Module
6

Actuators

Lesson
28

Industrial Hydraulic Circuits

Lesson Objectives

After learning the lesson students should be able to

- Describe typical industrial actuation problems
- Interpret hydraulic system symbols and circuit diagrams
- Describe techniques for energy saving in hydraulic systems

Introduction

Typical hydraulic circuits for control of industrial machinery are described in this lesson. Graphical hydraulic circuit diagrams incorporating component symbols are used to explain the operation of the circuits.

Case Study I: Unloading System for Energy Saving

An "unloading" system is used to divert pump flow to a tank during part of the operational cycle to reduce power demand. This is done to avoid wasting power idle periods. For example, it is often desirable to combine the delivery of two pumps to achieve higher flow rates for higher speed while a cylinder is advancing at low pressure. However, there may be considerable portions of the cycle, such as when the cylinder is moving a heavy load, when the high speed is no longer required, or cannot be sustained by the prime mover. Therefore, one of the two pumps is to be unloaded resulting in a reduction of speed and consequently, power. The components of this system are: A, B: Hydraulic pumps, C, E: Pilot operated Spring loaded Relief valves, D: Check valve

Mode 1: Both Pumps Loaded

In Figure 28.1 below, when both pumps are delivering, oil from the pump A passes through the unloading valve C and the check valve D to combine with the pump B output. This continues so long as system pressure is lower than the setting of the unloading valve C.
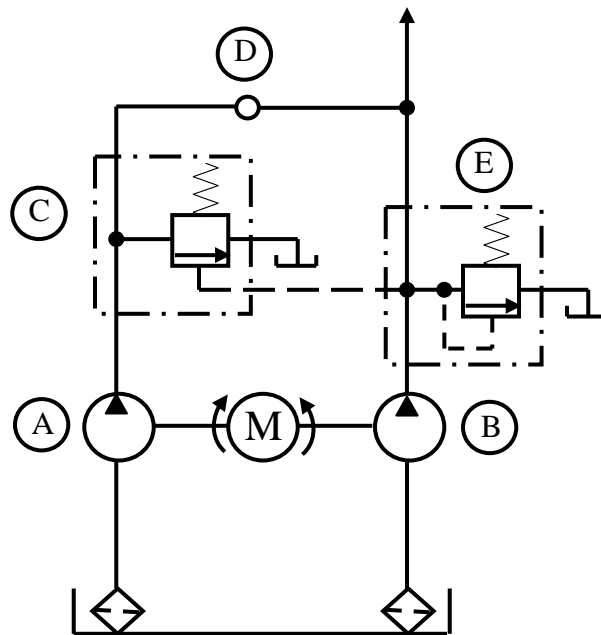
Fig. 28.1 Unloading Circuit

Mode 2: One pump unloaded

In Fig. 28.1, when system pressure exceeds the setting of the unloading valve C, it makes pump A to discharge to the tank at little pressure. Although the system pressure, supplied by pump B, is high, the check valve prevents flow from B through the unloading valve. Thus only pump B now drives the load at its own delivery rate. Thus the load motion becomes slower but the power demand on the motor M also reduces. If the system pressure goes higher, say because load motion stops, pump B discharges when its relief valve settings would be exceeded.

Points to Ponder: 1

A. *Can you imagine what would happen, if the check valve was not present?*

B. *How would you modify the system if you wanted to unload pump B instead of pump A?*

Case Study II: Selection of System Operating Pressure

The circuit shown in Figures 28.2-28.4 allow selection of operating pressure limits in a hydraulic system from three options, namely, two maximum pressures, plus venting. First note the components, namely, A: Reservoir with Filter, B: Hydraulic Pump, C, E: Pilot Relief Valve, D: Solenoid activated Four-way Directional valve.

Venting Mode

In Figure 28.2, both solenoids a and b of the directional valve D are de-energized. The open-center spool is centered by the valve springs, and the vent port on the relief valve is opened to tank. Therefore, the pump flow opens to tank at a very low pressure.
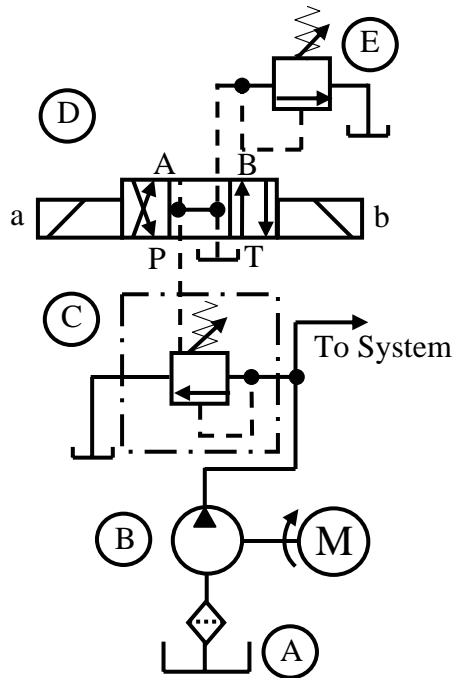
Fig. 28.2 Venting Mode

Intermediate Maximum Operating Pressure

In Figure 28.3, the left-hand solenoid a of the directional valve is energized. The valve spool is shifted to the leftmost position and connects the relief valve vent port to the remote control valve. Pump flow is now diverted to tank when the pressure setting of the remote valve E is reached.
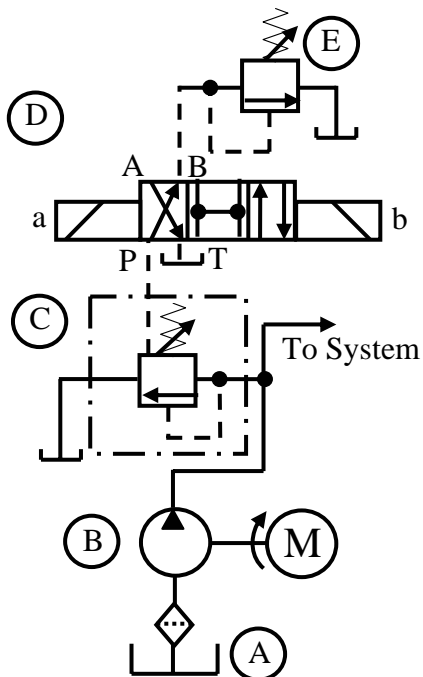

Fig. 28.3 Operating Mode with Intermediate Maximum Operating Pressure

High Maximum Pressure

In Figure 28.4, the right solenoid b of the directional valve is energized. The spool now shifts right to connect the relief valve vent port to a plugged port in the directional valve. The relief valve C now functions at the setting of its integral pilot stage.
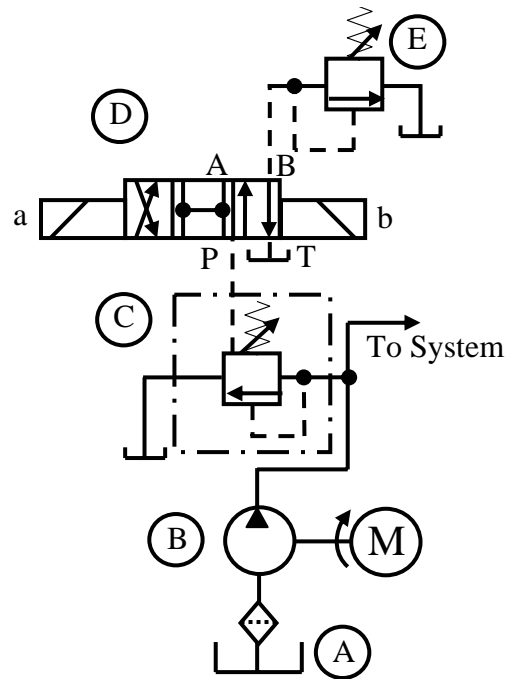

Fig. 28.4 Operating Mode with High Maximum Operating Pressure

Points to Ponder: 2

A. *Why are lines connecting C to D and D to E marked in dashed lines?*

B. *Can you briefly describe a scheme to automate the above system such that whenever, in the intermediate pressure mode, pressure setting is exceeded, the system would automatically switch to the low pressure mode?*

Case Study III: Reciprocating Cylinder with Automatic Venting at End of Cycle

A reciprocating cylinder drive is a very common hydraulic system. In systems where it is not necessary to hold pressure at the end of a cycle, it is desirable to unload the pump by automatically venting the relief valve, to save energy. Figures 28.5-28.8 show such a system. The system components are : A : Reservoir with Filter, B : Hydraulic pump, C, E : Check valve, D : Pilot operated relief valve, F : Two-position electro-hydraulic pilot operated Four-way Directional valve, G : Cam operated pilot valve, H : Double acting Single rod Cylinder, I : Limit Switch.

Extension Stroke

Consider the beginning of the machine cycle when the solenoid of the spring offset directional valve F is energized. Pump output is connected to the cap end of the cylinder. The vent line drawn from the directional valve output connected to the cap end of the cylinder is blocked at the cam-operated pilot valve G. Thus, vent port of the relief valve D is blocked, and the cylinder moves under full pump pressure applied to the cap end.
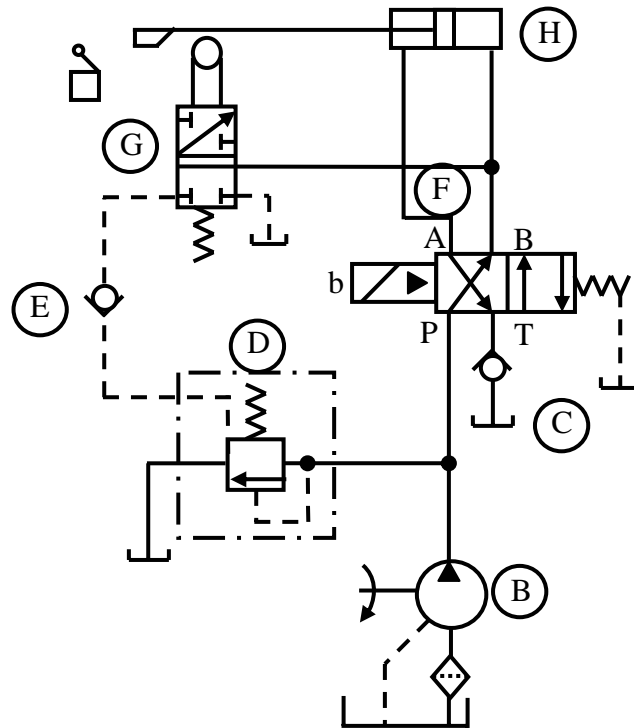

Fig. 28.5 Extension Stroke

Retraction Stroke

At the extreme end of the extension stroke, the limit switch is made on by the cylinder rod to break the solenoid circuit for the directional valve F. The directional valve now shifts to its right position and the pump gets connected to the rod end of the cylinder which now retracts. Note that the relief valve vent connection is still blocked.

Automatic Venting at End of Retraction Stroke

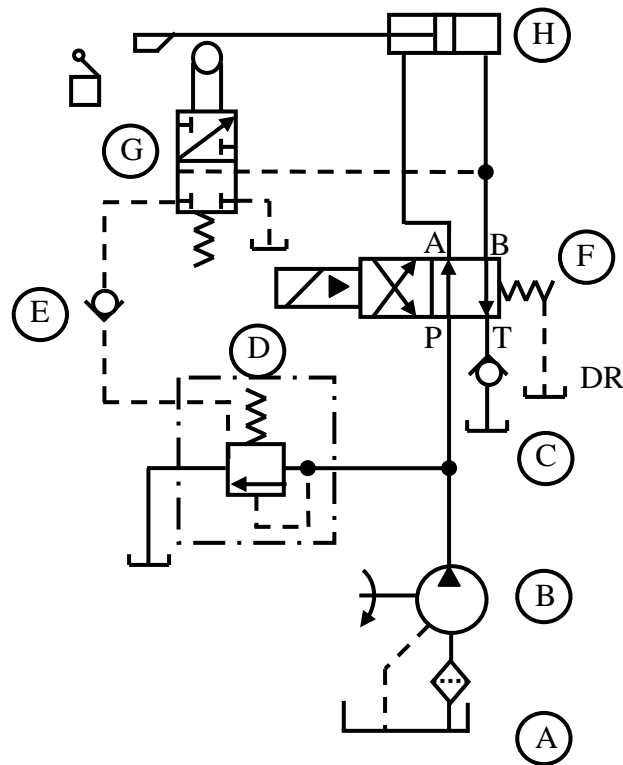At the extreme end of the retraction stroke, the cam on the cylinder is operated by the rod

Fig. 28.6 Retraction Stroke

to shift valve G. The relief valve vent port is thus connected, through E and G, to the line from the cap end of the cylinder, and to tank through the F and the inline check valve C. This vents the relief valve D and unloads the pump.

Push Button Start of Cycle

If another cycle of reciprocating motion is desired, a start button connected to the solenoid circuit is depressed to energize the solenoid, and, in turn, the directional valve shifts to direct pump output into the cap end of the cylinder. This causes the check valve in the vent line to close. Pressure again builds up and the cylinder starts extending. This releases the cam, which, under spring action, shifts and the vent port of E is again blocked at G. Thus the cycle repeats.

Points to Ponder: 3

A. *How does the solenoid get energized if the limit switch is made?*

B. *Is the speed of the cylinder going to be equal during extension and retraction? If not, then what decides the speeds?*
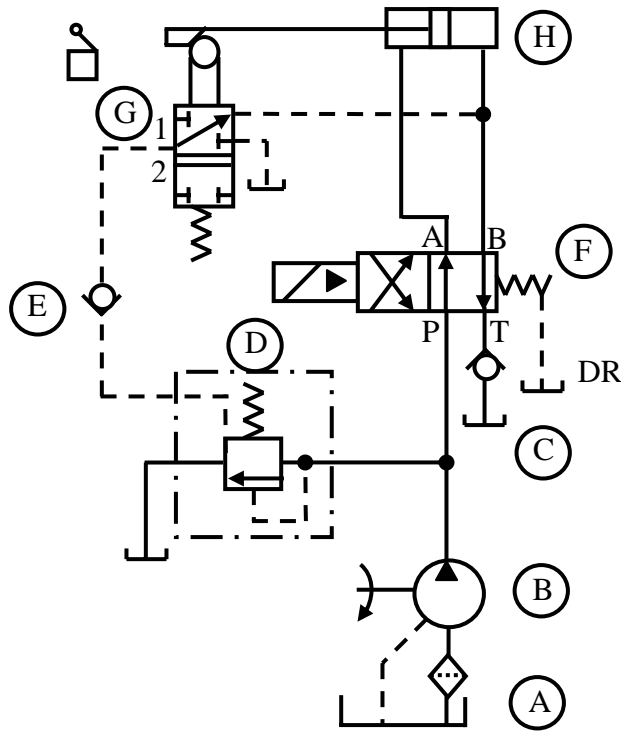
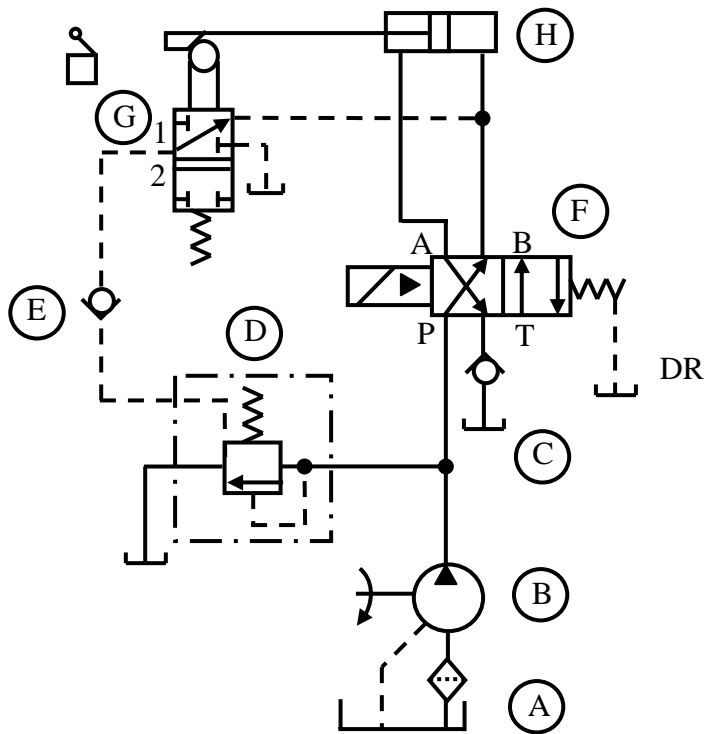**Fig. 28.7 Automatic Venting at End of Retraction Stroke**

Fig. 28.8 Push Button Start of Cycle

Case Study IV: Regenerative Reciprocating Circuit

Conventional reciprocating circuits use a four-way directional valve connected directly to a cylinder. In a regenerative reciprocating circuit, oil from the rod end of the cylinder is directed into the cap end to increase speed, without requiring to increase pump flow. Such a circuit is shown below in Figures 28.9-28.10. The circuit components are : A : Hydraulic Pump, B : Relief valve, C : Four-way two position solenoid operated valve, D : Double-acting Single-rod Cylinder. The operation of the regenerative circuit is shown in Figures 28.9-28.10.

Regenerative Advance

In Figure 28.9, the "B" port on the directional valve C, which conventionally connects to the cylinder, is plugged and the rod end of the cylinder is connected directly to the pressure line. With the valve shifted to the left most position, the "P" port is connect to the cap end of the cylinder. If the ratio of cap end area to rod end annular area in the cylinder is 2:1, the pressure being the same at both end, the force at the cap end is double that at the rod end. There is therefore a net force on the cylinder to move the load. Similarly, at any speed of the cylinder, the flow into the cap end would be double that of the rod end. However, in this connection, the flow out of the rod end joins pump delivery to increase the cylinder speed. Thus only half of the flow into the cap end is actually supplied by the pump. However, the pressure during advance will be double the pressure required for a conventional arrangement for the same force requirement. This is because the same pressure in the rod end, effective over half the cap end area, opposes the cylinder's advance.

In the reverse condition shown in Figure 28.10, flow from the pump directly enters the rod end of the cylinder through two parallel paths, one through the directional valve and the other directly. Exhaust flow from the cap end returns to the tank conventionally through the directional valve. Note that, in contrast to the conventional case, the force on the cylinder as well as the pump flow remains unchanged during extension and retraction. Thus, the speed of the piston during both advancement and retraction remain same.
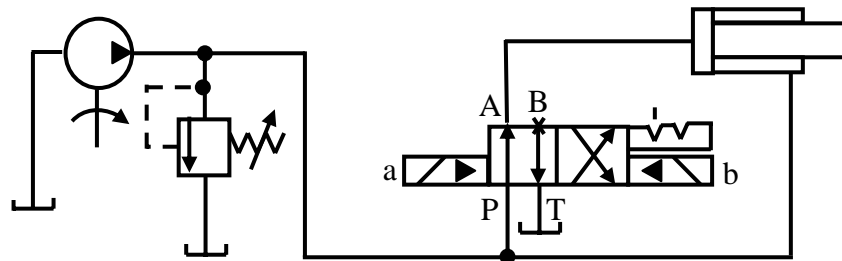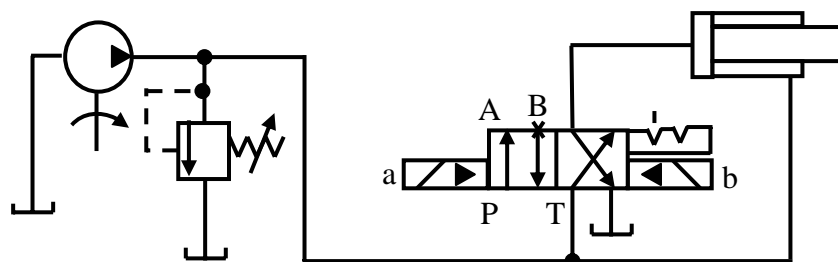

Fig. 28.9 Regenerative Extension Stroke

Fig. 28.10 Regenerative Retraction Stroke

Points to Ponder: 4

    A. *Explain all parts of the symbol of the directional valve C in Figures 28.9-28.10.*

    B. *Compare, point by point a regenerative reciprocation circuit with a conventional one.*

Case Study V: Sequencing Circuits

In many applications, it is necessary to perform operations in a definite order. Following is one of several such circuits. The components of the system are as follows. A : Reservoir and Filter ; B : Hydraulic Pump ; C : ; Relief valve : D ; F_1, F_2, G : Relief valve with integral check valve ; H, J : Cylinders ; I : Check Valve

The sequence of operation realized by the circuit shown in Figure 28.11-28.14 is:

        Step A – Extend Cylinder H
        Step B – Extend Cylinder J while holding pressure on Cylinder H
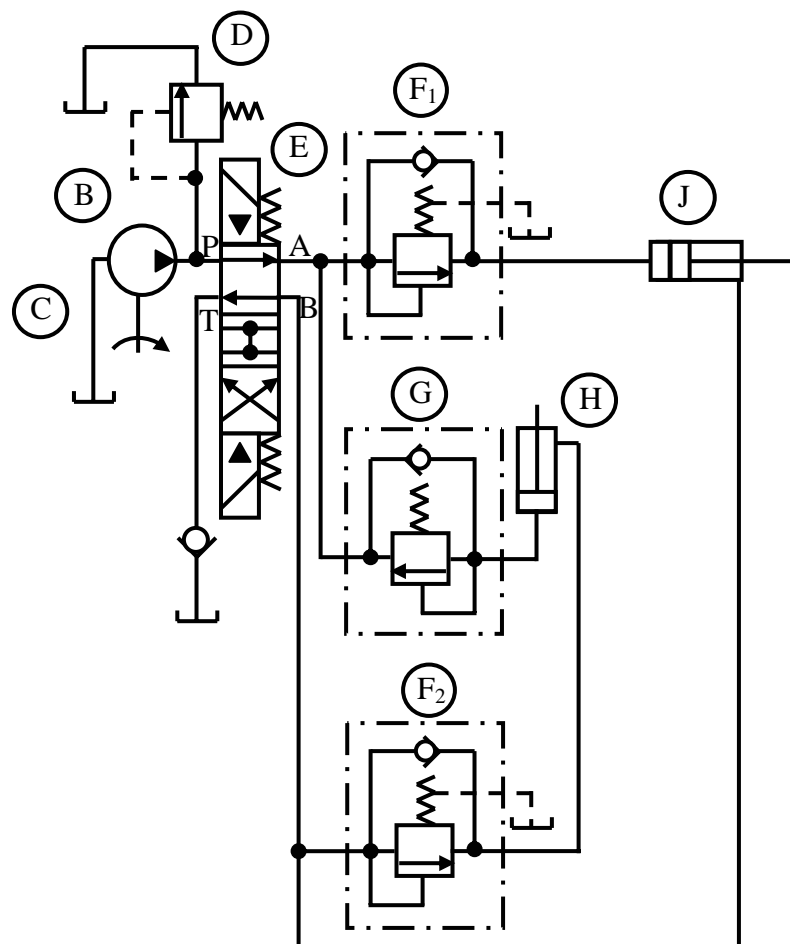   Step C – Retract Cylinder J
        Step D – Retract Cylinder H

Fig. 28.11 Cylinder H Extending

Step A

Pressing a pushbutton would start the cycle and shift the directional valve E to the position shown in Fig 28.11. At first the fluid flows through the integral check valve in G into the cap end of H and returns freely through the check valve in F_2. The pump pressure is low during this period, only to the extent of pushing the load on H.

Step B

Once H reaches its rod end, the pressure builds up and now the flow develops through F_1 into the cap end of J and out through the rod end to go back directly to tank through F_2, E and C. Note that a pressure equal to the setting of the valve F_1 is maintained on H. When J is fully extended, pressure increases further and is limited by the setting of D, providing overload protection to B.

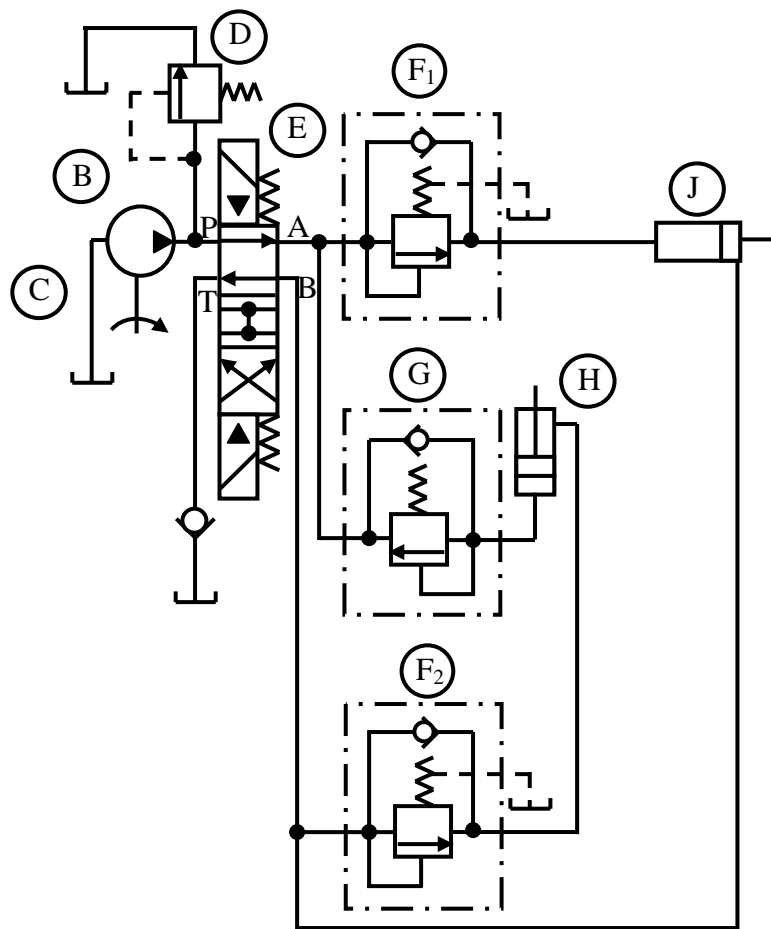**Fig. 28.12 Cylinder J Extending**

Step C

Similarly, when the other solenoid of E is energized, the directional valve shifts to the other position, as shown in Fig. 28.13. Now, pump delivery is directed through D, E and F_2, into the rod end of J. As before, the flow out of the cap end of J flows to tank through F_1, E and C. Step C is illustrated in Fig. 28.13.

Step D

On completion of Step C, the pressure increases again, and the flow is directed through F_2 to the rod end of H and out through the cap end to flow into the tank through the valve G at its pressure setting and then freely to tank through F_1, E and C. Note that F_2 maintains a pressure equal to the setting of H at the rod end of J during the retraction of H. Note further that, while H is retracting, a back pressure is provided to it by G, to prevent rapid falling of the load during lowering, under gravity.

In the above circuit, sequencing is achieved by grading the pressure settings of the relief valves. Note that sequencing can also be achieved electronically by PLC control of the solenoids of separate directional valves driving H and J.
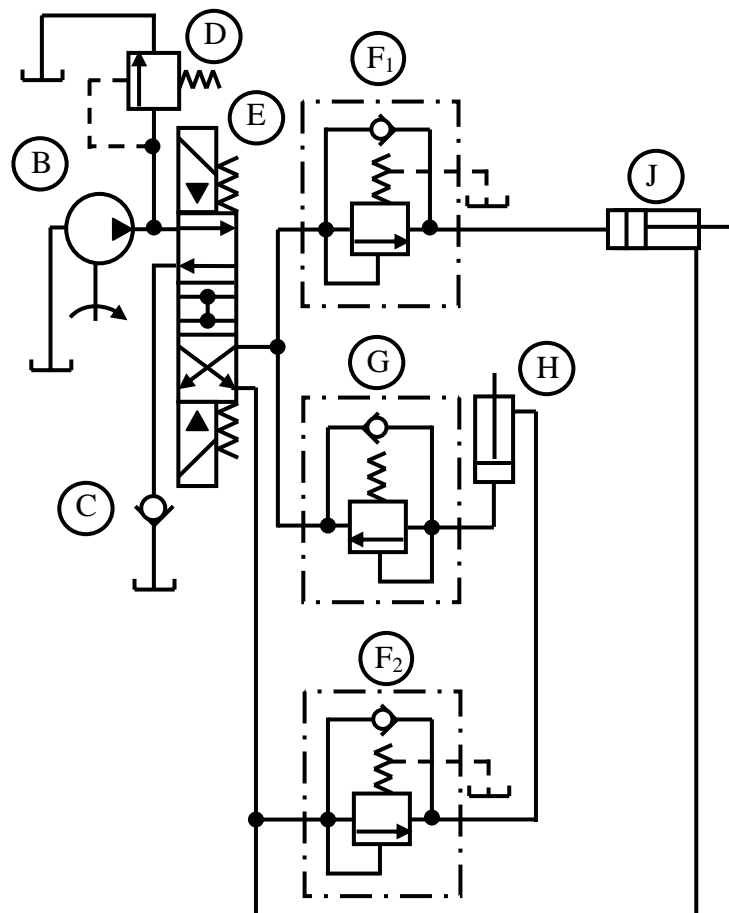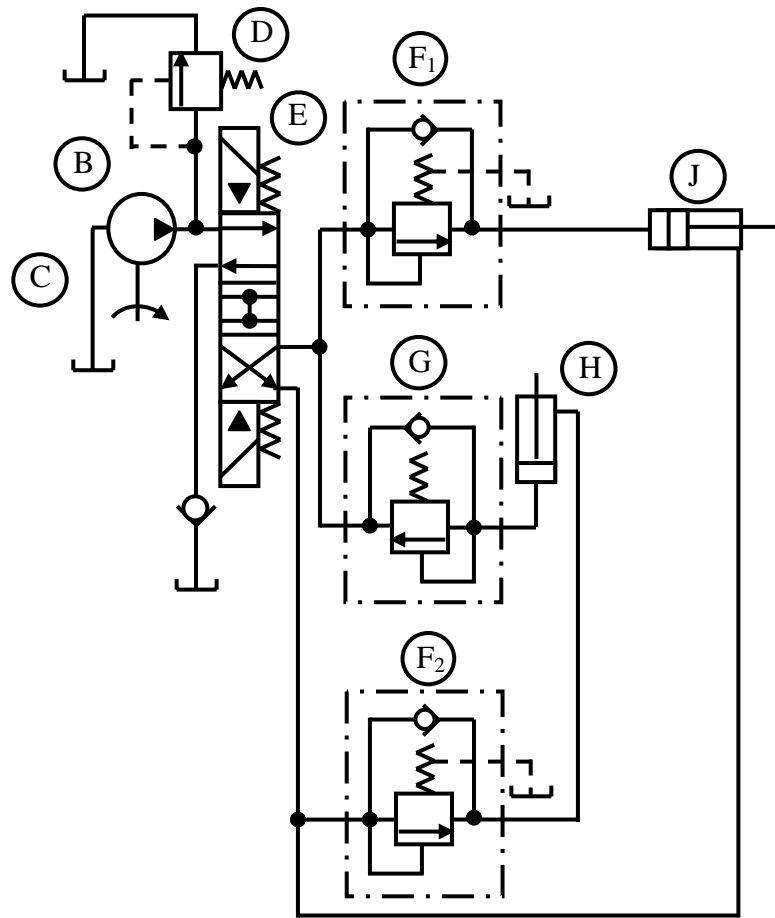
Fig. 28.13 Cylinder J Retracting

Fig. 28.14 Cylinder H Retracting

Lesson Summary

In this lesson we have presented industrial hydraulic circuits for following applications:

A. Unloading of pumps based on relief valve and check valve to avoid overloading.

B. Selection of system operating pressure from two values based on settings of relief valves and their selection with a directional valve.

C. Extension-retraction Circuit for one cylinder with automatic unloading of pump at the end of cycle

D. Extension-retraction Circuit for one cylinder with regenerative feedback

E. Sequenced extension-retraction circuit for two cylinders.

Answers, Remarks and Hints to Points to Ponder

Points to Ponder: 1

A. *Can you imagine what would happen, if the check valve was not present?*

Ans: Then, if the setting of the relief valve C is reached, both pumps would have unloaded.

B. *How would you modify the system if you wanted to unload pump B instead of pump A?*

Ans: Then, a check valve is to be placed between pump B and the system, after the relief valve D. The relief valve after C would be removed. Finally, the setting of D would have to be set lower than that of C.

Points to Ponder: 2

A. *Why are lines connecting C to D and D to E marked in dashed lines ?*

Ans: Because these are pilot lines for the relief valve.

B. *Can you briefly describe a scheme to automate the above system such that whenever, in the intermediate pressure mode, pressure setting is exceeded, the system would automatically switch to the low pressure mode?*

Ans: One of the ways is to devise an automated logic for exciting the solenoids of the directional valve. The above feature can be implemented by using a pressure switch which would be made if the pressure setting is exceeded. This pressure switcvh contacts can then be incorporated into a relay circuit or a PLC program that would drive the solenoid of the directional valve corresponding to high pressure.

Points to Ponder: 3

A. *How does the solenoid get energized if the limit switch is made?*

Ans: The limit switch contacts can be incorporated into a relay circuit or a PLC program that would drive the solenoid of the directional valve.

B. *Is the speed of the cylinder going to be equal during extension and retraction? If not, then what decides the speeds?*

Ans: The speed of the cylinder is going to be different during extension and retraction. Note that the cross-sectional areas of the two sides of the piston are different because of the single-rod configuration. During extension, the pump pressure acts on the cap end of the cap end of the cylinder which has higher area than the rod end. Therefore, the net force acting on the piston during extension is more than that during retraction. The speeds reached during these strokes depend on the load that exists during these

strokes. Thus, to summarize, the speeds depend on the loads as well as the areas of the rod and the cap ends f the cylinder.

Points to Ponder: 4

A. *Explain all parts of the symbol of the directional valve C in Figures 28.9-28.10.*

Ans: The directional valve has two positions and is a four-way valve with the pump port and the tank port on one side and the two load side ports A and B on the other. The valve is not spring loaded and therefore requires two solenoids for moving it to the two positions. The solenoid moves a hydraulic pilot valve spool, which, in turn, moves the main valve spool. The valve is called detented because it has a mechanism that locks the piston into the position it moves into and holds it there. In the circuit in which the valve is used, in the left position, one port of the valve is plugged, as marked by a cross.

B. *Compare, point by point a regenerative reciprocation circuit with a conventional one.*

Ans: In a regenerative circuit higher cylinder speed can be reached with a lower pump flow rate. However, for a given force requireent to move the load, higher pup pressures are needed, since there exists a back pressure at the rod end of the piston, unlike in a conventional reciprocation circuit. In the retraction stroke, however, regeneration is not possible. In both cases, regenerative and conventional, cylinder speeds during retraction and extension are different in general. Or the regenerative case, however, they may be made equal with area ration of 2:1 of the cap and the rod ends of the piston.