the boom swing while gingerly lowering a pipe into a trench. Now the operator finds that the machine is too sensitive and too hard to control. The operator calls the technician back to fix the new problem—a hydraulic system that is overly reactive. In addition...
to the downside of a callback repair, the technician’s lack of ability to follow the manufacturer’s service instructions may have voided the manufacturer’s warranty, reduced the machine’s normal life cycle, and placed personnel in danger due to the overly responsive hydraulic system.

**Note**

If a technician could substantially increase the low-pressure standby value to a high value such as 2000 psi (138 bar), the LSPC system would operate more as a traditional PC system than the traditional LSPC system. The system would be noisy, operate at a high pressure constantly, and its actuators would respond very quickly to DCV spool movements.

**Figure 18-17.** In the working mode, the axial piston pump output pressure will equal the working pressure plus the flow control spring value (also known as margin pressure). Bias spring pressure overcomes the resistance of the control piston, pushing the swash plate at a greater angle to increase the displacement of the rotating axial pistons.

---

### PQ Curve Differences

Some manufacturers have their engineers graph a PQ curve, which consists of graphing the hydraulic pump’s flow rate (Q) at different operating pressures (P). To understand the effects of low-pressure standby on LSPC system performance, it is helpful to compare a PQ curve with a low value for low-pressure standby and a PQ curve with a higher value for low-pressure standby. **Figure 18-18** is a graph that students charted on an LSPC hydraulic system in a Pittsburg State University laboratory setting. The flow rate (Q) is listed on the left side of the graph, and the operating pressure (P) is on the bottom of the graph. Notice that the performance improved when the low-pressure standby (LPSB) was set at 550 psi (38 bar) versus 200 psi (14 bar).

When charting a PQ curve, be sure to follow all of the test procedures, as performance can drastically change based on many factors, especially pump speed. Manufacturers might provide correction factors to aid the diagnostic process.

### A Low-Pressure Standby Problem

In a laboratory setting, instructors can demonstrate to students how a mistake in setting the low-pressure standby can affect a hydraulic system. After an instructor set LPSB pressure close to 100 psi (7 bar) on a LSPC variable-displacement hydraulic pump, no oil reached the DCVs. The students working on the project later determined that the steering priority valve was biased at a spring value of 150 psi (10 bar). Therefore, a low-pressure standby value of 100 psi (7 bar) was too low to shift the steering priority’s spool valve and would not allow any oil to flow to the DCVs. This type of priority valve is found on 9300 Case IH Steigers 4WD tractors and Caterpillar 420D loader backhoes.

The solution involved setting the LPSB to a value slightly above the pressure value of the steering priority spring. Once this adjustment was made, oil was able to reach the DCVs.

### Adjusting the Flow Control Spool

Some manufacturers might focus more on setting margin pressure than low-pressure standby. The reason is that low-pressure standby is a static test, whereas the margin pressure test is a more dynamic test.

Low-pressure standby is a measure of the pressure the spool is set at when the DCV is in a neutral position. Margin pressure tends to have a little lower value than low-pressure standby. Margin pressure values have a tighter tolerance (for example, ± 15 psi) than low-pressure standby pressure values (for example, ± 100 psi). The margin pressure value is based on the system flowing oil and the spool balancing between pump output pressure and signal pressure.

For example, a low-pressure standby specification might be 410 psi ± 105 psi, while the margin pressure specification might be 305 psi ± 15 psi. If a technician accurately adjusts margin pressure, low-pressure standby is typically also within its specification. Some manufacturers might only provide a specification for low-pressure standby or margin pressure and not both. Other machines will have both specified.
Chapter 18 Load-Sensing Pressure-Compensating (LSPC) Hydraulic Systems

Chapter 21 will discuss hydraulic test equipment, including a differential pressure gauge. This type of gauge is essential for measuring margin pressure. Margin pressure requires reading two different pressures simultaneously while oil flows through a circuit and subtracting one pressure reading from the other pressure reading.

An example is measuring margin pressure in a bulldozer hydraulic system while actuating the dozer blade to lift. The problem is that the load on the blade will cause the pressure value to constantly change as the blade is moving. Operating the DCV at a relatively slow speed rather than a faster speed helps minimize this issue. As the pump outlet pressure varies so will the signal pressure change during the test. It is difficult to simultaneously watch two pressure gauges with fluctuating pressures and attempt to subtract the difference.

A differential pressure gauge solves this problem. The gauge displays the difference in pressure between two separate input pressure values, which, in this case, are the pump outlet pressure and signal pressure. One pressure line is connected to the left side of the gauge and the other is connected to the right.

Chapter 25 explains warm-up signal pressures used in steering circuits.

Stall Mode

When a cylinder reaches its end of travel, the pump begins to stall, also known as pump cut off. The stall mode pressure is set by the PC spool spring. This is the same PC spool that was explained in Chapter 17. The PC acts similar to a main system relief valve. Anytime the system pressure deadheads, the PC spool shifts, allowing oil to be sent to the control piston to destroke the pump. See Figure 18-19. The PC spool does not need to sense signal pressure.
If the PC spool is set at 2500 psi (172 bar), once the pump reaches that pressure, the PC spool shifts down, directing oil to the pump's control piston to destroke the pump. The pump flow will be reduced to practically no flow but will remain at the high stall pressure value until the DCV is returned to a neutral position.

Another interesting point about stall mode on a variable-displacement LSPC pump is that the flow control spool is technically shifted up, while the pressure compensator spool is shifted down. How is this possible? The bottom of the flow control spool has a 300 psi (21 bar) spring setting and 2500 psi (172 bar) of pump outlet pressure acting on it, while the top of the spool only has pump outlet pressure, 2500 psi (172 bar), acting on it. As a result, the flow control spool is shifted upward due to the higher combined pressure value at the bottom of the spool. However, the pump outlet pressure can still make its way around the top of the flow control spool so that it can still act on the top of the PC spool, allowing the PC spool to shift down and destroke the pump.

Main System Relief in Variable-Displacement LSPC Systems

Many agricultural variable-displacement LSPC systems do not use any type of a main system relief valve, and rely solely on the pump's PC valve to protect the system during high-pressure conditions. Conversely, many construction equipment machines contain a main system relief valve in addition to the pump's PC valve. If the machine has both a main system relief and a pump PC, traditionally one of those components is used as a backup in case the primary fails. This means that one of the components serves primarily as a high-pressure relief while the other is not normally used but is set higher than the primary component. Normally the main system relief is set higher than the pump's PC. However, in a few rare cases, a machine can have the pump compensator set higher (for example, 4000 psi [276 bar]) than the main system relief (for example, 3600 psi [248 bar]).

Most systems set the main system relief valve as the secondary safety feature in the event that the pump PC is slow or is ineffective at destroking the pump. A Caterpillar D8R dozer has a main system relief set at 3900 psi (269 bar) and the pump pressure cutoff set at 3500 psi. In this example, if the main system relief valve is inaccurately set below the pressure compensator value, the LSPC system will be operating inefficiently. The inefficiency will be evident during stall mode, when the pump is destroked. If the main system relief valve takes command during high system pressures, the pump will not only be running at high pressure, but will also be flowing a lot of oil over the main relief valve, consuming unnecessary energy.

Industry experts recommend that when using a main system relief in conjunction with a variable-displacement pump, the main system relief value should be set 10 to 15% above the pressure compensator value.

Torque-Limiting Control

Some variable-displacement LSPC pump systems are designed to provide high amounts of flow or high amounts of pressure, but use an engine that does not have the capacity to deliver enough horsepower to provide both maximum system flow and maximum system pressure simultaneously. In these applications, a torque-limiting spool is incorporated into the pump compensator assembly. It destrokes the pump when the operator requests too much hydraulic horsepower.

Corner Horsepower

Corner horsepower is the point on a PQ curve that shows the total amount of horsepower required to deliver both maximum system hydraulic pressure and maximum system hydraulic flow simultaneously. See Figure 18-20. The corner horsepower is located in the upper right-hand corner of the PQ curve.

A pump with torque-limiting control shaves off the corner horsepower requirement by preventing the operator from requesting both maximum flow and maximum pressure simultaneously. Figure 18-21. Manufacturers save on production costs by designing a machine equipped with torque-limiting controls. The system allows a smaller engine with reduced fuel consumption compared to unequipped machines.

In addition to housing the pressure compensator and flow control spools, the variable-displacement LSPC pump in Figure 18-22 uses two components as torque-limiting controls: a piston that senses the angles of the pump's swash plate and a torque-limiting spool valve. The piston uses an orifice that drops oil pressure based on the angle of the pump's swash plate. When the pump swash plate is at a large angle, delivering high amounts of hydraulic flow, the swash plate sensing piston is pulled out of its bore resulting in little pressure drop. As a result, high pump outlet pressure causes the torque-limiting spool valve...
to shift against its spring, opening a passage to allow oil to destroke the pump. A torque limiter acts like an infinitely variable relief valve that destrokes the pump anytime too much hydraulic horsepower is requested.

Torque limiting is a common descriptor used by many manufacturers. However, horsepower limiting is a more accurate descriptor because the control is limiting the total amount of hydraulic horsepower in an effort to prevent the engine from lugging, stalling, or even dying.

In Chapter 16, jammer solenoids were described in open-center hydraulic systems. Jammer solenoids are also used in LSPC variable-displacement systems. Even though the solenoids provide the same effect—placing the system on demand (maximum system pressure)—the jammer solenoid has an opposite design when used in LSPC variable-displacement pump systems.

In an LSPC variable-displacement hydraulic system, anytime the pump outlet pressure is directly connected to the signal pressure, the pump will suddenly enter the stall mode. Why is this? The flow compensator has pump outlet oil pressure acting on the top of the spool while pump outlet oil pressure and the flow control spring pressure are acting on the bottom of the spool. Therefore, the flow control spool remains shifted upward, asking for more oil. As the pump attempts to upstroke, however, the PC spool senses the high system pressure and holds the pump destroked in the stall mode.

A jammer solenoid in an LSPC variable-displacement pump is normally closed, which is the opposite of the design in an open-center system. See Figure 18-23. When the jammer solenoid valve is energized, it opens to connect pump outlet pressure to signal pressure. John Deere uses an LSPC jammer solenoid on their sprayers. Case IH uses LSPC jammer solenoids on their combines. AGCO uses LSPC jammer solenoids on their Massey Ferguson, Gleaner, Challenger, and Fendt combines.

Case IH used the 12-volt diode assembly that was discussed in Chapter 16 on their 2100 and 2300 series combines. However, like most manufacturers, late-model machines have the jammer solenoid directly controlled by the ECM, allowing the manufacturer to eliminate an external diode module. The jammer solenoid is sometimes called a signal valve solenoid because it creates a false signal by connecting pump outlet pressure to signal pressure.

Figure 18-21. Torque-limiting control reduces the required amount of engine horsepower by preventing an operator from requesting maximum flow and maximum pressure simultaneously. Note the movement of the corner horsepower point on the PQ curve for a hydraulic system equipped with torque-limiting controls.

Figure 18-22. A hydraulic pump with torque-limiting control allows the operator to request maximum flow and maximum pressure individually but not simultaneously. A piston senses the angle of the swash plate, and when too much hydraulic horsepower is requested from the system, it causes a torque-limiting spool to destroke the pump.

Case Study

Understanding the theory behind jammer solenoids in an LSPC variable-displacement system has helped an instructor diagnose an LSPC system built for laboratory use. The system consisted of an LSPC variable-displacement pump, a set of DCVs, a priority valve from a Case IH Steiger 4WD tractor, and a steering DCV from a John Deere tractor.

The first time the hydraulic system was operated, it appeared to be operating as a traditional closed-center PC hydraulic system. Time was spent reviewing the fabrication of the hydraulic system, including the signal network, as well as having conversations with the pump supplier. Eventually, the instructor focused on the jammer solenoid concept, “anytime pump outlet pressure is connected directly to signal pressure, the pump will enter the stall mode.” He used cross-sectional drawings to look for a place where pump outlet pressure could be hydraulically connected to signal pressure. The instructor determined that if the steering priority valve compensator spool was missing, the pump would immediately enter the stall mode.
Reasons to Use a Jammer Solenoid in an LSPC System

Manufacturers typically use jammer solenoids in LSPC systems for two reasons. The first reason is to force the hydraulic system to perform the same as a PC hydraulic system described in Chapter 17. Any time the jammer solenoid is activated, the LSPC pump operates at high system pressure and little flow.

Figure 18-23. A jammer solenoid valve used in an LSPC variable-displacement system is designed to connect pump outlet pressure to signal pressure when energized, resulting in the LSPC system operating in the stall mode.

Signal Network Problems

A leak in a load-sensing signal network can cause other problems within a hydraulic system.

Technicians were called to service an LSPC variable-displacement tractor with an overheating hydraulic system. The technicians were having trouble determining why the machine was overheating. The OEM territory representative visited the technicians, examined the tractor, and requested that they follow the specified service information. After carefully following the specified diagnostic procedures outlined in the literature, the technicians were surprised at the source of the problem. The service brakes had developed a leak in the load-sensing circuit, which caused the pump to constantly run at higher flows and higher pressures than required by the actuators. This was the underlying cause of the overheating hydraulic system.

The technician found that the closed-center (service) brake control valve was not fully blocking the pump’s flow when the foot pedal was released. The valve was allowing fluid pressure to leak into the signal line leading back to the pump’s flow control valve, causing the pump to upstroke. The brake valve was not serviceable. A new service brake valve was ordered and installed, which remedied the overheating hydraulic system.

Power Beyond in LSPC Systems

As mentioned in Chapter 9, power beyond in open-center systems simply consists of a single coupler assembly. An LSPC power beyond option consists...
of three coupler ports as shown in Figure 18-24. One port taps directly into pump outlet pressure, one port allows for a return, and the third port requires sending a signal pressure to the signal network. Figure 18-25 shows two similar LSPC systems with one main difference in their designs. The signal network in Figure 18-25A does not have power beyond. The signal network in Figure 18-25B is equipped with power beyond and contains the necessary shuttle valve and couplers for proper operation.

**DCV Hydraulic Detent Kickout in LSPC Systems**

As explained in Chapter 9, some manually operated DCVs have detented levers that mechanically hold the spool in a fixed position during operation. Once a high pressure is reached, the lever returns to neutral. The detent kickout pressure is adjustable. The primary shuttle in this type of system has the responsibility of choosing the higher working pressure from either the extend or retract pressure and sending it to three locations: the secondary shuttle valve, the detent kickout valve, and the pressure compensator valve.
Variable-Displacement LSPC System Advantages

Several decades ago, when hydraulic engineers began to design variable-displacement LSPC systems, they envisioned a hydraulic system that would deliver only the “pressure and flow” required to do the work and nothing more. Today, nearly four decades later, manufacturers are still using these systems on much more complex and expensive machines. LSPC variable-displacement hydraulic systems have the following advantages:

- The system runs at low pressures (300 to 500 psi [21 to 34 bar]) when the DCVs are in a neutral position and produces very little flow (perhaps less than 0.5 gpm).
- The hydraulic system uses only a fraction of a horsepower when the system requires no flow.
- With the DCVs are in a neutral position, the system generates very little heat and very little noise.
- The system can quickly ramp up to deliver hydraulic flow and pressure on demand.

The agricultural industry serves as one of the largest customers for machines equipped with variable-displacement LSPC hydraulic systems. The systems are commonly used on large agricultural tractors and some combine harvesters.

Variable-Displacement LSPC System Disadvantages

LSPC variable-displacement systems do have some disadvantages:

- The system costs more to manufacture than open-center hydraulic systems and PC systems.
- The system requires a complex signal network of primary and secondary shuttle valves that sense the highest system working pressure and send that signal back to the pump compensator.
- Perhaps the largest drawback to LSPC pre-spool compensation systems is that if an operator requests multiple hydraulic functions at one time and if that request was for more oil than the pump is capable of delivering, the actuators with the smallest load will receive the oil first, while the highest system loads will receive no oil. The next chapter will explain the benefit of using flow-sharing post-spool compensation, an advanced style of pressure compensation that will solve this problem.

Summary

- A load-sensing hydraulic system is designed to operate at a prescribed pressure value above the highest working pressure.
- Pressure compensation enables a hydraulic actuator to maintain a specific speed based on how far the operator has positioned the DCV spool.
- Pressure compensation is accomplished by using a primary shuttle valve to sense actuator working pressure and directing the actuator working pressure to a pressure compensator valve.
- An LSPC system has a pressure compensator in the variable-displacement pump.
- An LSPC system also has a pressure compensator within the DCV prior to its spool, an arrangement known as pre-spool compensation.
- The pressure compensator valve counteracts changes to system pressures and flow to help maintain the prescribed actuator speed as dictated by the position of the DCV spool that is set by the operator.
- When the DCVs in an LSPC fixed-displacement hydraulic system are in a neutral position, the system operates in the standby mode, and the pump delivers maximum flow at a low pressure value, for example 300 to 500 psi.
- When the DCVs, in an LSPC variable-displacement hydraulic system are in a neutral position, the system operates in the standby mode. The system generates very little flow and low pressure, wasting very little hydraulic horsepower.
- When an LSPC hydraulic system is in the working mode, an actuator will be moving and the system pressure will equal the highest signal pressure plus margin pressure.
- When a LSPC fixed-displacement system is in the stall mode, the unloading valve blocks the pump flow, forcing the oil flow to dump over the main system relief valve. In this mode, the pump generates maximum pressure and flow, equaling maximum hydraulic horsepower.
- When an LSPC variable-displacement pump is in the stall mode, the flow control spool will be closed and the PC spool will open, directing oil to the control piston to destroke the pump, resulting in high system pressure with little flow.
- PQ graphs consist of mapping a hydraulic pump's flow rate (Q) at different operating pressures (P).
- Torque limiting is a pump control that destrokes the pump to prevent the engine from stalling any time the operator simultaneously requests high flow and high pressure.
- Jammer solenoid valves in variable-displacement LSPC systems will connect pump outlet pressure to signal pressure when activated. This puts the system in stall mode, so that high pressure is available immediately when the operator activates a control.
Chapter 18

Load-Sensing Pressure-Compensating (LSPC) Hydraulic Systems

Technical Terms

- corner horsepower
- differential pressure
- dime valves
- flow control spool
- isolators
- load-sensing (LS) hydraulic system
- margin pressure
- PQ curve
- pressure cutoff spool
- primary shuttle valve
- resolvers
- secondary shuttle valve
- signal network
- signal pressure
- stall mode
- standby mode
- torque-limiting control
- upstream compensation
- working mode

Review Questions

Answer the following questions using the information provided in this chapter.

1. Load-sensing pressure-compensating hydraulic systems can be called all of the following, EXCEPT:
   A. Closed-center load-sensing system.
   B. Negative flow control system.
   C. Pressure compensation load-sensing system.
   D. Pressure and flow compensated system.

2. Which of the following terms can be defined as a system that is designed to operate at a fixed value above working pressure?
   A. Load sensing.
   B. Pressure compensating.
   C. Stall mode.
   D. None of the above.

3. Which of the following terms can be defined as a system that provides a constant cylinder speed for a fixed position of a DCV spool?
   A. Load sensing.
   B. Pressure compensating.
   C. Stall mode.
   D. None of the above.

4. What is the name of the valve that chooses that higher working port pressure between two different control valves and sends the higher pressure to the pump compensator? Assume that the higher working port is the top or cap end of a double-acting cylinder.
   A. Shuttle valve.
   B. Pressure-reducing valve.
   C. Pressure relief valve.
   D. Drop check valve.

5. What does John Deere's agricultural division call the valve that chooses the higher working port pressure between two different control valves and sends the higher pressure to the pump compensator?
   A. Nickel valve.
   B. Dime valve.
   C. Quarter valve.
   D. Isolator.

6. What does Caterpillar call the valve that chooses the higher working port pressure between two different control valves and sends the higher pressure to the pump compensator?
   A. Restitution valve.
   B. Reiterator valve.
   C. Resolver valve.
   D. Isolator.

7. In what time era did variable-displacement LSPC pumps begin appearing in agriculture equipment?
   A. Late 1950s-early 1960s.
   B. Late 1960s-early 1970s.
   C. Late 1970s-early 1980s.
   D. Late 1980s-early 1990s.

8. What is the name of the valve that has the responsibility of choosing the higher cylinder working pressure, either from the rod end or the cap end of a double-acting cylinder?
   A. Primary shuttle.
   B. Secondary shuttle.
   C. Intermediate shuttle.
   D. None of the above.

9. What is the name of the valve that has the responsibility of choosing the higher working pressure between two different DCVs?
   A. Primary shuttle.
   B. Secondary shuttle.
   C. Intermediate shuttle.
   D. None of the above.

10. A tractor with an LSPC hydraulic system has a total of 4 DCVs, with no hitch and no power beyond. How many total primary shuttle valves are required?
    A. Three.
    B. Four.
    C. Five.
    D. Six.

11. A tractor with an LSPC hydraulic system has a total of 4 DCVs, with no hitch and no power beyond. How many total secondary shuttle valves are required?
    A. Three.
    B. Four.
    C. Five.
    D. Six.

12. Technician A states that LSPC systems can use fixed-displacement pumps. Technician B states that LSPC systems can use variable-displacement pumps. Who is correct?
    A. Technician A.
    B. Technician B.
    C. Both A and B.
    D. Neither A nor B.

13. An LSPC hydraulic system with a plugged orifice in the signal network will exhibit what?
    A. Only low system pressure.
    B. Only moderate system pressure.
    C. Only high system pressure.
    D. Stall.

14. All of the following can be used to describe an unloading valve's spring, EXCEPT:
    A. Margin.
    B. Differential.
    C. Standby.
    D. Stall.

15. All of the following are required for a gear pump and two DCVs to be used in a load-sensing system, EXCEPT:
    A. Closed-center DCVs.
    B. Unloading valve.
    C. Pressure-reducing valves.
    D. Shuttle valves.

16. All of the following are required for a pressure-compensated DCV to operate a bidirectional motor, EXCEPT:
    A. Closed-center DCV.
    B. Unloading valve.
    C. Pressure-reducing valve.
    D. Shuttle valve.

17. An in-line axial variable-displacement pump that is used in an LSPC torque-limiting hydraulic system has how many control spools (used for controlling the pump flow and pressure)?
    A. Three.
    B. Four.
    C. Five.
    D. Six.

18. What is a common system pressure in an LSPC hydraulic system when the control valves are in the neutral position?
    A. 300–550 psi.
    B. 550–1000 psi.
    C. 1000–1500 psi.
    D. 2000–2500 psi.
19. What type of pressure will an LSPC hydraulic system have in the stall mode?
   A. Zero pressure.
   B. Low pressure.
   C. Moderately average pressure.
   D. High pressure.

20. When an LSPC system is running a hydraulic motor, signal pressure plus margin pressure equals ________
   A. pump outlet pressure
   B. working pressure
   C. regulated pressure
   D. relief pressure

21. Anytime pump outlet pressure is directly connected to signal pressure what will occur?
   A. Standby mode.
   B. Working mode.
   C. Stall mode.
   D. Carryover mode.

22. In a traditional LSPC variable-displacement pump equipped with two spools, what is the name of the small spool that has a hydraulic port for connecting a hydraulic line?
   A. Pressure compensator spool.
   B. Torque-limiting spool.
   C. Flow control spool.

23. When actuated, a signal valve (sometimes called a jammer valve) does what hydraulically in an LSPC system?
   A. Puts the system in a low-pressure standby.
   B. Connects case pressure to signal pressure.
   C. Connects pump outlet pressure to signal pressure.
   D. Lowers pump outlet pressure.

24. Which of the following systems has the ability to provide either high pressures or high flows for a given amount of horsepower?
   A. Open-center.
   B. Pressure compensating.
   C. Load sensing pressure compensating.
   D. LSPC and torque limiting.

25. Within a torque-limiting LSPC pump, which of the following components has the responsibility of conveying the angle of the swash plate?
   A. Pressure compensator spool.
   B. Flow control spool.
   C. Sensing piston.
   D. Bias piston.

26. Power beyond is being added to an LSPC hydraulic system. What else must be added?
   A. An extra shuttle valve.
   B. A relief valve.
   C. Torque-limiting controls.
   D. A variable-displacement pump.

27. Looking at a PQ graph, the corner horsepower point illustrates what system condition?
   A. Minimum pressure, minimum flow.
   B. Maximum pressure, maximum flow.
   C. Wasted horsepower.
   D. Usable horsepower.

28. A variable-displacement LSPC hydraulic system that uses a jammer solenoid for all of its functions can eliminate which of the following from the system?
   A. Signal network.
   B. Flow control valve.
   C. Pressure compensator valve.
   D. Hydraulic pump.

29. An LSPC DCV has a manual detent kickout. The DCV’s primary shuttle will send oil to all of the following, EXCEPT:
   A. DCV detent kickout.
   B. Pressure compensator valve.
   C. DCV secondary shuttle.
   D. main system relief valve.

30. Which one of the following systems will consume the least amount of horsepower when the DCVs are in a neutral position?
   A. Traditional open-center system.
   B. Pressure-compensating system.
   C. Fixed-displacement LSPC system.
   D. Variable-displacement LSPC system.