

INTRODUCTION TO FLUID POWER CIRCUITS AND SYSTEMS

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Stanley M. Brodsky, Series Editor

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CHAPTER 9

ENERGY CONTROL CONSIDERATIONS: PRESSURE CONTROL

We saw in Chapter 8 that the two areas of control important in optimizing energy transfer are pressure control and flow control. Pressure control affects the potential energy level to which the fluid is raised in passing through the pump. Flow control regulates the weight of fluid undergoing a change in energy level (i.e., a change in pressure). The product of pressure (psi) and flow rate (lb/min) is the energy transferred by the fluid in the circuit (ft·lb).

Two modes of pressure control are employed in fluid power circuits:

- a) direct control of the pressure level itself and
- b) secondary control exercised when a given pressure level is achieved.

Examples of means of *direct* control include (i) the relief valve, which is used to achieve control of maximum pressure; (ii) the reducing valve, for control at some pressure level below maximum system pressure; and (iii) pressure-compensated variable-displacement pump. Examples of means of *secondary* control include (i) the sequence valve, which is used to switch the flow to a secondary circuit when the pressure in the primary circuit has reached a set level; and (ii) the unloading valve, which is used to bypass pump flow to the reservoir when the circuit pressure reaches a predetermined level.

DIRECT CONTROL OF PRESSURE LEVEL

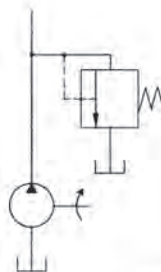
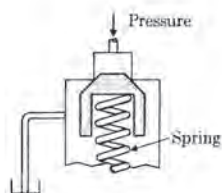
Control of Maximum Pressure

Control of maximum pressure can be realized in its simplest form by using an orifice, as shown in Fig. 9.1. In order for control to be uniform, this method requires constant load resistance and a fixed-displacement pump. A sharp-edged orifice has the advantage that it is virtually viscosity insensitive; that is, its performance is not affected by changes in temperature of the fluid. Orifices provide a minimum-cost type of control—and also minimum performance.



9.1

1. Relief valve. The relief valve is by far the most commonly used means of control of maximum pressure. It consists basically of an area exposed to primary circuit pressure. (See Fig. 9.2.) A force pA is opposed by a spring. When the pressure reaches



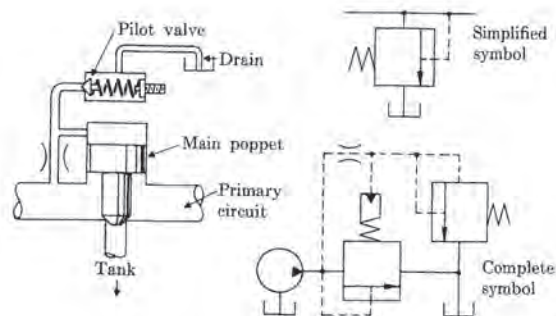
9.2

the set level, pA overcomes the spring force and the relief valve allows fluid to bypass to the tank. The pressure drop across the valve is equal to the primary system pressure. Note that the relief valve poppet and its seat form an annular orifice. The further open the relief valve, the greater the area of this orifice.

Flow through an orifice is expressed by an equation of the form

$$Q = CA_o \sqrt{2gh_p}$$

where C is a coefficient characteristic of the orifice, A_o is the orifice area, and h_p is the pressure drop across the orifice (expressed in feet of head instead of psi). This expression indicates that flow is a function of the square root of the pressure differential across the valve. As Δp approaches "set pressure" the valve will open, but not all the way. Therefore, not all of the pump output will pass through the valve, but only part of it. A direct-acting relief valve operates over a pressure band, rather than at one specific pressure. At some pressure level, called the "cracking pressure," the valve will open slightly and allow a small percentage of the total flow to bypass to the tank. In effect, it "bleeds off" some of the pump output and reduces the flow rate to the circuit by that amount. As the pressure level increases, the valve opens further and more fluid is bypassed. At the rated pressure setting, the valve is open far enough for all of the pump output to be bypassed.

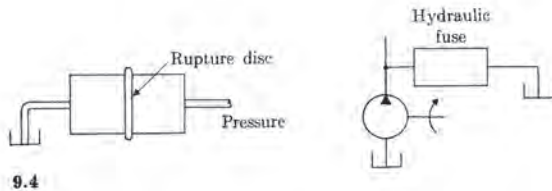


9.3

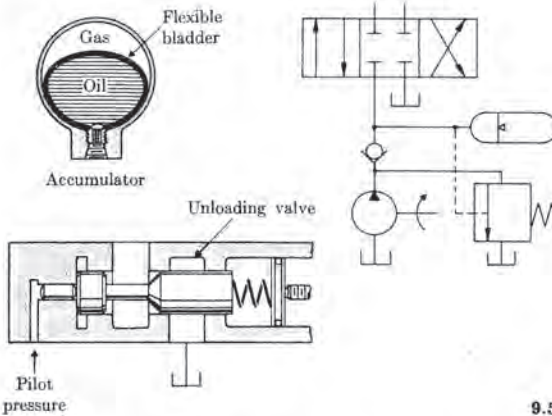
Thus the circuit is protected from excessive pressure. In order to properly design a circuit with a relief valve, the designer must know the cracking pressure for the particular valve in question.

2. Piloted relief valve. A two-stage relief valve designed so as to overcome the disadvantages of the direct-acting relief valve is called a pilot-operated valve. (See Fig. 9.3.) A small pilot piston is held against its seat by a spring that is relatively long and therefore has a low gradient. Since the pilot piston is small in diameter, the hydraulic force on it is also small. Thus the cracking effects, so noticeable in the direct-acting valve, are minimized. The main poppet is held against its seat by hydraulic pressure acting across an area differential. When the pilot valve opens, it dumps fluid from the area above the main poppet. A pressure imbalance is created which causes the main poppet to be raised off its seat. This happens so rapidly that the cracking range of the main poppet is greatly reduced. The pilot-operated relief valve is much more stable than the direct-acting type. In addition, it can be remotely vented to unload the pump. Thus it adds to the arsenal of the circuit designer a means of ensuring greater stability and closer control, and the possibility of remote control.

3. Hydraulic fuse. The hydraulic fuse consists of a rupture disc which blows out at a given pressure level, releasing system oil to the tank. It is used where the rate of pressure rise is very high, of the



9.4

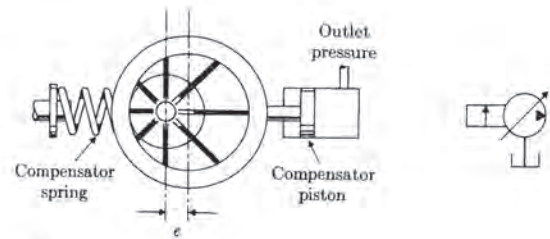


9.5

order of 150,000 psi/sec; this rate is too high for the conventional relief valve to respond to. (See Fig. 9.4.)

4. Shock suppressor valve. This is a special valve designed to open on a signal which is given when the rate of pressure rise reaches a certain level. It clips off shocks before they reach their maximum potential amplitude.

5. Accumulator control. Maximum circuit pressure can be controlled by using an accumulator and an unloading valve as shown in Fig. 9.5. In this configuration, system pressure is a function of the precharge of gas in the accumulator and the volume of fluid introduced into the accumulator. Maximum pressure depends on the unloading valve setting. When a predetermined pressure is reached, the unloading valve opens and bypasses pump output to the tank. A check valve in the line prevents unloading of the accumulator at the same time.

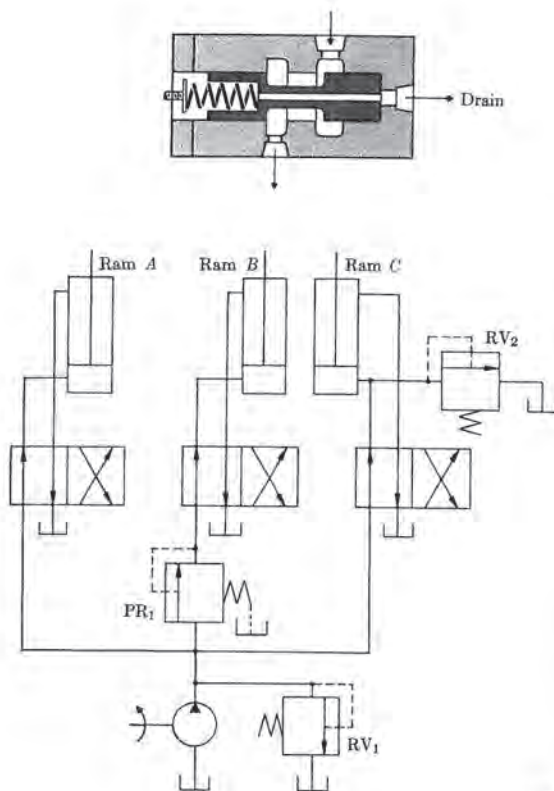


9.6

6. Pump control. Pump control of maximum pressure involves the use of a pressure-compensated variable-displacement pump. Functionally, a pressure compensator control consists of a hydraulic cylinder which can vary the position of the pumping elements. Opposing this cylinder is a spring. (See Fig. 9.6.) The spring, called the *compensator spring*, holds the pumping elements in the maximum-displacement position. When the circuit pressure reaches a certain level, called the "cutoff" pressure, the compensator cylinder force overcomes the spring force and starts to shift the pumping elements. The higher the pressure, the farther it shifts the elements toward neutral. At some level, called the "deadhead" pressure, the cylinder force has become great enough to shift the pump elements all the way to neutral, with the result that no oil is delivered to the system. A pressure-compensated pump can function as a system relief valve, and since no oil is being throttled across the valve, the pressure-compensated pump is more efficient than a relief valve. In most cases it is not desirable to use both a pressure-compensated pump and a relief valve in the same circuit because of the feedback between them.

Pressure Control in Circuit Branches

I. Pressure reducing valve. The pressure reducing valve is a normally open, two-way valve which senses pressure downstream from the valve inlet.



9.7

There are two basic types. One type maintains fixed *reduced pressure* in a circuit branch, regardless of what the pressure is in the balance of the system. The second type of pressure reducing valve maintains a fixed *reduction in pressure*, thus giving a varying reduced pressure with change in circuit pressure.

Like relief valves, reducing valves can be either direct-acting or pilot-operated. The circuit of Fig. 9.7 illustrates several points. On the *extension stroke*, the pressure of ram *A* is controlled by the system relief valve. The pressure of ram *B* is controlled by the pressure reducing valve within the maximum pressure controlled by *RV₁*. If the pressure in ram *B*

is low, then *RV₁* controls the overall system pressure. Ram *C* is controlled by the relief valve *RV₂*. If the pressure in ram *B* is less than the setting of *RV₂*, then ram *C* will also operate at the same pressure as ram *B*.

On the *retraction stroke*, rams *A* and *C* are controlled by relief valve *RV₁*, while ram *B* is controlled by the reducing valve *PR₁*.

To ensure proper functioning, pressure reducing valves should be drained in the direction of the tank. This will prevent downstream pressure buildup due to leakage.

A second application, feasible with some types of reducing valves, is shown in Fig. 9.8. Here a reducing valve is used to supply a secondary branch at a pressure reduced below the level in the primary circuit.

2. Sequence valve. A sequence valve is a normally closed, (usually) internally piloted valve which remains closed until the pressure in the primary circuit reaches the set level of the valve. When this occurs, the sequence valve (*SV*) opens and permits flow into the secondary circuit. (See Fig. 9.9.) As illustrated, this type of control is frequently used to switch flow to a second circuit after the actuator in the primary circuit has reached the end of its stroke and the pressure starts to rise. It eliminates the necessity of switching a direction control valve, timing it, and so on.

Note that in the circuit of Fig. 9.9 the sequence valve will close again when the direction control valve in Branch 1 is shifted to retract ram *A*. To prevent premature operation, the design operating pressure of the cylinder in Branch 1 must be below the setting of the sequence valve.

3. Counterbalance valve. Figure 9.10 illustrates a typical application of the counterbalance valve (*CB*), which is a normally closed, two-way valve with internal pilot, internal drain, and (usually) a built-in free-flow check valve for reverse flow. It is used to prevent free fall of a load held up by a cylinder or a motor, or to provide controlled resistance in a line.

CHAPTER 26

ELECTRICAL CONTROLS FOR FLUID POWER CIRCUITS

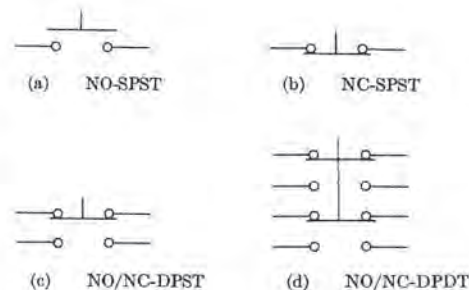
Having discussed fluid power circuits (Chapters 1 through 20) and fluid control in the form of logic systems (Chapters 23 through 25), we now turn to a discussion of electrical control systems. Probably the earliest form of remote or automatic control for fluid power circuits was electrical, and despite the advances being made in fluidics and moving-part fluid logic control, electrical control remains the dominant control method today. The solenoid-operated direction control valve is the basic building block for electrical control circuits. No one can deny that it will be challenged by the newer fluid logic techniques. However, it is unlikely that it will be completely displaced.

Just as it was necessary for us to learn the USASI graphic symbols in order to communicate about fluid power circuits, we must also learn the standard electrical symbology. The electrical symbols most used for fluid power control circuits are summarized in the Appendix. Note that in this chapter we are dealing mainly with electrical *control* circuits, not electrical *power* circuits.

SWITCHES AND OTHER ELECTRICAL COMPONENTS

Switches are the basic devices for producing control signals. They can be manually operated, like the *push-button switches* shown in Fig. 26.1.* Figure 26.1(a)

* SPST stands for "single pole, single throw"; DPST, "double pole, single throw"; DPDT, "double pole, double throw."



26.1

illustrates a normally open (NO) switch; Fig. 26.1(b) shows a normally closed (NC) switch. In a normally open switch the circuit is open—i.e., not made, or OFF—until the button is depressed. A normally closed switch provides a made, or ON, circuit until the button is pushed. The *input* is the act of pushing the button. Figure 26.1(c) shows a double-contact switch; this type of switch has one normally open and one normally closed pair of contacts. Depressing the push button opens the normally closed pair and closes the normally open pair of contacts. The switch of Fig. 26.1(d) has two pairs of normally open and two pairs of normally closed contacts. This device allows the inverting of two circuits with one input.

A second type of electrical switch is the *limit switch*. Limit switches perform the same functions as push-button switches, but they are mechanically rather than manually operated. The basic symbology

CHAPTER 31

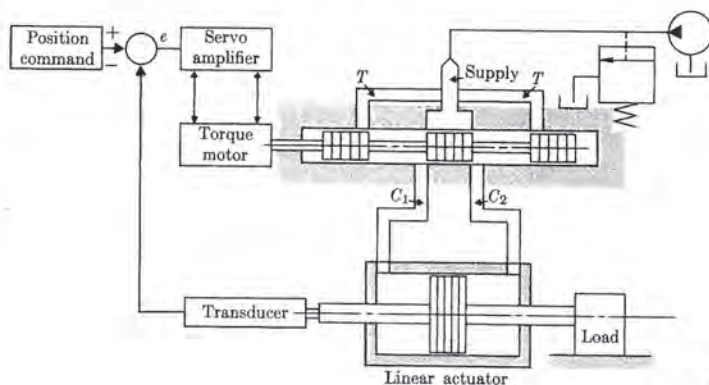
APPLICATIONS OF SERVO SYSTEMS: POSITION CONTROL

The basic elements of a hydraulic, linear position servo system are shown in Fig. 31.1. These include (i) a power supply (pump), (ii) an output device (a servo actuator), (iii) a servo valve, which is usually an integral part of the actuator assembly, (iv) an input or command controller, (v) a servo amplifier (electronic or fluidic), (vi) and a feedback transducer. The load completes the system.

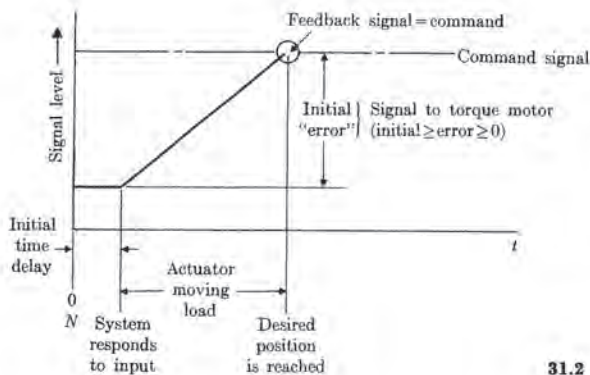
The pump supplies oil to the servo valve under pressure. A "command signal" which establishes the desired operating point is injected into the system. The feedback signal is compared to the command, and any difference between the command and feedback signals constitutes the "error" signal. The torque motor on the servo valve then shifts the valve spool a distance proportional to the "error."

This action, in turn, ports pressurized oil to the actuator. The actuator moves the load and the feedback transducer simultaneously. When the feedback signal from the transducer is such that the difference between it and the command signal—the error—is reduced to zero, the torque motor is recentered. This action recenters (nulls) the servo-valve element, causing the actuator to stop. The load has now been positioned properly. A new command signal is necessary to initiate any further motion of the load. The sequence of events is illustrated graphically in Fig. 31.2.

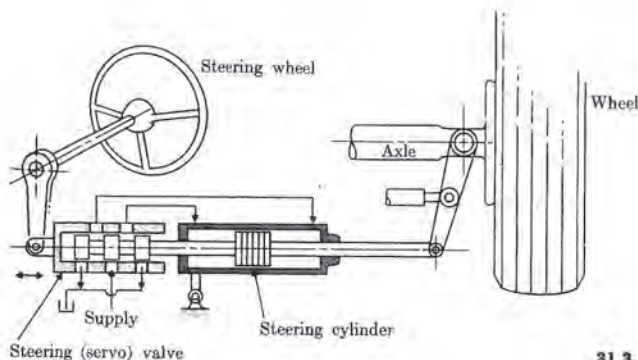
That the feedback signal need not always be electrical is illustrated by one of the most common types of position servo mechanisms: the power steering system for vehicles, as illustrated in Fig. 31.3. In



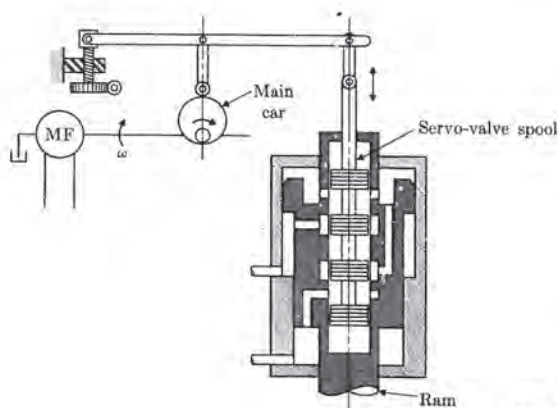
31.1



31.2



31.3



31.4

this case the input or command signal is the turning of the steering wheel. This moves the valve sleeve so as to port oil to the actuator: the steering cylinder. The piston rod moves the steering linkage and the wheels. The valve spool is attached to the linkage in such a way that it moves with the linkage. When the spool has been moved so as to cut off the flow to the cylinder, the actuator stops. Thus mechanical feedback recenters (nulls) the servo valve and stops the motion at the desired point. This point is determined by how far the steering wheel turned initially. A new input signal—further motion of the steering wheel—is necessary to cause further motion of the system.

An application of this type of mechanical feedback to a hydraulic press is shown in Fig. 31.4. In this case the input is from a fluid-motor-driven cam. The linkage shifts the servo-valve spool. The sleeve is an integral part of the main ram. When the spool is shifted, oil is ported to the ram, causing it to move so as to recenter the spool. The ram always follows the motion of the spool, no matter in which direction. This type of servo valve is sometimes referred to as a "follower valve."

Another application of position control is the platen-leveling system shown in Fig. 31.5. This application illustrates the typical problem encountered in trying to move large machine members by means of multiple cylinders. One cylinder functions as the master, while the other is the slave. Transducers on the master cylinder feed back one signal, which is compared with the input or command; a second signal acts as the command for the slave cylinder. The transducer on the slave unit sends back its feedback signal to be compared with the input from the master. Thus the relative positions of the two cylinders can be controlled, as well as the overall position of the platen or machine member.

The field of web guiding is a major control application area in paper making and reducing, and printing—indeed, any application involving the winding, processing, and rewinding of thin paper, metal, or plastic films. Figure 31.6 illustrates a typical web guide system. In this case the *edge* of the web is sensed by the feedback transducer. In some systems this is