Exercise 3-1

Hydraulic Sequencing of Cylinders

EXERCISE OBJECTIVE

- To describe the design and operation of a sequence valve;
- To describe the function and operation of a mechanical limit switch;
- To assemble and test a clamp and work system sequenced by a hydraulic sequence valve.

DISCUSSION

Hydraulic sequencing of cylinders

In many industrial systems, there is a need for two or more actuators to move in a certain programmed order, cycle after cycle. An example might be a cutting machine which first clamps the workpiece and then starts the cut. The cutting operation must begin only after the clamp operation is finished. This is called **sequential** operation and a **sequence valve** might be used to perform this sequence.

Sequence valves

Figure 3-1 shows the Sequence Valve of the Hydraulics Trainer. The valve body has three ports: an inlet **pressure (P) port**, a **sequence (S) port**, and a **drain (D) port** which is to be connected to the reservoir. Similar to the Relief Valve, the Sequence Valve is normally closed and it senses the pressure upstream. Unlike the Relief Valve, however, the Sequence Valve is externally drained to the reservoir through its drain port.

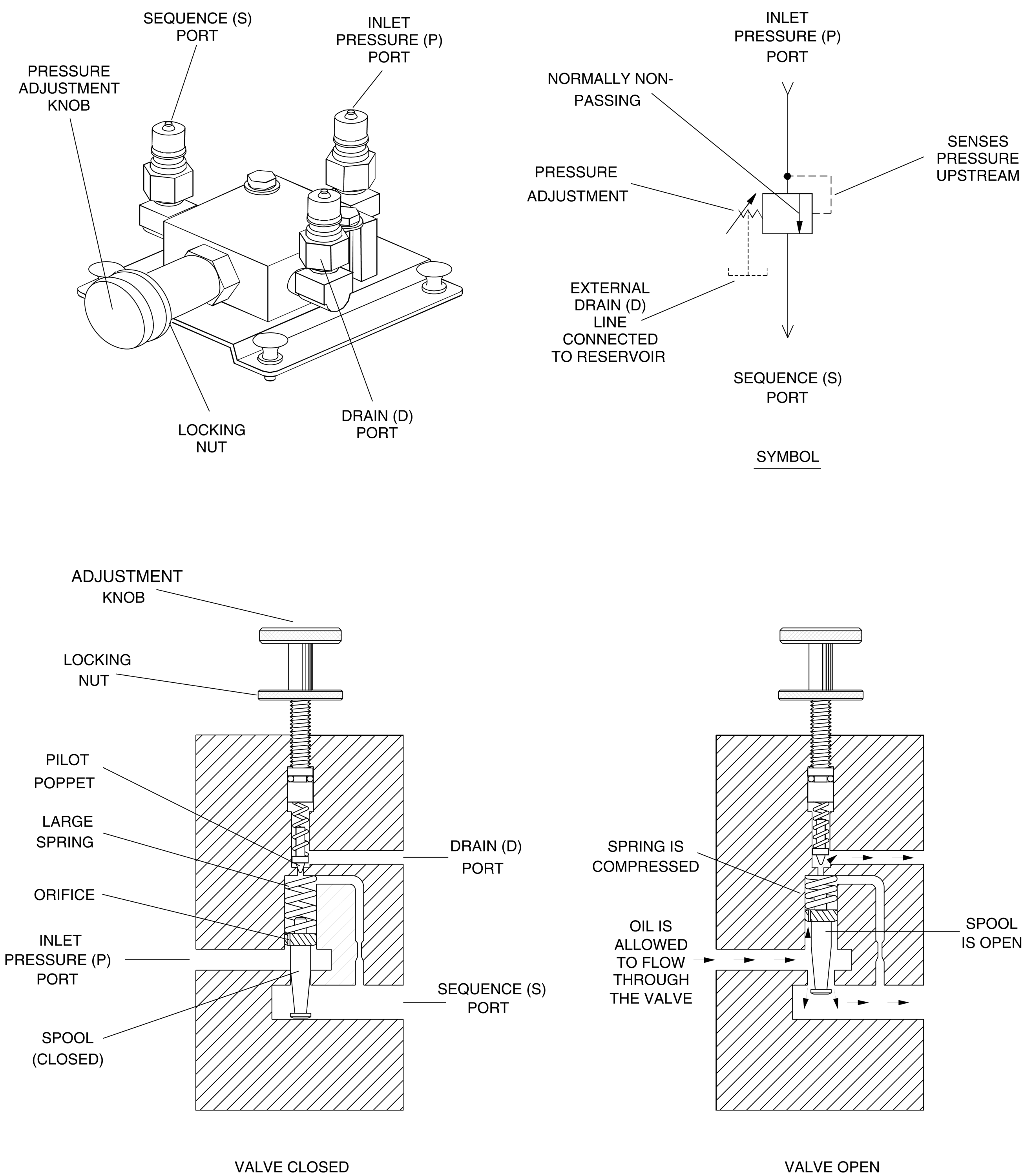


Figure 3-1. Pilot-operated sequence valve.

An internal spool controls the oil flow through the valve by acting on a large spring. The pressure level where the spool begins to open to allow some oil to flow through the valve is called **cracking pressure**. The pressure level where the spool is completely open is called **operating pressure**. The operating pressure can be adjusted by using the adjustment knob on the valve body. Turning the knob clockwise increases the valve operating pressure. Once the operating pressure is set, tightening a locking nut on the adjustment screw will prevent vibrations and shocks from modifying the adjustment.

As long as the pressure upstream of the valve is lower than the valve cracking pressure, the spool will remain closed and oil will not be allowed to flow through the valve. When the upstream pressure becomes higher than the valve cracking pressure, the spool will move up towards its open position to allow oil to flow through the valve. When the valve becomes fully open, the pressure at the sequence port of the valve will rise to the level demanded by the load. This means that the full system pressure (pressure setting of the Relief Valve) will be available downstream.

In order for the Sequence Valve to be able to hold its spool open against this downstream pressure, the valve spring chamber must be drained to the reservoir. If the reservoir connection is missing or blocked, the downstream oil will back up into the spring chamber and cause the valve to close completely.

Sequence valves will not allow the oil to flow very well in the reverse direction, because they will try to close, resulting in a restricted flow rate. When reverse flow is required, as in a circuit containing an extending and retracting cylinder, a sequence valve with a built-in check valve may be used, or an external check valve may be connected across the valve inlet pressure (P) and sequence (S) ports. The Sequence Valve of the Hydraulics Trainer does not have a built-in check valve, so an external check valve must be connected across it when reverse flow is required.

Figure 3-2 shows the Check Valve of the Hydraulics Trainer. The valve consists of inlet and outlet ports, a ball, and a light spring. When the pressure of the oil at the inlet port is high enough to overcome the spring force, the ball is lifted off the valve seat and oil flows through the valve. This is known as the **free flow direction**. When the direction of the oil is reversed, however, the ball is pushed against the valve seat, and oil cannot flow through the valve. This is known as the **blocked flow direction**.

Figure 3-2 also shows the symbol for the Check Valve. The valve blocks the oil flowing in the direction of the arrow, but allows the oil to flow freely in the opposite direction.

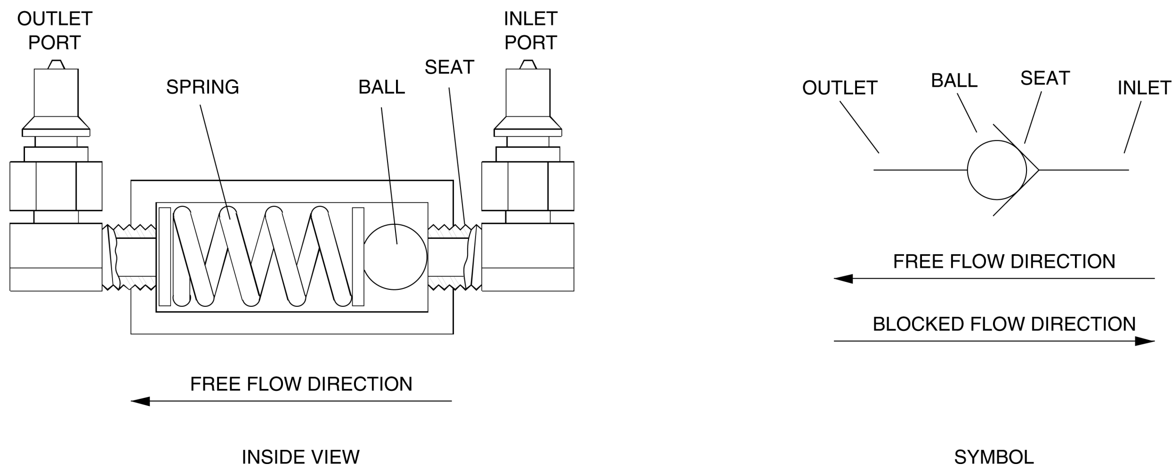
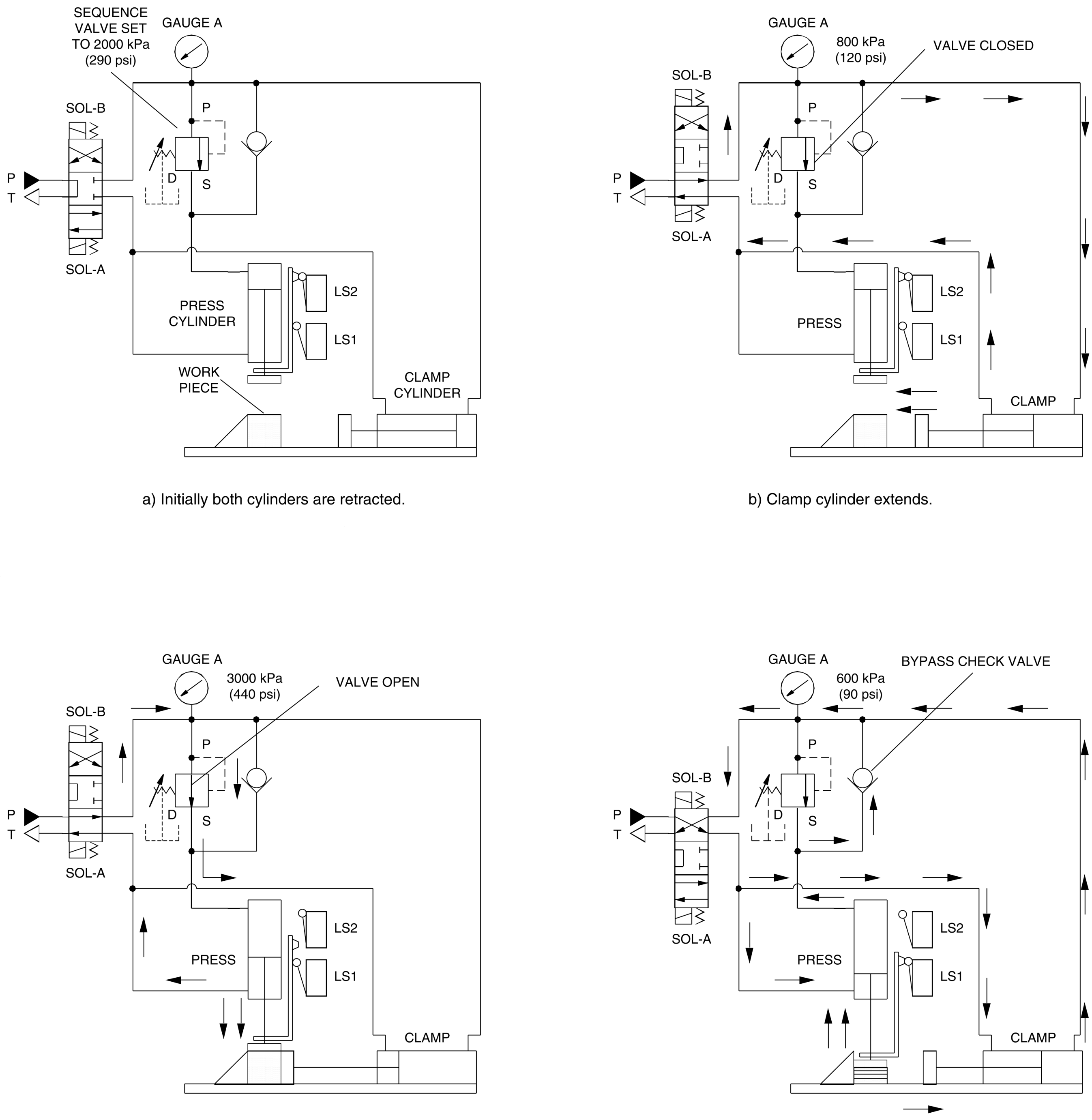


Figure 3-2. Check valve.

Application example

The most common application of sequence valves is for “clamp and work” circuits. Clamp and work circuits usually consist of two cylinders. The clamp cylinder, which is a small-bore cylinder, advances until it stalls against the workpiece. The work cylinder, which is a larger-bore cylinder, performs a particular task on the clamped workpiece, such as bending, pressing, drilling, cutting, or grinding. The clamp cylinder must always extend first, and the workpiece must be clamped with sufficient force at the moment when the work cylinder starts to extend. Full clamping force must continue during extension of the work cylinder. Sequence valves are a good way to achieve this action.

As an example, Figure 3-3 shows a clamp and press system sequenced by a sequence valve. The clamp operation is performed by a small-bore cylinder to limit the clamping force and prevent distortion or damage to the workpiece. The press operation is performed by a large-bore cylinder to press the workpiece with full force. A sequence valve connected upstream will not open unless the system pressure reaches the valve pressure setting of 2000 kPa (290 psi). Therefore, the oil flow to the press cylinder is blocked until the workpiece is clamped with sufficient force.



a) Initially both cylinders are retracted.

b) Clamp cylinder extends.

c) Clamp cylinder extended : press cylinder extends.

d) Both cylinders retract.

Figure 3-3. Clamp and press system sequenced by a hydraulic sequence valve.

- In the normal condition of the circuit, both cylinders are retracted, so the operator can load a workpiece into the machine, as Figure 3-3 a) shows. Solenoids A and B of the directional valve are deenergized, so the valve is in its center position.

Since this valve is of the **tandem-center** type, the pumped oil is allowed to return to the reservoir **at low pressure**. This **unloads** the pump and saves energy.

- When the operator presses a START pushbutton, the directional valve is shifted to the straight-arrows condition, as illustrated in Figure 3-3 b). The clamp cylinder starts to extend. Since this cylinder extends under no load, it requires a pressure that is less than the 2000 kPa (290 psi) setting of the sequence valve. Therefore, the sequence valve stays closed and the flow is blocked to the press cylinder.

- Once the clamp cylinder is extended, the pumped oil becomes deadheaded and the system pressure rises quickly. When it reaches 2000 kPa (290 psi) upstream of the sequence valve, the valve opens and the press cylinder extends. When the cylinder contacts the workpiece, the system pressure rises to its maximum level (setting of the relief valve) to press the workpiece with full force. This is illustrated in Figure 3-3 c).

  Notice that this pressure is also applied to the cap end of the clamp cylinder. This means that a sequence valve cannot be used as a relieving device to limit pressure in the other circuit branches. For that reason, a pressure reducing valve is often used to limit the pressure in the branch of the clamp cylinder.

- Once the press cylinder is extended, it activates mechanical limit switch LS1. This causes the directional valve to shift to the crossed-arrows condition to retract the cylinders, as illustrated in Figure 3-3 d). The clamp cylinder completes its stroke first because it requires the lowest pressure to move. The press cylinder then completes its stroke, which activates mechanical limit switch LS2 and stops the cycle.

Mechanical limit switches

In the circuit of Figure 3-3, automatic reversal and stopping of the cylinders is achieved by using the electrical signals provided by mechanical limit switches to shift the directional valve when the cylinders become fully extended or retracted. Mechanical limit switches are used extensively on industrial hydraulic equipment. They are reliable, small in size, simple to use, and generally cheaper than the other types of switches.

A mechanical limit switch basically consists of an actuator and one or more sets of N.O. and N.C. contacts. It is activated when a moving part, such as a cylinder rod or machine member, strikes the actuating mechanism, shifting the contacts to their activated state.

Figure 3-4 shows the Limit-Switch Assembly supplied with your Hydraulics Trainer. Also shown are the hydraulic and ladder diagram symbols of a mechanical limit switch. Each switch has a roller-type actuator and a set of SPDT contacts of the single-pole, double-throw (SPDT) type. When the cylinder tip travels across one of the switches, it pushes against the roller, depressing the lever arm. The lever arm acts on an internal plunger, causing the SPDT contacts to activate. The N.O. contact goes closed while the N.C. contact goes open. When the cylinder tip moves away from the switch, a spring returns the lever arm and SPDT contacts to their normal condition.

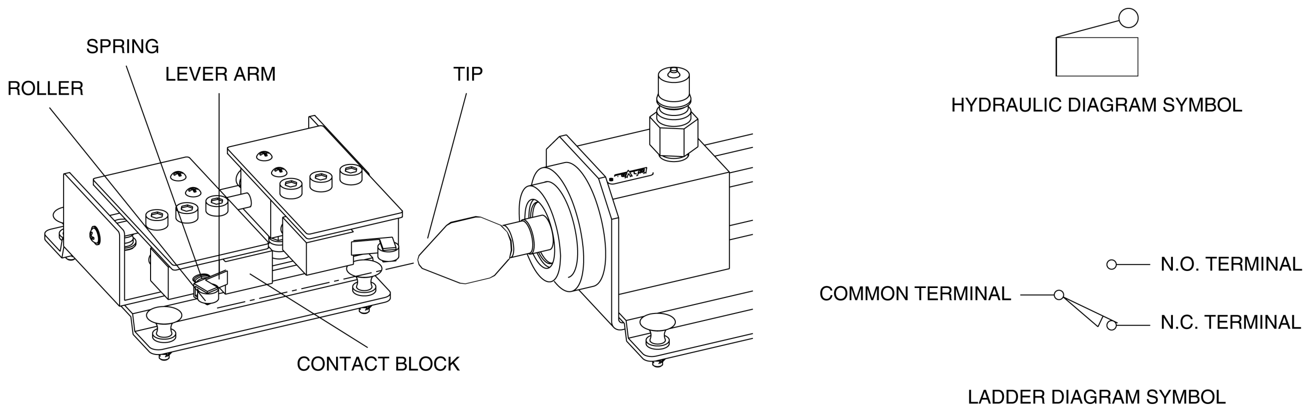


Figure 3-4. Mechanical limit switch with roller arm actuator and SPDT contacts.

Mechanical limit switches are often available as multiple-switch assembly with two or more limit switches mounted on the same supporting frame. The two mechanical limit switches supplied with your Hydraulics Trainer, for example, are mounted on the same supporting frame. This design is ideal for situations which require two switches mounted side by side.

Procedure summary

In the first part of the exercise, you will test the operation of a sequence valve.

In the second part of the exercise, you will connect and test the hydraulically-sequenced clamp and press system described in the DISCUSSION section of the exercise.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix A of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

Operation of a sequence valve

☐ 1. Connect the circuit shown in Figure 3-5. In this circuit, the Flow Control Valve will be used to simulate a varying load downstream of the Sequence Valve. The lever-operated Directional Valve will be used to simulate a clamp cylinder extending to a workpiece.

Note: *If required, refer to Figure 3-1 to locate ports P, S, and D on the Sequence Valve .*

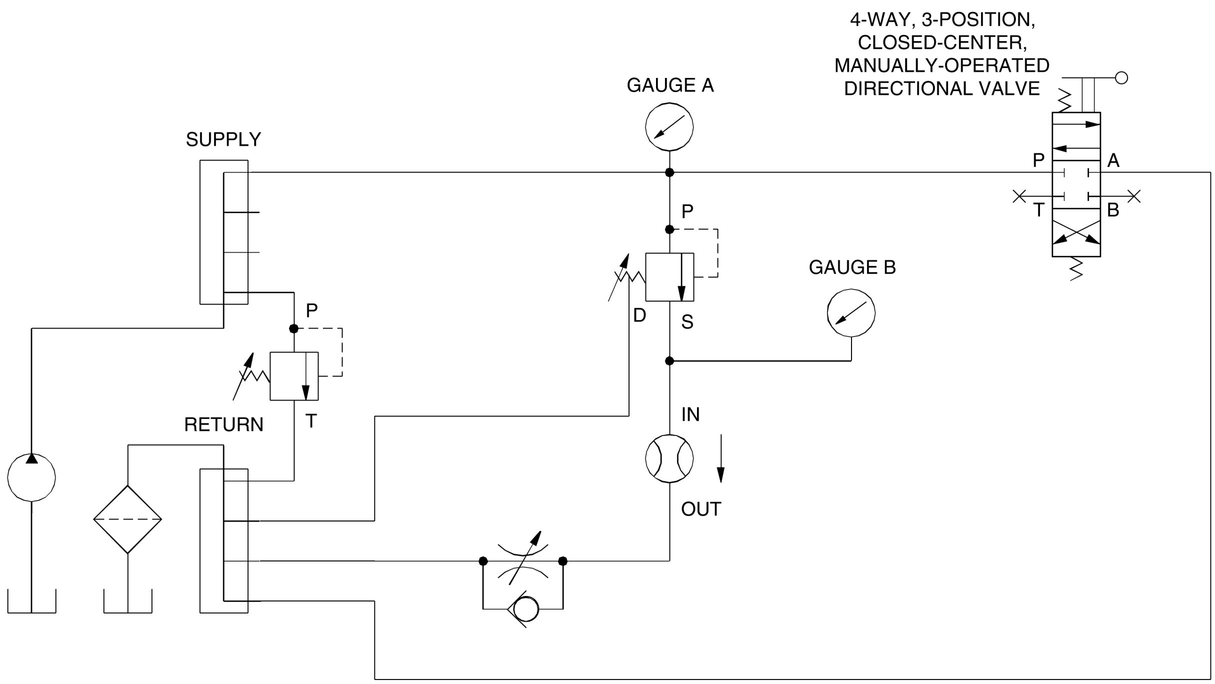


Figure 3-5. Testing the operation of a sequence valve.

☐ 2. Open the Flow Control Valve completely by turning its adjustment knob fully counterclockwise.

☐ 3. Close the Sequence Valve completely. To do so, first loosen the locking nut on the adjustment screw by turning this nut fully counterclockwise. Then, turn the valve adjustment knob fully clockwise. The operating pressure of the Sequence Valve is now set at the highest possible pressure.

☐ 4. Before starting the Power Unit, perform the following start-up procedure:

a. Make sure the hydraulic hoses are firmly connected.
b. Check the level of the oil in the Power Unit reservoir. Oil should cover, but not be over, the black line above the temperature/oil level indicator on the Power Unit. Add oil if required.
c. Put on safety glasses.
d. Open the Relief Valve completely by turning its adjustment knob fully counterclockwise.

☐ 5. Turn on the Power Unit.

☐ 6. With the Sequence Valve fully closed and the Directional Valve in its center condition, the pumped oil is now being forced through the Relief Valve. Turn the adjustment knob of the Relief Valve clockwise until the system pressure at Pressure Gauge A is 3000 kPa (440 psi).

☐ 7. Observe the Flowmeter reading. Since the Sequence Valve is closed, no oil flows downstream of the Sequence Valve.

Decrease the operating pressure of the Sequence Valve by turning its adjustment knob counterclockwise until the reading of Pressure Gauge A starts to decrease. As indicated by the Flowmeter reading, the Sequence Valve is now open because its operating pressure is lower than the pressure setting of the Relief Valve. The operating pressure of the Sequence Valve is indicated by Pressure Gauge A.

> **Note:** *The adjustment knob of the Sequence Valve can be turned over approximately six turns. You may have to turn the valve knob four or five turns counterclockwise before the reading of Pressure Gauge A starts to decrease.*

☐ 8. Open the Sequence Valve completely by turning its adjustment knob fully counterclockwise. Observe the reading of Pressure Gauge A. This is the minimum operating pressure of the Sequence Valve. Record this pressure below.

Minimum operating pressure: ______ kPa or ______ psi

☐ 9. Set the operating pressure of the Sequence Valve to 2000 kPa (290 psi). To do so, turn the valve adjustment knob clockwise until the reading of Pressure Gauge A is 2000 kPa (290 psi).

☐ 10. Decrease the Flow Control Valve opening (turn knob clockwise) until the reading of Pressure Gauge B is 1000 kPa (150 psi). This creates a downstream load that is lower than the operating pressure of the Sequence Valve. What happens to the condition (open/closed) of the Sequence Valve and reading of Pressure Gauge A? Explain.

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☐ 11. Further decrease the Flow Control Valve opening (turn knob clockwise) until the reading of Pressure Gauge B is 2500 kPa (360 psi). This creates a downstream load that is higher than the operating pressure of the Sequence

Valve. What happens to the condition (open/closed) of the Sequence Valve and reading of Pressure Gauge A? Why?

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☐ 12. Move the lever of the Directional Valve toward the valve body to simulate a clamp cylinder extending under no load to a workpiece. What happens to the reading of Pressure Gauge A and condition (open/closed) of the Sequence Valve? Explain.

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☐ 13. Release the lever of the Directional Valve to simulate the clamp cylinder stalling against the workpiece. What happens to the condition (open/closed) of the Sequence Valve and reading of Pressure Gauge A? Explain why.

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☐ 14. Decrease the pressure setting of the Relief Valve by turning its adjustment knob counterclockwise until the upstream pressure at Pressure Gauge A is 1000 kPa (150 psi). Is the Sequence Valve still open? Why?

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☐ 15. Increase the pressure setting of the Relief Valve by turning its adjustment knob until the Sequence Valve re-opens (Flowmeter reads full flow). The upstream pressure at Pressure Gauge A should now correspond to the operating pressure (2000 kPa/290 psi) of the Sequence Valve. Is this your observation?

☐ Yes ☐ No

☐ 16. Turn off the Power Unit. Open the Relief Valve completely (turn knob fully counterclockwise). Do not modify the 2000-kPa (290-psi) pressure setting of the Sequence Valve. Lock the Sequence Valve to this setting by turning its locking nut fully clockwise. Then, disconnect and store all hoses and hydraulic components.

Hydraulically-sequenced clamp and press system

☐ 17. Get the 3.8-cm (1.5-in) bore cylinder from your storage location. Clamp this cylinder to the Work Surface. Connect the two cylinder ports to the Power Unit return line port through a manifold.

☐ 18. Mount a mechanical limit switch at the beginning of the 3.8-cm (1-5 in) bore cylinder stroke, and another mechanical limit switch at the end of the cylinder stroke. To do so, perform the following steps:

– Screw the cylinder tip (bullet) onto the rod end of the cylinder.

– Manually extend the cylinder rod completely.

– Clamp the Limit-Switch Assembly along the cylinder rod.

– Loosen the positioning screw on each limit switch. Position the switches side by side at the center of the support bracket, as Figure 3-6 a) shows. Tighten the limit-switch positioning screws.

– Loosen the support-bracket positioning screws until you are able to slide the bracket over the mounting base, as Figure 3-6 b) shows. Adjust the position of the bracket so that the switches are activated when the cylinder tip pushes against the switch arm and deactivated when the cylinder tip releases the switch arm. To test this out, manually extend and retract the cylinder rod, and listen for the “click”. Then, tighten the support-bracket positioning screws down on the mounting base.

– Loosen the positioning screw on each limit switch. Adjust the positioning of the switches so that they are activated when the cylinder rod is fully extended and fully retracted, as Figure 3-6 c) shows. To test this out, manually extend and retract the cylinder rod, and listen for the click. Then, tighten the limit-switch positioning screws.

– Retract the cylinder rod completely, as Figure 3-6 d) shows.

Note: *If the cylinder rod cannot be extracted and retracted manually, you will have to actuate the cylinder rod hydraulically. To do this, disconnect the two cylinder ports from the Power Unit return line port, then connect a simple cylinder reciprocation circuit using the lever-operated Directional Valve (P/N 6320) and the Relief Valve (P/N 6322). With the pressure setting of the Relief Valve at minimum (knob turn fully counterclockwise), turn on the Power Unit. Perform the above steps in order to position the limit switches, using the lever of the Directional Valve to extend and retract the rod. When the switches are correctly positioned, turn off the power and disconnect the hoses, then proceed with the exercise.*

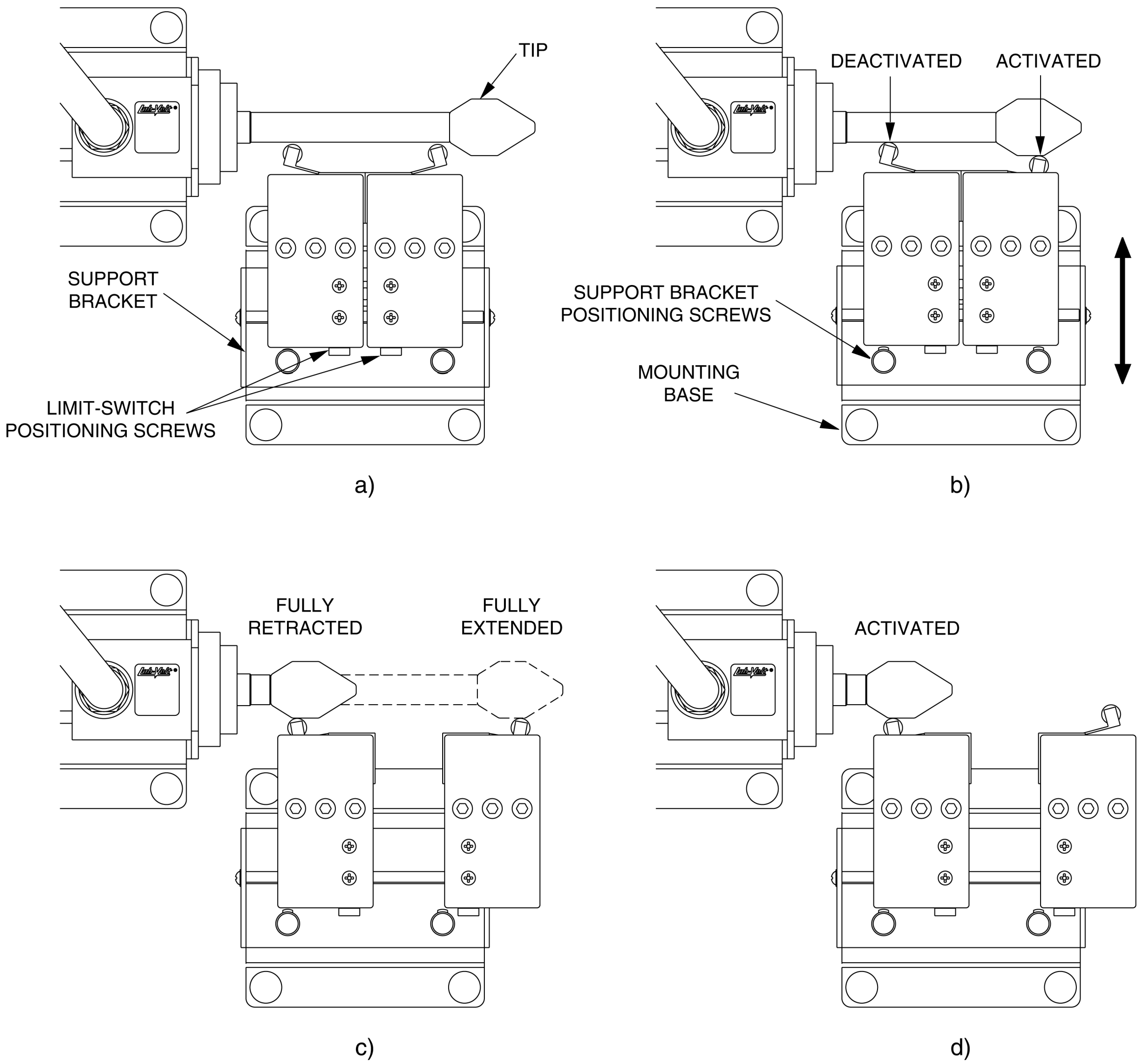
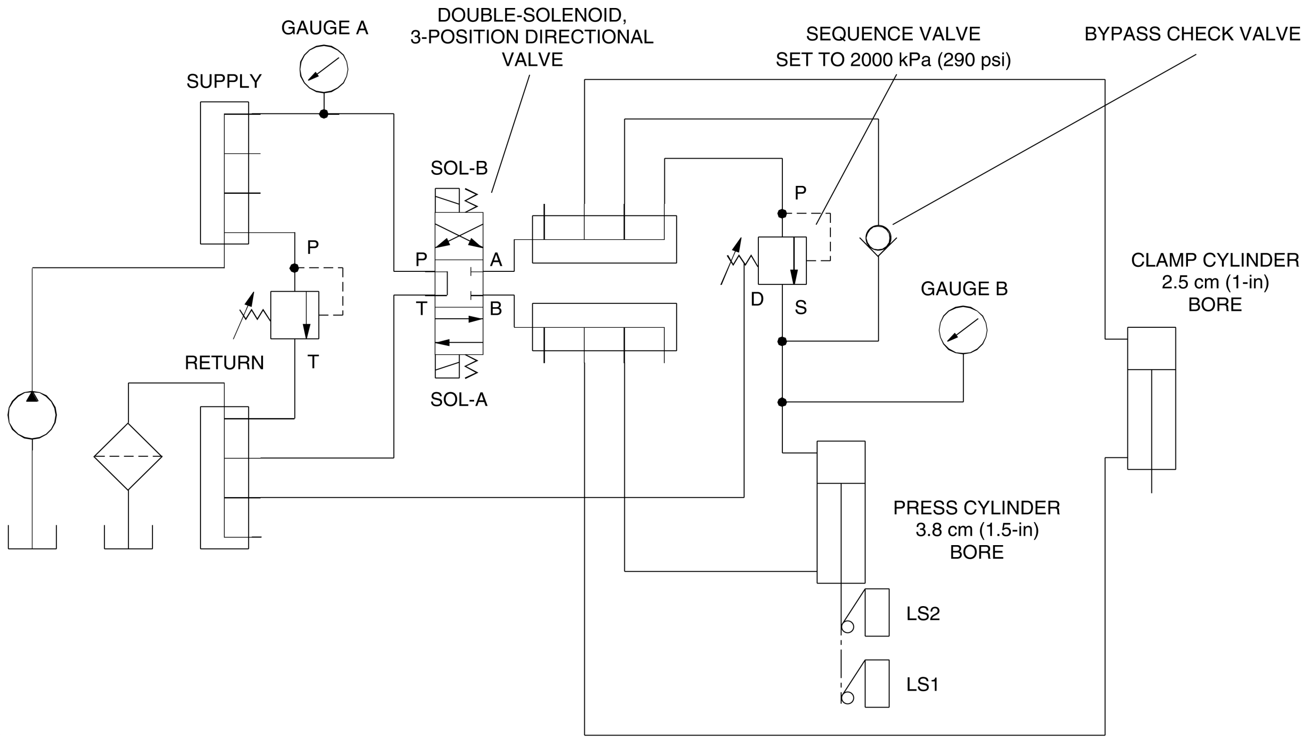


Figure 3-6. Mounting of the mechanical limit switches.

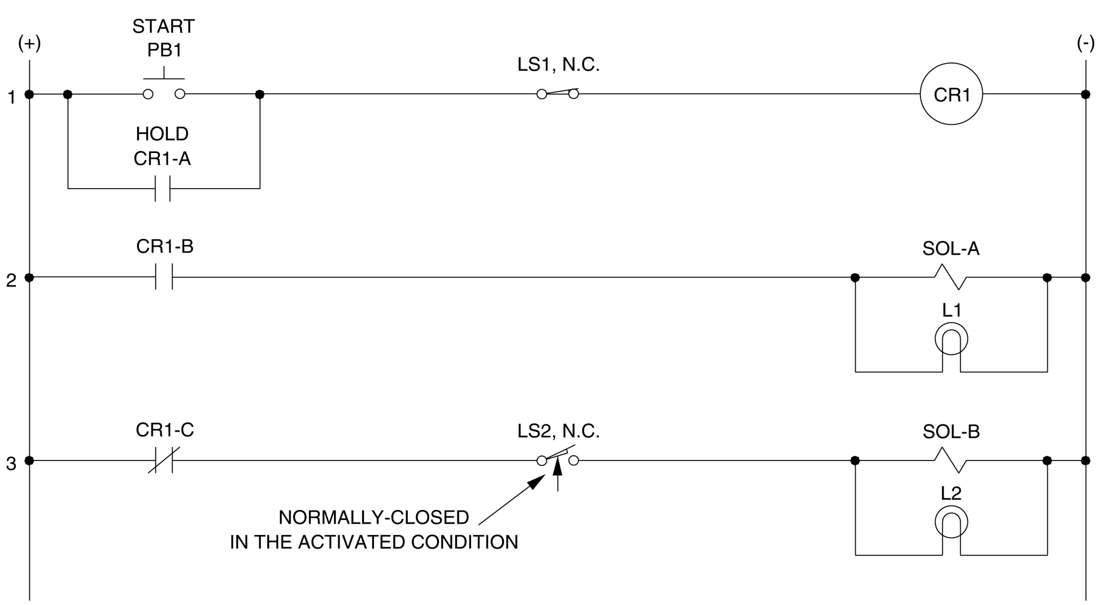
☐ 19. Connect the system shown in Figure 3-7. As you do this, be careful not to modify the mounting of the 3.8-cm (1.5-in) bore cylinder and mechanical limit switches (LS1 and LS2).

Note that these switches are to be wired **normally closed**. In the ladder diagram of Figure 3-7 b), the side arrow on N.C. contact LS2 shows that it is being held in the open condition before the cycle starts. This is because the press cylinder [3.8-cm (1.5-in) bore], in fully retracted position, is holding mechanical limit switch LS2 activated.

> **Note:** *The Sequence Valve should still be set to 2000 kPa (290 psi) from the first part of the exercise. Continue to use this setting.*



a) Hydraulic section



b) Electrical section

Figure 3-7. Schematic diagram of an hydraulically-sequenced clamp and press system.

☐ 20. Adjust the maximum system pressure to 3000 kPa (440 psi). To do so, remove the hose connecting Pressure Gauge A to port P of the Directional Valve. Turn on the Power Unit. Turn the adjustment knob of the Relief Valve clockwise until the system pressure at Pressure Gauge A is 3000 kPa (440 psi), then turn off the Power Unit. Reconnect Pressure Gauge A to port P of the Directional Valve.

☐ 21. Turn on the Power Unit. Then, turn on the 24-V DC Power Supply.

☐ 22. Start the system by pressing pushbutton PB1 momentarily. The system should operate as follows:

- The clamp cylinder (2.5-cm/1-in bore) starts to extend first;
- When the clamp cylinder becomes extended, the press cylinder (3.8-cm/1.5-in bore) starts to extend;
- When the press cylinder becomes extended, both cylinders automatically retract;
- When both cylinders are fully retracted, they stop and wait for the operator to start a new cycle.

This cycle simulates a clamp and press system. Do you observe this?

☐ Yes ☐ No

☐ 23. Repeat step 22 several times to become familiar with the operation of a clamp and press system.

What causes the cylinders to extend when pushbutton PB1 is pressed? Explain by referring to the ladder diagram in Figure 3-7.

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☐ 24. Why does the clamp cylinder start to extend first?

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☐ 25. Does the reading of Pressure Gauge A climb to the 2000-kPa (290-psi) setting of the Sequence Valve when the clamp cylinder (2.5-cm/1-in bore) becomes fully extended? Explain why.

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☐ 26. What causes the cylinders to automatically retract when the press cylinder becomes fully extended? Explain by referring to the ladder diagram in Figure 3-7.

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☐ 27. What causes the cycle to automatically stop when the press cylinder becomes fully retracted? Explain by referring to the ladder diagram in Figure 3-7.

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☐ 28. Turn off the Power Unit. Open the Relief Valve completely by turning its adjustment knob fully counterclockwise. Turn off the 24-V DC Power Supply.

☐ 29. Disconnect and store all hoses and electrical leads. Remove and store all electrical and hydraulic components. Wipe off any hydraulic oil residue.

☐ 30. Clean up any hydraulic oil from the floor and the trainer. Properly dispose of any towels and rags used to clean up oil.

CONCLUSION

In the first part of the exercise, you tested the operation of a sequence valve. You saw that this type of valve remains closed as long as the upstream pressure is lower than the valve operating pressure. When the upstream pressure becomes higher than the operating pressure, the valve opens and the full system pressure (relief valve setting) is allowed to build downstream. This means that a sequence valve cannot be used to limit the maximum circuit pressure.

In the second part of the exercise, you tested a clamp and press system sequenced by a hydraulic sequence valve. You observed that the press cylinder only extended when the clamp cylinder had extended and the system pressure had increased enough to “crack” the sequence valve. This was not simply a delay between the two operations. No matter how slowly the clamp cylinder extended, the press cylinder could not start until the cylinder had finished its full stroke. This feature is important in clamp and work systems where the actual times involved are not so important, but where the two operations must take place in a certain order.

REVIEW QUESTIONS

1. Why are sequence valves used?

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2. What is the normal condition of a sequence valve? Explain.

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3. How is the sequence valve different from the relief valve?

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4. What is the condition required for a sequence valve to open?

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5. Why is a bypass check valve required across a sequence valve when reverse flow is required?

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