Fluid Power

Hydraulics Fundamentals

Courseware Sample

30794-F0

Order no.: 30794-00
First Edition
Revision level: 01/2015

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Printed in Canada

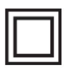
ISBN 978-2-89289-349-6 (Printed version)
ISBN 978-2-89640-651-7 (CD-ROM)
Legal Deposit – Bibliothèque et Archives nationales du Québec, 1996
Legal Deposit – Library and Archives Canada, 1996

Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

We invite readers of this manual to send us their tips, feedback and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

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Introduction

The Lab-Volt Hydraulics Training System, Model 6080, is designed to familiarize students with the fundamentals of hydraulic energy and its controlled application. It consists of an introductory and an advanced training program demonstrating manual, electrical and PLC control of hydraulic systems.

The basic trainer demonstrates the basic principles of hydraulics. It comes with a hydraulic pump, a tank, a hydraulic motor, cylinders, flow control valves, directional control valves, and pressure gauges. Also provided is a work surface consisting of a solid-metal perforated plate hinged to a drip tray. Lying flat over the drip tray, or tiltable at 45°, the work surface provides a large area on which the components can be mounted. Mounting and removal of the components is especially easy with push-lock fasteners that snap effortlessly into the perforations of the work surface.

Additional components can be added to the basic trainer to demonstrate electrical and PLC control of hydraulic systems. The additional components required for electrical control are time-delay relays, counter relays, sensors, and pilot lamps. Those required for PLC control are a programmable logic controller (PLC) and an extra work surface designed to mount on the main work surface.

The courseware is structured in four separate courses to form a complete educational program in hydraulic control:

The course entitled “Hydraulics Fundamentals” covers the theory, generation, storage, and usage of hydraulic energy. The creation of pressure by applying force to a confined liquid is discussed. The usefulness of fluid pressure and velocity is examined, and the relationship between flow rate, velocity, and power are defined. The basic types of hydraulic circuits are introduced. Finally, a methodical approach to troubleshooting is outlined, based on the first principles of hydraulics.

The course entitled “Electrical Control of Hydraulic Systems” covers basic electricity, ladder diagrams, limit switches, standard industrial relays, and solenoid-operated directional valves. Functional electrically-controlled hydraulic systems are studied, assembled, and tested. Students then use the acquired knowledge to design their own systems and to simulate the operation of typical industrial systems.

The course entitled “Hydraulics Applications - PLC” explores the use for PLCs in hydraulic systems. Students begin with a revision of the basic PLC instructions. Functional PLC-controlled hydraulic systems are then studied, assembled, and tested. Students are invited to troubleshoot an industrial-type clamp and work system based on the principles of hydraulics and PLC. Finally, students use the acquired knowledge to design their own systems to simulate the operation of typical industrial applications.

Finally, the course entitled “Hydraulics Applications - Servo-proportional Control” deals with PID control of hydraulic motor speed and cylinder position.

Courseware Outline

HYDRAULICS FUNDAMENTALS

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Ex. 3-3 Cylinders in Parallel

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Ex. 3-4 Regenerative Circuits

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HYDRAULICS FUNDAMENTALS

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Ex. 5-2 Directional Valve Testing

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ELECTRICAL CONTROL OF HYDRAULICS SYSTEMS

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Courseware Outline

HYDRAULICS APPLICATIONS – PLC

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Courseware Outline

Sample Exercise

from

Hydraulics Fundamentals

Exercise 2-1

Pressure Limitation

EXERCISE OBJECTIVE

- To introduce the operation of a pressure relief valve.
- To establish the oil flow path in a circuit using a pressure relief valve.
- To connect and operate a circuit using a pressure relief valve.

DISCUSSION

Pressure limitation

Pressure is the amount of force exerted against a given surface. **Flow** is the movement of fluid caused by a difference in pressure between two points. Fluid always flows from a higher pressure point to a lower pressure point. The city waterworks, for example, builds up a pressure greater than the atmospheric pressure in our water pipes. As a result, when we turn on a water tap, the water is forced out.

When two parallel paths of flow are available, fluid will always take the path of least resistance. An example of this in the everyday life would be a garden hose branching into two sections, as Figure 2-2 shows. One section is blocked, while the other section allows water to move freely in it. All the water will flow through the unblocked section since it is less restrictive than the blocked section. The input pressure will rise just enough for the water to flow through the unblocked section. The pressure in the blocked section will not build up beyond the level required to make the water flow in the unblocked section. The Pressure Gauges in Figure 2-2, therefore, will indicate low, equal pressures.

Pressure Limitation

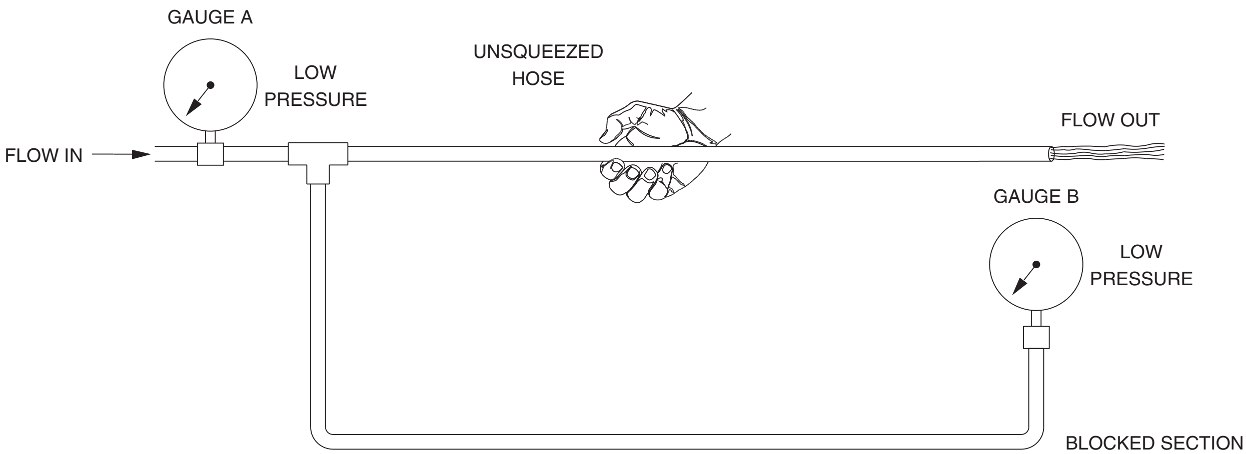

Figure 2-2. Unrestricted flow path.

Now what happens if we squeeze the unblocked section so that water is restricted but not completely confined, as Figure 2-3 shows? All the water will flow through the squeezed section since it is still less restrictive than the blocked section. The input pressure will rise to the level necessary to flow through the restricted path. The pressure in the blocked section will not build up beyond the needs of the squeezed section. The Pressure Gauges in Figure 2-3, therefore, will indicate high, equal pressures.

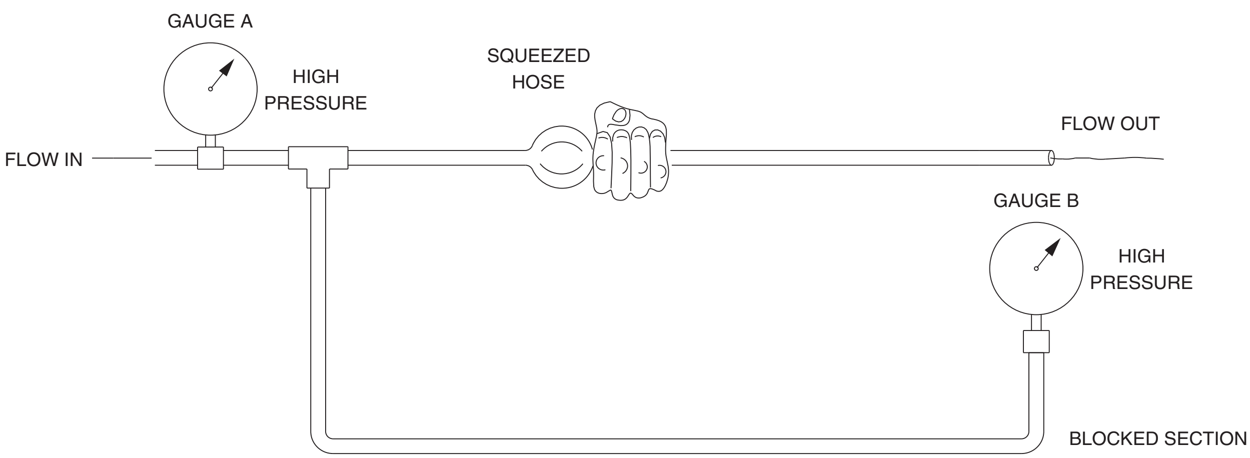

Figure 2-3. Restricted flow path.

So we see that the pressure in the blocked section can never be higher than the pressure in the unblocked section. In fact, these pressures will always be equal. If the restricted section were closed completely, confining water instead of merely restricting it, the pressure in both sections would equal the maximum pressure available at the input.

Pressure Limitation

In a hydraulic circuit, flow is produced by the action of a pump, which continuously discharges the oil at a certain flow rate. Pressure is not created by the pump itself but by **resistance** to the oil flow. When the oil is allowed to flow with no resistance through a hydraulic circuit, the pressure in that circuit is theoretically zero. When the flow is resisted, however, the circuit pressure increases to the amount necessary to take the **easier** path.

Relief Valve

Figure 2-4 shows a hydraulic circuit consisting of two parallel paths of flow. The oil from the pump can pass through a **Relief Valve** or through a hydraulic circuit consisting of a Directional Valve, Lever-Operated and a cylinder.

The Relief Valve can be compared to the hand in the hose example previously described. It limits the maximum pressure in the system by providing an alternate flow path to the reservoir whenever the oil flow to the circuit is blocked, as when the directional valve is in the blocked center position or when the cylinder is fully extended or retracted.

The Relief Valve is connected between the pump pressure line and reservoir. It is normally non-passing. It is adjusted to open at a pressure slightly higher than the circuit requirement and divert the pumped oil to the reservoir when this pressure is reached.

In Figure 2-4, for example, all the oil from the pump flows through the circuit as long as the cylinder is not fully extended because the circuit provides an easier path than the Relief Valve. While the cylinder is extending, the pressure rises only to the amount necessary to force oil on the rod side of the cylinder into the reservoir (here 700 kPa, or 100 psi).

Pressure Limitation

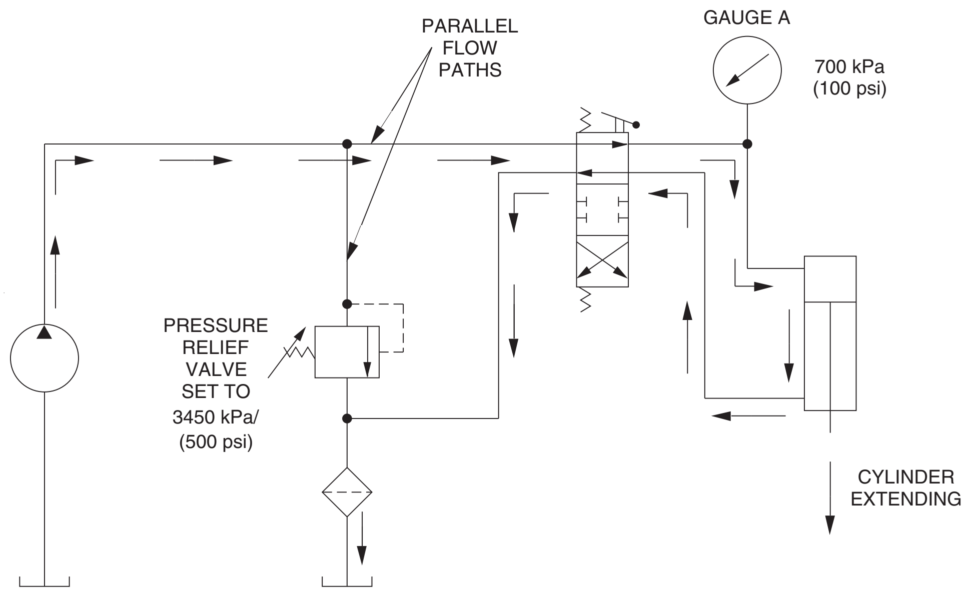

Figure 2-4. Oil flows through the circuit.

Once the cylinder is fully extended, the cylinder circuit becomes blocked and the pumped oil can no longer flow through it. The system pressure climbs to 3450 kPa (500 psi), then the Relief Valve opens and the oil is dumped back to the reservoir at the relief valve pressure setting of 3450 kPa (500 psi), as Figure 2-5 shows. Thereafter, no flow occurs throughout the circuit and the pressure is equal throughout. The circuit pressure, therefore, cannot build up beyond the relief valve pressure setting.

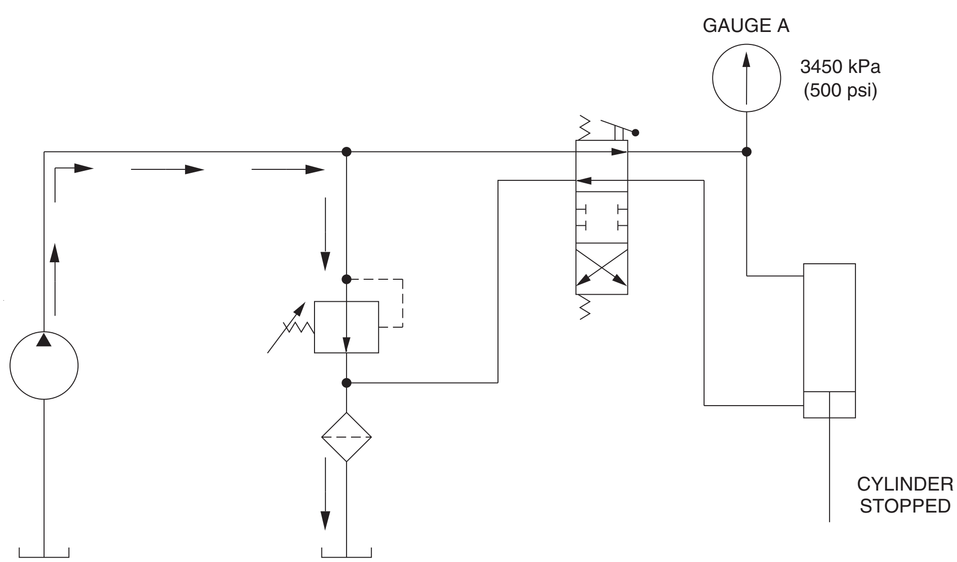

Figure 2-5. Oil flows through the Relief Valve.

Hydraulics Trainer relief valves

Your Hydraulics Trainer contains two Relief Valve s. One of these valves, called **main relief valve**, is located inside the Power Unit. The other valve, called **secondary relief valve**, is supplied with your kit of hydraulic components. The two valves are identical. However, you will operate the secondary valve only. The main valve is factory-set at a higher pressure than the secondary valve. It is used as an additional safety device for backing up the secondary valve. It should not be readjusted or tampered with.

Figure 2-6 illustrates the relief valve supplied with your kit of hydraulic components. This valve is of **pilot-operated** type. The valve body has three ports: a **pressure** (P) port, which is to be connected to the pump pressure line, a **tank** (T) port, which is to be connected to the reservoir, and a **vent** (V) port, which is used for control of the valve from a remote point by external valve. The use of the vent port will be discussed in detail in Exercise 4-4. When not used, this port should be left unconnected.

By sensing the upstream pressure on the P port of the valve, an internal spool controls the flow of oil through the valve by acting on a large spring. The pressure level where the spool is wide open and all the pumped oil passes through the valve is called **relieving pressure**, or **full-open pressure**.

The relieving pressure can be set by using the adjustment knob on the valve body. Turning the knob clockwise increases the compression of a small spring located above the valve spool, which increases the relieving pressure and allows higher pressures to build up in the circuit. Notice that the knob must first be pulled before it can be turned. When the knob is released, a spring forces the knob to engage a fixed spline. This prevents vibrations and shocks from changing the adjustment.

Pressure Limitation

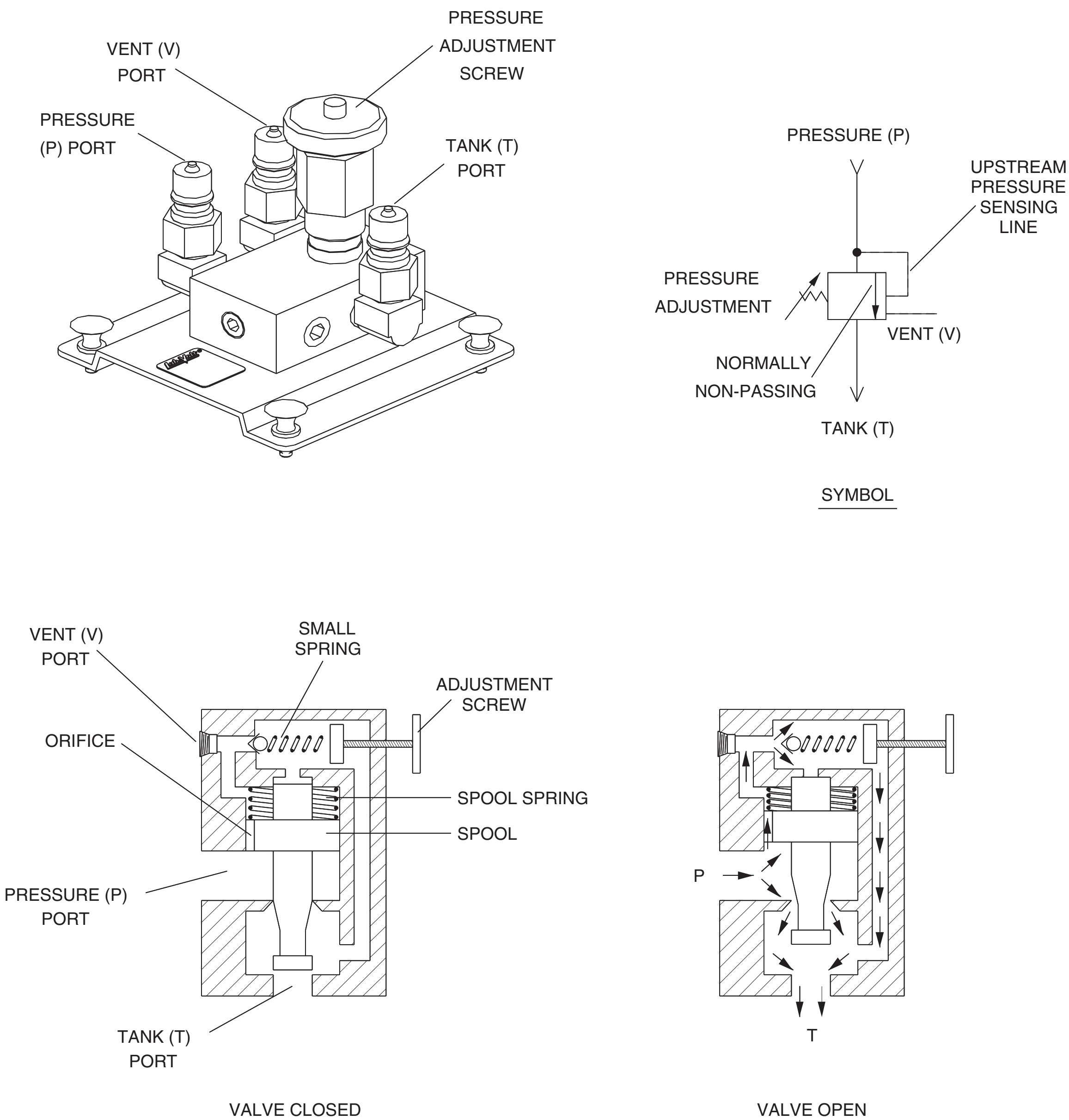

Figure 2-6. Pilot-operated Relief Valve.

The pressure at which the relief valve begins to open is called **cracking pressure**. This pressure is below the valve relieving pressure. At cracking pressure, the valve opens just enough to let the first few drops of oil through**. Pressure override** is the pressure difference between the cracking pressure and the relieving pressure.

Before turning on the Power Unit, the valve should always be **completely open** (adjustment knob turned fully counterclockwise) to allow the pump to start under the lightest load and to prevent the system components from being subjected to pressure surges. Once the Power Unit is running, the relief valve can be closed gradually until the desired pressure is reached.

REFERENCE MATERIAL

For detailed information on pilot-operated relief valves, refer to the chapter entitled *Pilot Operated Pressure Control Valve* in the Parker-Hannifin's manual *Industrial Hydraulic Technology*.

Procedure summary

In the first part of the exercise, you will measure the cracking pressure of the Relief Valve supplied with your kit of hydraulic components. You will adjust the valve relieving pressure by modifying the compression of its spring.

In the second part of the exercise, you will test the effect of pressure limitation on a basic hydraulic circuit.

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

Relief valve operation

☐ 1. Connect the circuit shown in Figure 2-7. Refer to the connection diagram shown in Figure 2-8 to make your connections.

> **Note:** *As Figure 2-7 shows, the vent (V) port of the* Relief Valve *is unused in this circuit. Therefore, leave this port unconnected.*

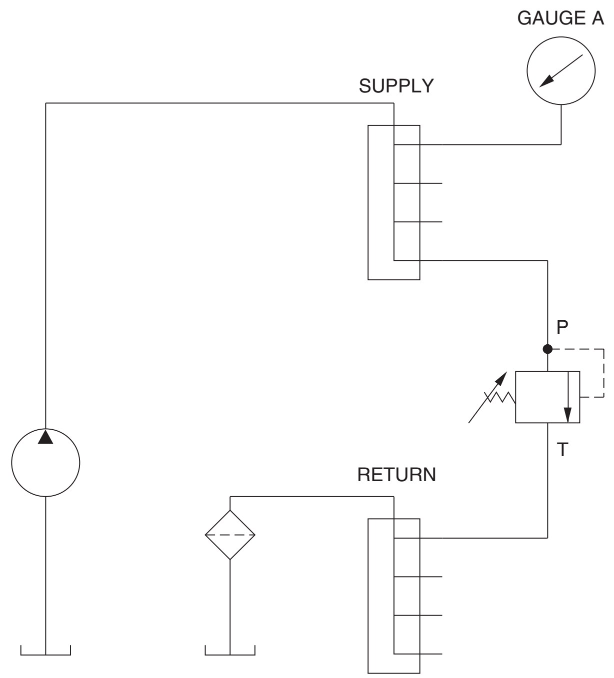

Figure 2-7. Schematic diagram of the circuit for adjusting the Relief Valve.

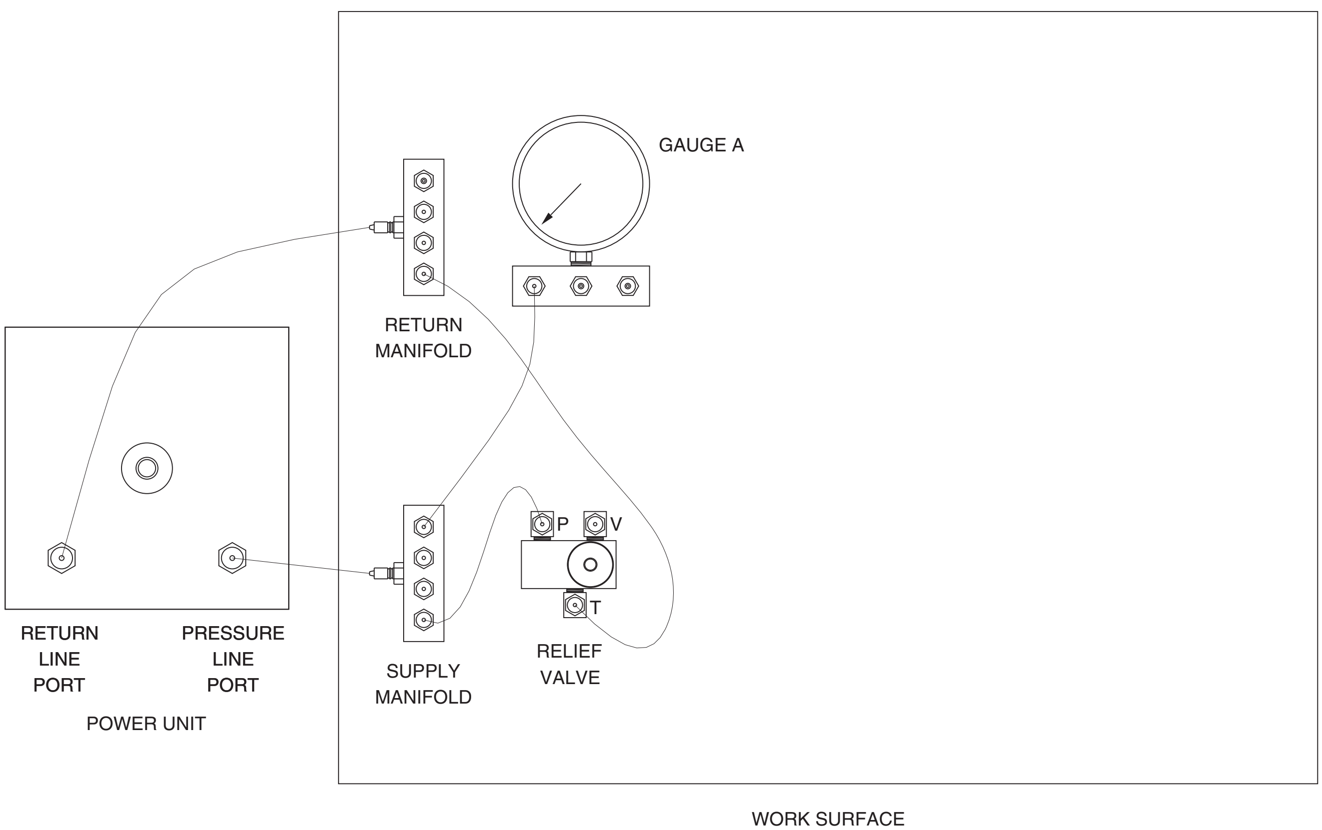

Figure 2-8. Connection diagram of the circuit for adjusting the Relief Valve.

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

a. Make sure the hoses are firmly connected.
b. Check the level of the oil in the reservoir. Add oil if required.
c. Put on safety glasses.
d. Make sure the power switch on the Power Unit is set to the OFF position.
e. Plug the Power Unit line cord into an ac outlet.
f. Open the Relief Valve **completely**. To do so, pull the valve adjustment knob and turn it fully counterclockwise.

☐ 3. Turn on the Power Unit by setting its power switch to ON. Since the oil flow is blocked at gauge A, all the pumped oil is now being forced through the Relief Valve.

The pressure reading of gauge A is the minimum pressure required to develop an oil flow through the valve. It corresponds to the pressure required to counteract the resistance of the spring inside the valve. Record below the pressure reading of gauge A.

Gauge A pressure = ______ kPa or ______ psi

Note: *The Trainer* Pressure Gauge*s provide "bar" and "psi" readings. Since bar is a metric unit of measurement for pressures, students working with S.I. units must multiply the measured pressure in bars by 100 to obtain the equivalent pressure in kilopascals (kPa).*

☐ 4. Now, compress the spring of the relief valve by turning its adjustment knob clockwise 2 turns. Use the vernier scale on the knob for the adjustment. What is the reading of gauge A?

Pressure = ______ kPa or ______ psi

☐ 5. Why does the pressure reading increase as the spring compression is increased?

____

____

☐ 6. Turn the relief valve adjustment knob fully clockwise while watching the reading of gauge A. Can the pressure level be increased beyond 6200 kPa (900 psi)? Why?

____

____

____

☐ 7. Turn off the Power Unit.

☐ 8. Given that the minimum valve pressure setting registered in step 3 approximately corresponds to the pressure override of the valve, at which pressure will the relief valve start to open if the relieving pressure is set to 3450 kPa (500 psi)?

____

Limiting system pressure

☐ 9. Modify the existing circuit in order to obtain the circuit shown in Figures 2-9 and 2-10. Make sure to mount the 3.81-cm (1.5-in) bore cylinder in a position where its rod can extend freely.

> **Note:** *For ease of connection, the Directional Valve, Lever-Operated supplied with your Hydraulics Trainer is bolted to a subplate to which the hoses can be connected. The arrangement of ports P, T, A, and B on the valve subplate does not follow the symbol for the directional valve appearing in Figure 2-9 and on the manufacturer nameplate on top of the valve. Thus, port P actually faces port B on the subplate, while port T faces port A. Therefore, always refer to the letters stamped on the valve subplate when connecting the valve into a circuit.*

Pressure Limitation

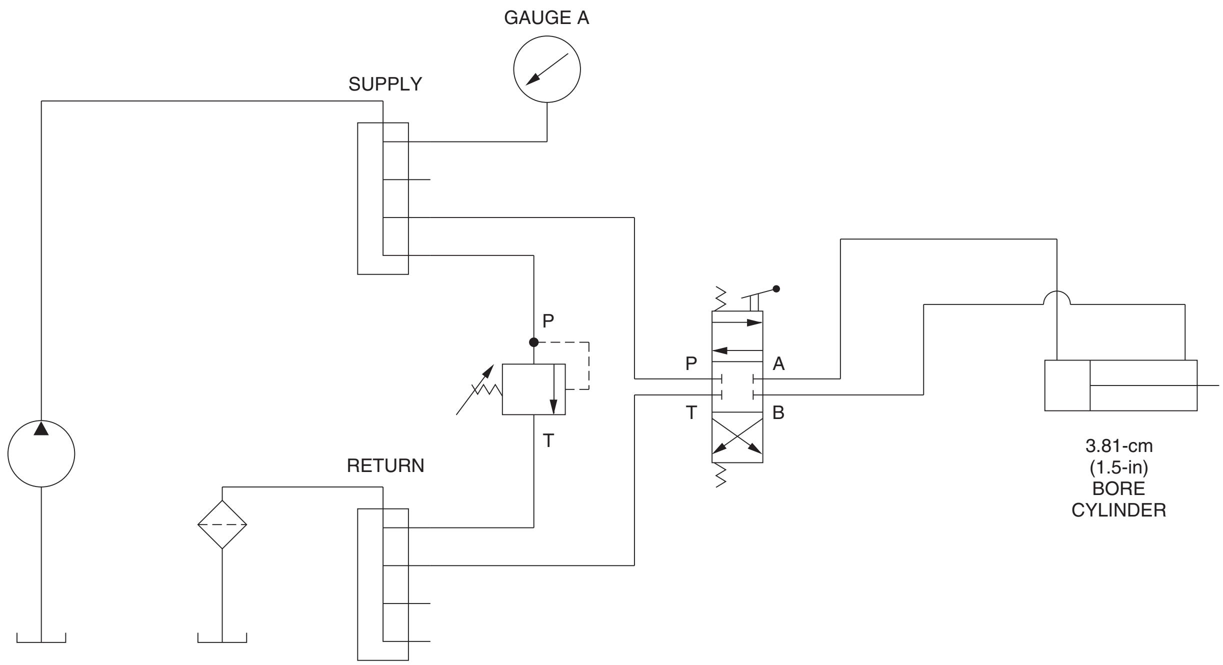

Figure 2-9. Schematic diagram of the cylinder actuation circuit.

☐ 10. Make sure the hoses are firmly connected. Open the relief valve completely by turning its adjustment knob fully counterclockwise.

☐ 11. Turn on the Power Unit.

☐ 12. Turn the relief valve adjustment knob clockwise until gauge A reads 1400 kPa (200 psi).

☐ 13. Stay clear of the cylinder rod. Move the lever of the Directional Valve, Lever-Operated toward the valve body, which should extend the cylinder rod. Then, move the lever outward from the valve body, which should retract the rod.

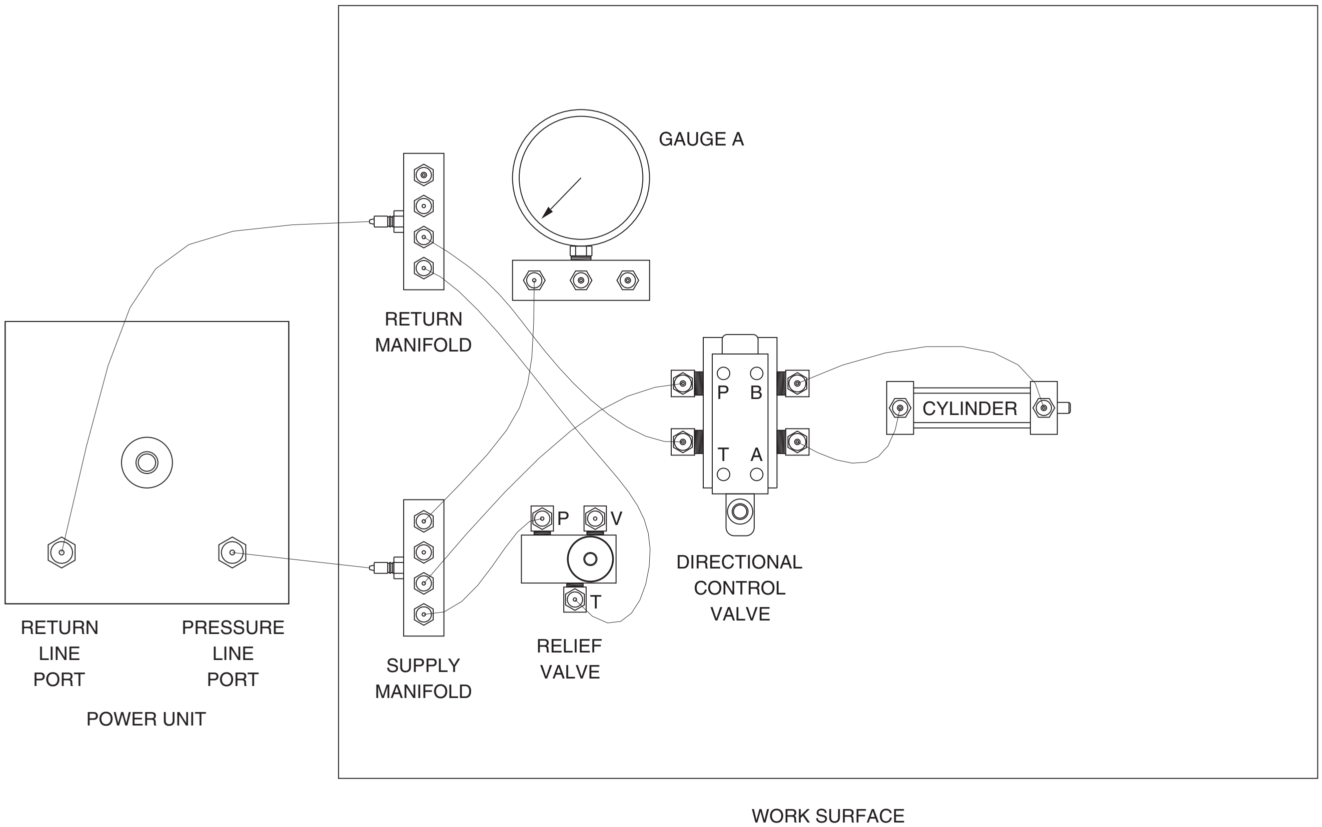

Figure 2-10. Connection diagram of the cylinder actuation circuit.

☐ 14. While watching the reading of gauge A, move the lever of the directional valve toward the valve body to extend the cylinder rod. What is the pressure at gauge A during the extension stroke of the rod?

Pressure = ______ kPa or ______ psi

☐ 15. What is the pressure at gauge A when the cylinder is fully extended?

Pressure = ______ kPa or ______ psi

☐ 16. Move the lever of the directional valve outward from the valve body to retract the cylinder rod.

☐ 17. Turn the relief valve adjustment knob clockwise until gauge A reads 2100 kPa (300 psi).

☐ 18. While watching the reading of gauge A, move the lever of the directional valve toward the valve body to extend the cylinder rod. What is the pressure at gauge A during the extension stroke of the cylinder rod?

Pressure = ______ kPa or ______ psi

☐ 19. What is the pressure at gauge A when the cylinder rod is fully extended?

Pressure = ______ kPa or ______ psi

☐ 20. Move the lever of the directional valve outward from the valve body to retract the cylinder rod.

☐ 21. Turn off the Power Unit. Open the relief valve completely by turning its adjustment knob fully counterclockwise.

☐ 22. Explain the reason for the nearly identical pressures registered during cylinder extension at the two relief valve pressure settings.

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☐ 23. Why does the circuit pressure increase when the cylinder rod is fully extended?

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☐ 24. Disconnect all hoses. It may be necessary to move the directional valve lever back and forth to relieve static pressure; the quick connects can then be removed. Wipe off any hydraulic oil residue.

☐ 25. Remove all components from the work surface and wipe off any hydraulic oil residue. Return all components to their storage location.

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

CONCLUSION

In the first part of the exercise, you measured the minimum pressure setting of a Relief Valve by connecting the valve between the pump pressure line and reservoir and by opening the valve completely.

You then modified the valve relieving pressure by increasing the compression of its internal spring, which increased the circuit pressure.

In the second part of the exercise, you tested the effect of pressure limitation on a basic hydraulic circuit. You learned that pressure changes depend on the movement of oil through the circuit. When the cylinder rod extends or retracts, the circuit pressure rises only to the amount required to force oil out of the cylinder back into the reservoir. When the cylinder rod becomes fully extended or retracted, however, the circuit pressure rises to the relief valve pressure setting.

Up to that point, we have seen that pilot-operated relief valves provide pressure control by sensing pressure upstream on their input line. Pilot-operated relief valves can also sense pressure in another part of the system or even in a remote system by means of a vent line. This type of operation is identified as remote control and is achieved through the use of the relief valve vent port. Remote control of a relief valve will be described in detail in Exercise 4-4.

REVIEW QUESTIONS

1. What is the purpose of a Relief Valve?

   ____

2. Explain the difference between the main relief valve in the Power Unit and the relief valve supplied with your kit of hydraulic components (secondary relief valve)?

   ____

   ____

   ____

   ____

3. What type of Relief Valve is used in your Hydraulics Trainer?

   ____

Pressure Limitation

4. What might happen to a hydraulic system if the tank port of the Relief Valve is not connected to the Power Unit return line port?

____

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____

5. Define the term *cracking pressure*.

____

____

6. In the circuit of Figure 2-11, what will be the pressure reading of gauge A during cylinder extension and when the cylinder is fully extended if the relief valve pressure setting is changed from 3400 kPa (500 psi) to 6900 kPa (1000 psi)?

   Note: *The pressure required to extend the cylinder rod is 600 kPa (85 psi).*

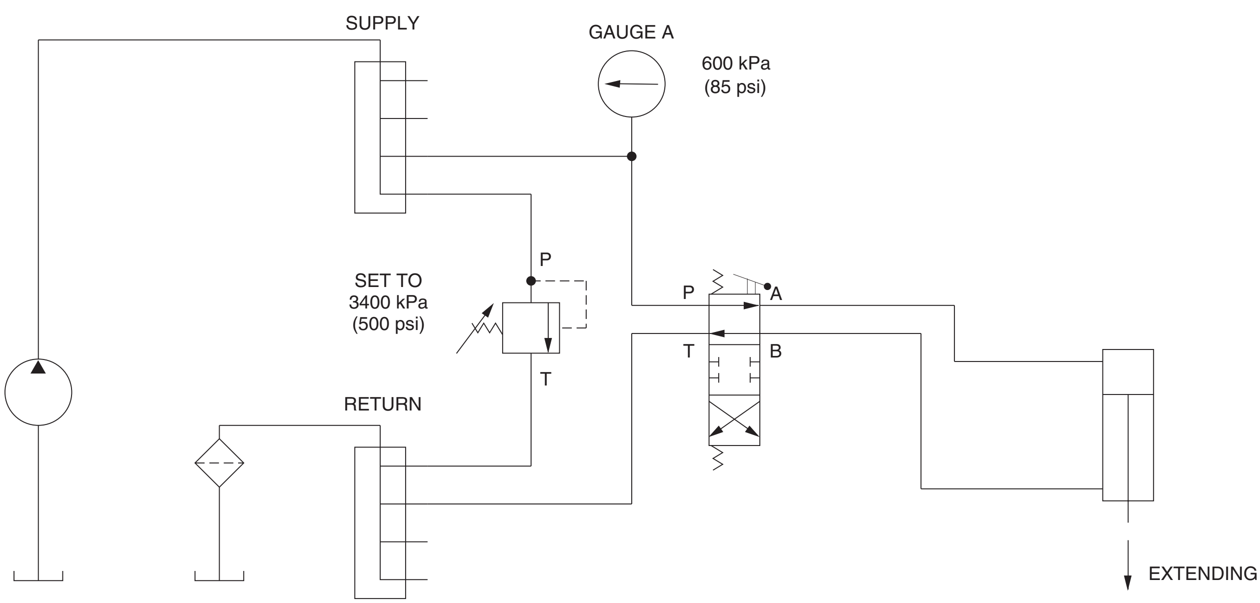

Figure 2-11. Circuit for review question 6.

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Sample Exercise

from

Electrical Control

of Hydraulic Systems

Exercise 2-3

Basic Electrically-Controlled Hydraulic System

EXERCISE OBJECTIVE

- To describe the function and operation of a magnetic proximity switch;
- To describe the purpose of a holding relay contact;
- To assemble and test a one-cycle reciprocation system.

DISCUSSION

Reciprocation of cylinders

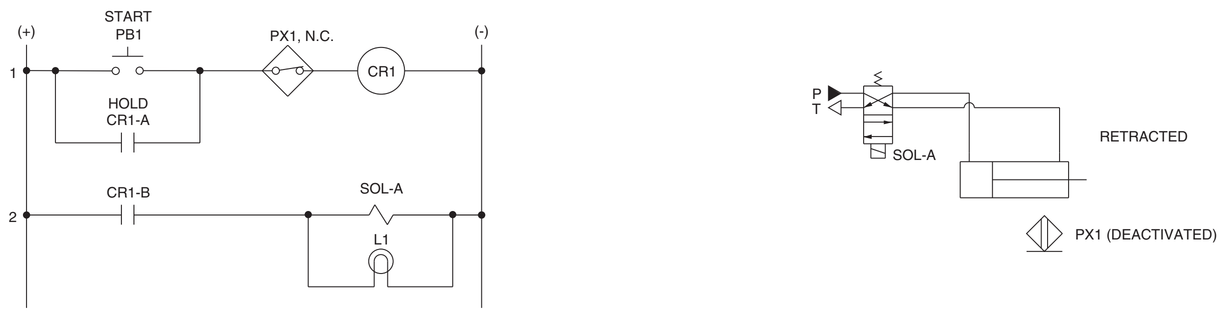
Many industrial applications require that a hydraulic cylinder be extended and retracted automatically after an operator presses a START pushbutton. This is called **reciprocation** of a cylinder, and an electrical control circuit can be used to perform this sequence. While the cylinder provides the muscles, or power, to do work, the electrical control circuit provides fast and accurate control of a directional valve to reciprocate the cylinder.

Reciprocation involves a change in the direction of the cylinder. Automatic reversal is achieved by using the electrical signal provided by a **sensing device**, such as a magnetic proximity switch, mechanical limit switch, or photoelectric switch, to shift the directional valve when the cylinder becomes fully extended or retracted.

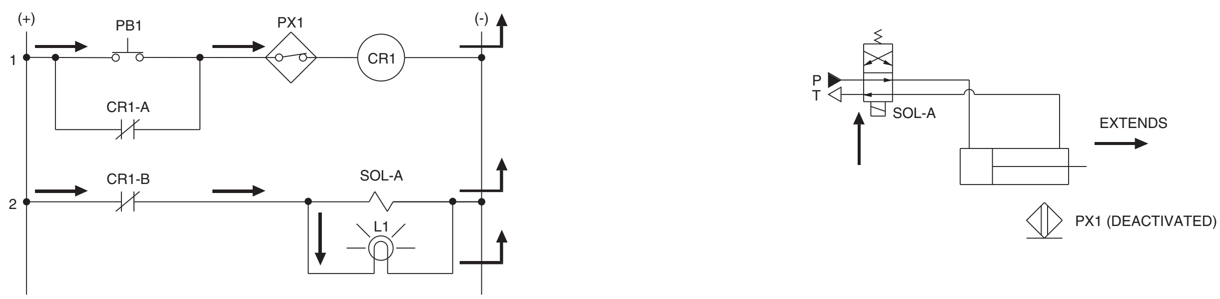
One-cycle reciprocation system

As an example, Figure 2-16 shows a ladder diagram providing one-cycle reciprocation of a hydraulic cylinder. One-cycle reciprocation means that when started by an operator, the cylinder rod extends fully, automatically retracts without attention of the operator, and stops, which makes a complete cycle.

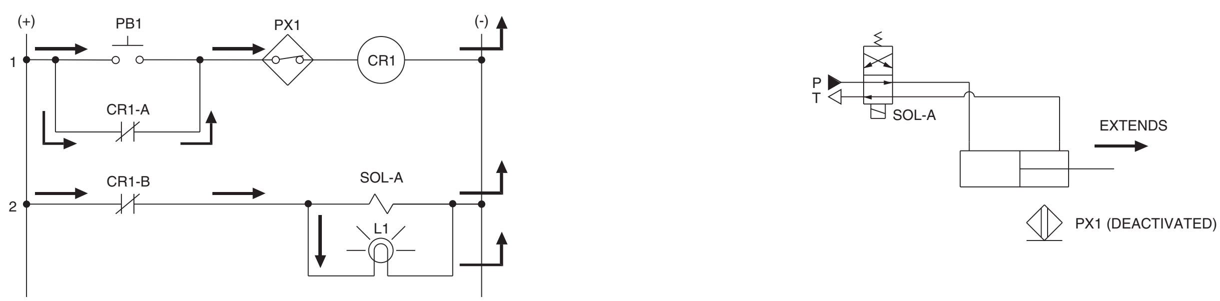
Automatic retraction is achieved with a solenoid-operated directional valve activated by a magnetic proximity switch, PX1, placed at the end of the extension stroke. The switch contact is normally closed (N.C.) in the deactivated condition.



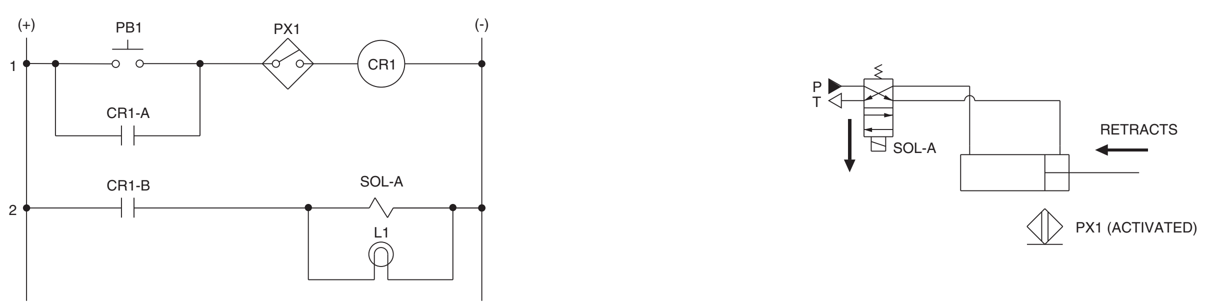
a) Initially, the cylinder rod is retracted.



b) Pressing a pushbutton starts cylinder extension.



c) The cylinder continues to extend after the pushbutton is released.



d) Retraction is automatic when the rod activates a magnetic proximity switch.

Figure 2-16. One-cycle reciprocation of a cylinder.

a. In the normal condition of the system, the cylinder rod is retracted, as illustrated in Figure 2-16 a). Relay coil CR1 is deactivated because an open circuit condition exists on ladder rung 1 by the open condition of N.O. contacts PB1 and CR1-A. Therefore, directional valve solenoid SOL-A is de-energized and the valve is in the crossed-arrows condition.

b. When pushbutton PB1 is pressed, as illustrated in Figure 2-16 b), the current flows from the + terminal of the power supply, through contacts PB1 and PX1 in rung 1, to energize relay coil CR1. This closes relay contacts CR1-A and CR1-B. Contact CR1-B in rung 2 causes solenoid SOL-A and lamp L1 to energize. This causes the directional valve to shift to the straight-arrows position and extend the cylinder rod. Contact CR1-A in rung 1 provides another path in parallel with contact PB1 for the current to flow to relay coil CR1, and is called a **holding**, or **seal-in** contact.

c. When pushbutton PB1 is released, as illustrated in Figure 2-16 c), the current continues to flow to relay coil CR1 through the alternate path provided by holding contact CR1-A being closed. Therefore, solenoid SOL-A stays energized and the cylinder rod continues to extend to full stroke.

d. When the cylinder rod becomes fully extended, magnetic proximity switch LS1 is activated by the magnetic piston inside the cylinder. This is illustrated in Figure 2-16 d). This opens N.C. contact PX1 in rung 1, de-energizing relay coil CR1. This causes relay contact CR1-B in rung 2 to open, de-energizing solenoid SOL-A and lamp L1. This causes the directional valve to return to the crossed-arrows condition and retract the cylinder. When the cylinder rod is fully retracted, it stops and waits for the operator to start another cycle.

Magnetic proximity switches

In the circuit described above, automatic reversal of the cylinder is achieved by using the electrical signal provided by a magnetic proximity switch to shift a directional valve when the cylinder rod becomes fully extended. Magnetic proximity switches are widely used in industrial hydraulic systems to sense the position of a cylinder piston. They can be easily and quickly mounted anywhere within the piston travel range.

Your Hydraulics Trainer comes with **two** magnetic proximity switches of the **Reed** type. As Figure 2-17 shows, each switch consists of two mechanical reeds (contact points) that open and close by touching and separating, and of an internal relay coil controlling a set of N.O. and N.C. contacts of the single-pole, double-throw (SPDT) type. The + and – terminals on top of the switch are to be connected to a 24-V dc power supply. The three other terminals provide access to the SPDT contacts.

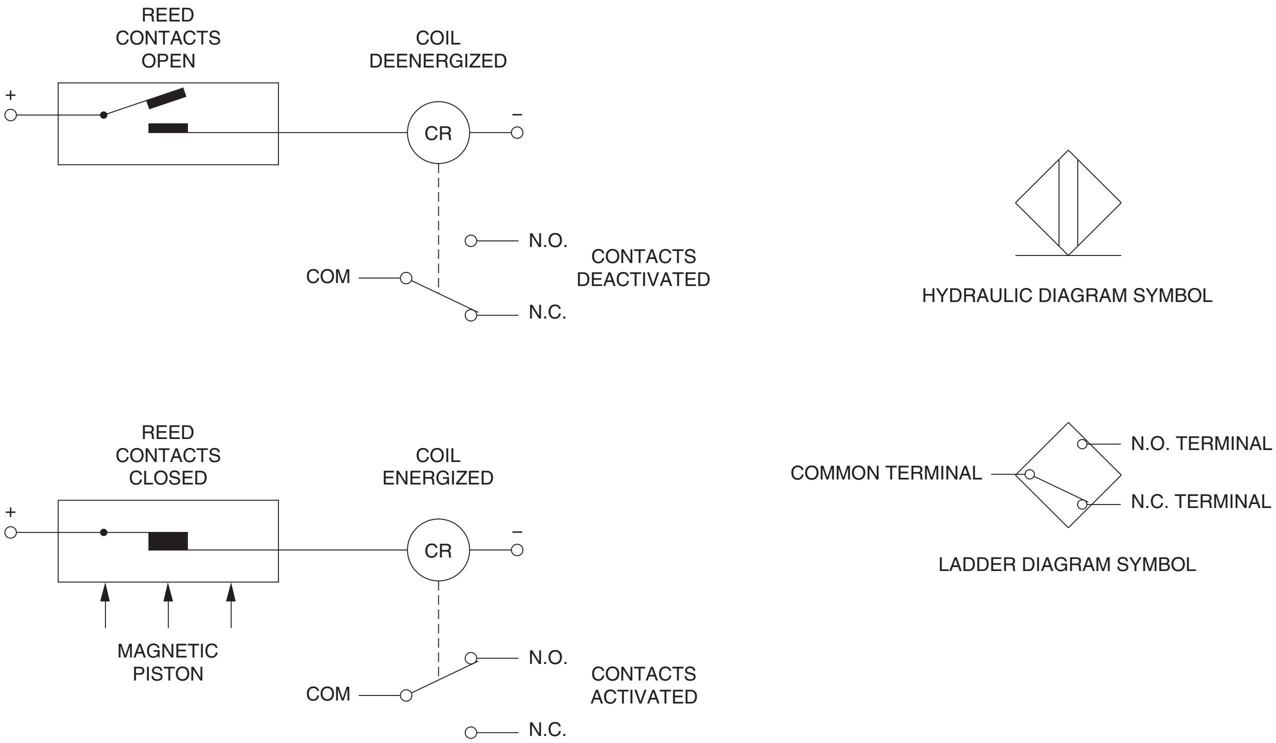


Figure 2-17. Magnetic proximity switch of the Reed type with SPDT contacts.

When the magnetic piston of a cylinder comes within proximity of the switch, the magnetic field pulls the switch reeds together, allowing the current to flow from the + terminal of the switch to energize the internal relay coil. This causes the switch SPDT contacts to activate. The N.O. contact goes closed while the N.C. contact goes open.

When the magnetic piston moves away from the switch, the switch reeds separate again, de-energizing the relay coil. This causes the switch contacts to return to their normal, deactivated state.

Procedure summary

In this exercise, you will assemble and test the one-cycle reciprocation system described in the DISCUSSION section of the exercise.

– In the first part of the exercise, you will clamp the 3.8-cm (1.5-in) bore cylinder to the work surface and mount a magnetic proximity switch at the end of its extension stroke. Then you will assemble the circuit.

– In the second part of the exercise, you will verify that the electrical control circuit operates properly. The purpose of this verification is to isolate problems such as wiring errors in a systematic, controlled manner before turning on the hydraulic power unit. Verification of the electrical control circuit is particularly important when working on electrically-controlled hydraulic systems because the functions being performed by this circuit may not be readily apparent to the operator, and unpredictable cylinder motion may occur at anytime.

– In the third part of the exercise, you will test system operation.

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

Setting up the system

☐ 1. Get the 3.8-cm (1.5-in) bore cylinder from your storage location. Clamp the cylinder to the work surface. Connect the two ports of the cylinder to the power unit return line port through a manifold.

☐ 2. Get a magnetic proximity switch from your storage location. Mount the switch on the 3.8-cm (1.5-in) bore cylinder so that the switch is activated when the cylinder rod is fully extended. To so do, perform the following steps:

– Manually retract the cylinder rod completely.

– Loosen the set screw on the magnetic switch until the clamp is loose enough to slip over the cylinder tie rod. Position the switch at the rod end of the cylinder, then tighten the set screw.

– Connect the circuit shown in Figure 2-18. Notice that the magnetic switch, PX1, is to be wired normally open. Also, notice that the switch + and – terminals are to be connected to the corresponding terminals of the 24-V dc power supply.

– Turn on the 24-V dc power supply. Pilot lamp L1 should be off, indicating that the magnetic switch is deactivated.

– Manually extend the cylinder rod completely. Pilot lamp L1 should now be on, indicating that the magnetic switch is activated. If L1 is off, loosen the set screw on the switch and reposition the switch until L1 turns on. Then, tighten the set screw.

– When you have finished, retract the cylinder rod completely. Turn off the 24-V dc power supply.

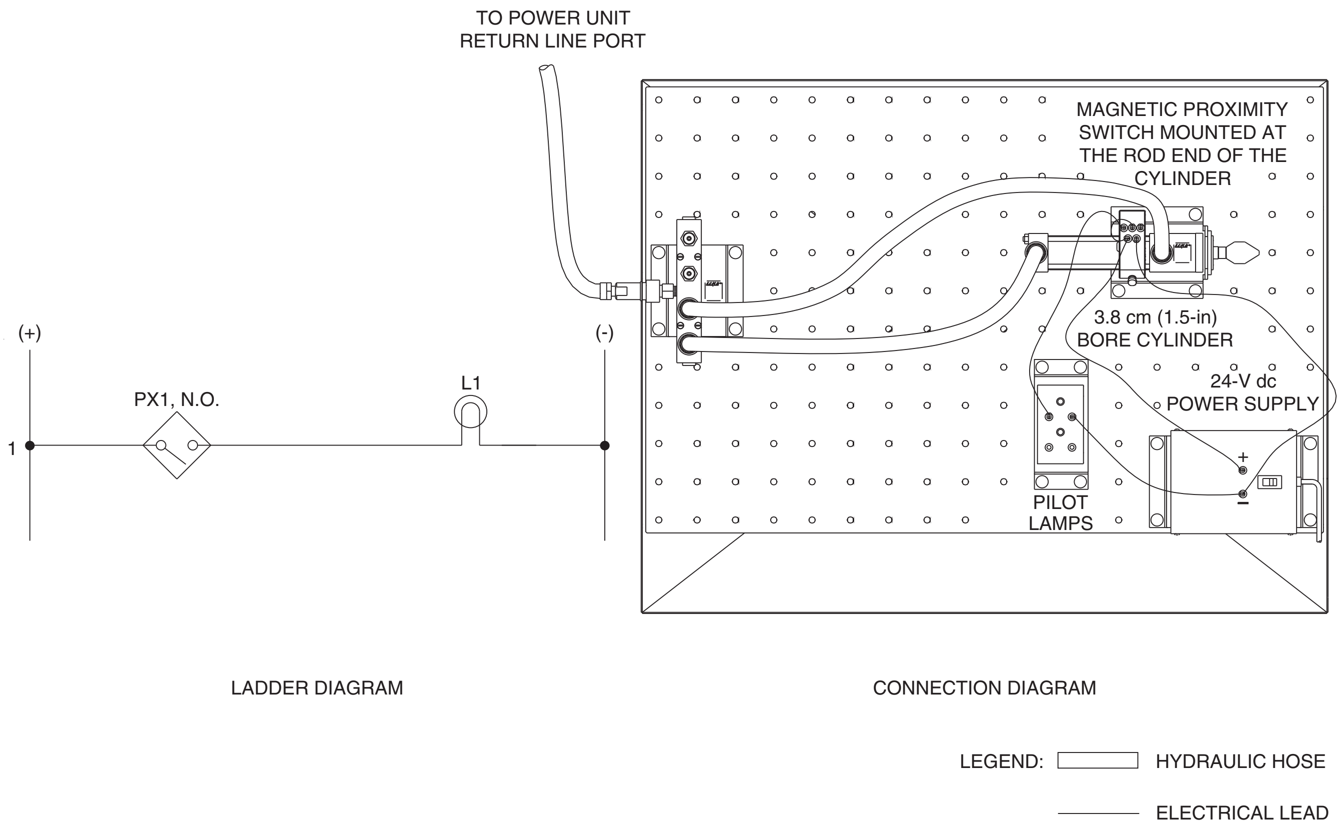
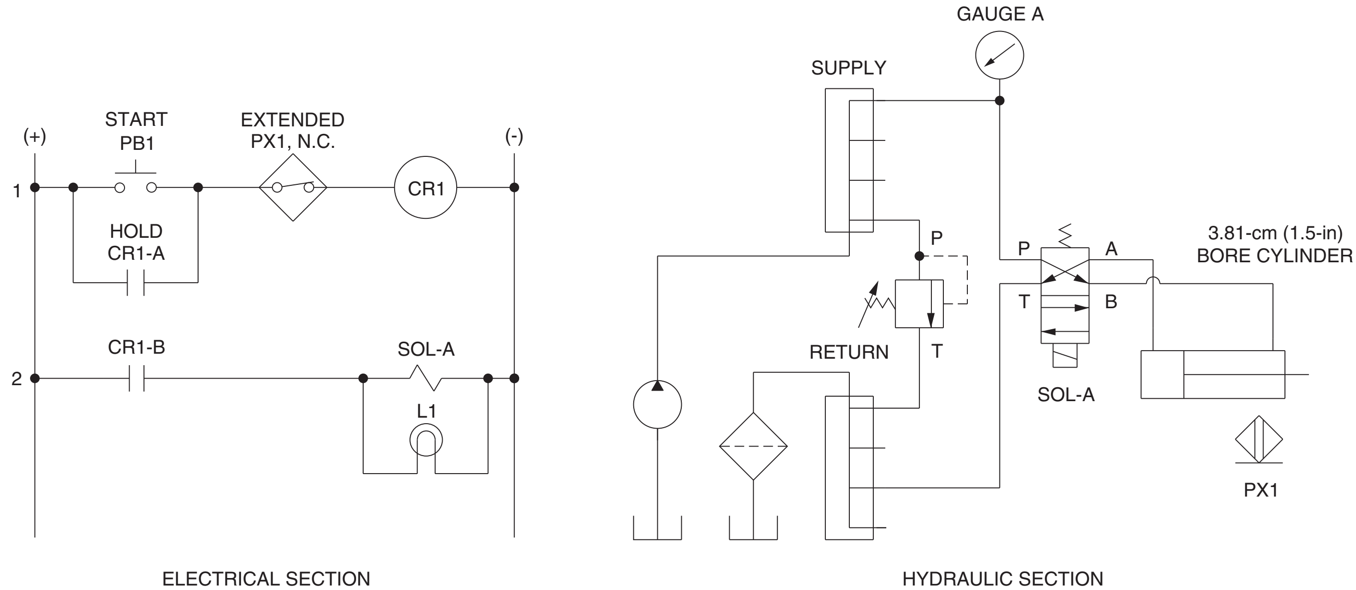


Figure 2-18. Mounting a magnetic proximity switch at the rod end of the 3.8-cm (1.5-in) bore cylinder.

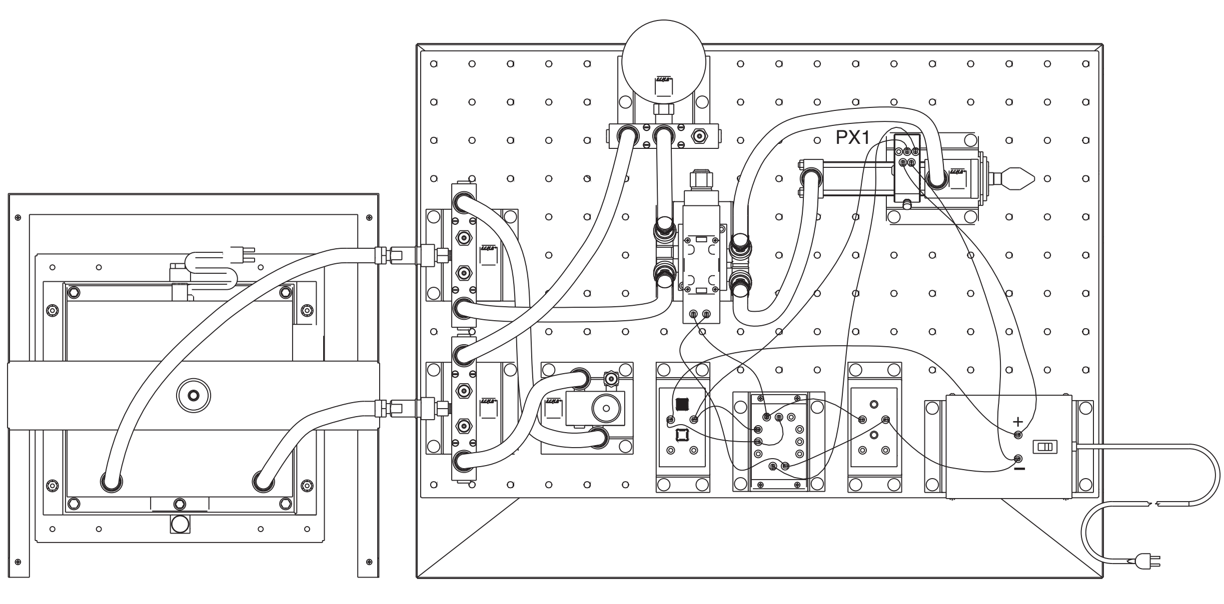
☐ 3. Disconnect and store all hoses and electrical leads.

☐ 4. Connect the one-cycle reciprocation system shown in Figure 2-19. As you do this, be careful not to modify the mounting of the cylinder and magnetic switch (PX1). Notice that PX1 is now to be wired normally closed. The + and – terminals of this switch are to be connected to the corresponding terminals of the 24-V dc power supply.

> **Note:** *The directional valve solenoid is not polarized, which means that it does not matter which solenoid terminal is connected to relay contact CR1-B and which solenoid terminal is connected to the – terminal of the 24-V dc power supply. Either way, the solenoid will still energize and shift the valve spool.*



a) Schematic diagram



b) Connection diagram

LEGEND: HYDRAULIC HOSE

ELECTRICAL LEAD

Figure 2-19. Schematic diagram of a one-cycle reciprocation system.

Testing the electrical control circuit

☐ 5. Turn on the 24-V dc power supply. **Do not** turn on the hydraulic power unit yet.

☐ 6. Momentarily press pushbutton PB1. If the circuit is working, pilot lamp L1 should turn on to indicate that directional valve solenoid SOL-A is energized. Is this your observation?

☐ Yes ☐ No

☐ 7. Verify that directional valve solenoid SOL-A is energized. Get your multimeter from its storage location and set it to read dc volts. Connect the multimeter probes across the + and − terminals of the solenoid. The voltage reading on the multimeter should be about 24 V, indicating that the solenoid is energized. Does the multimeter read 24?

☐ Yes ☐ No

☐ 8. Leave the multimeter probes connected across the solenoid. Turn off the 24-V dc power supply. Remove the electrical wire connecting N.C. switch contact PX1 to the + side of relay coil CR1. This will simulate activation of magnetic switch PX1. Turn on the power supply. You should observe that lamp L1 is off and that the voltage across the solenoid is about 0 V. Is lamp L1 off and voltage reading 0 V?

☐ Yes ☐ No

☐ 9. When all the above conditions are met, the electrical control circuit is operational. Turn off the 24-V dc power supply. Reconnect N.C. switch contact PX1 to the + side of relay coil CR1, as Figure 2-19 shows. Turn on the 24-V dc power supply, then proceed to the next part of the exercise.

CAUTION!

Do not proceed with the exercise if any of the above requirements are not met. Instead turn off the 24-V dc power supply and check the circuit connections. Modify the circuit connections as required, then turn on the power supply and test circuit operation.

Testing the one-cycle reciprocation system

☐ 10. Before starting the hydraulic 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. Make sure the power switch on the power unit is set to the OFF position. Plug the power unit line cord into an ac outlet.
e. Open the pressure relief valve completely by turning its adjustment knob fully counterclockwise.

CAUTION!

Ensure that the electrical leads and components are not placed in a position where they may become wedged or confined between rigid parts of the trainer when the cylinder rod extends. Damage to the operator and the trainer could result.

☐ 11. Turn on the hydraulic power unit.

☐ 12. With the directional valve solenoid de-energized, the valve is in the crossed-arrows condition and the oil from the pump is directed to the rod end of the cylinder. Since, however, the cylinder rod is fully retracted, the pumped oil is blocked at the cylinder piston and is now being forced through the pressure relief valve. Adjust the relief valve adjustment knob so that the system pressure at gauge A is 1400 kPa (200 psi).

☐ 13. Start the cylinder cycle by momentarily pressing pushbutton PB1. Record below what the cylinder rod does.

____

____

____

☐ 14. Does the cylinder rod cycle more than one time or does it stop after one cycle?

____

☐ 15. Start another cycle by momentarily pressing PB1. Is retraction automatic when the cylinder rod becomes fully extended? Why? Explain by referring to the ladder diagram in the electrical section of Figure 2-19.

____

____

____

☐ 16. Start another cycle by momentarily pressing PB1. Does the cylinder continue to extend when you release PB1? Why? Explain by referring to the ladder diagram in the electrical section of Figure 2-19.

____

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____

☐ 17. What would happen to circuit operation if relay contact CR1-A in rung 1 were removed? Would you still be able to extend the cylinder? Explain.

____

____

____

☐ 18. Turn off the power unit. Open the pressure relief valve completely by turning its adjustment knob fully counterclockwise.

☐ 19. Turn off the 24-V dc power supply and the multimeter.

☐ 20. Disconnect and store all hoses and electrical leads. Wipe off any hydraulic oil residue.

☐ 21. Remove and store all electrical and hydraulic components. Wipe off any hydraulic oil residue.

☐ 22. 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 this exercise, you tested the operation of a one-cycle reciprocation system. You saw that a cylinder can be made to retract automatically by using a magnetic proximity switch. You learned that a relay contact can be used to maintain a closed circuit to an output load, allowing a pushbutton to act as a maintained contact switch.

You also learned that it is a good practice to test the electrical control circuit before putting the whole system into operation. This is particularly important when working on electrically-controlled hydraulic systems because the functions being performed by a control circuit may not be readily apparent to the operator, and unpredictable motion may occur at any time.

REVIEW QUESTIONS

1. What is meant by “one-cycle reciprocation”?

2. What is the purpose of a magnetic proximity switch in a one-cycle reciprocation system?

3. In the ladder diagram of Figure 2-19, what is the purpose of holding contact CR1-A in ladder rung 1? Explain.

4. What will the cylinder rod do in the system of Figure 2-19 if N.C. contact PX1 in ladder rung 1 is changed for a N.O. contact? Explain.

5. What will the cylinder rod do in the system of Figure 2-19 if N.O. contact CR1-B in ladder rung 2 is changed for a N.C. contact? Explain.

Sample Exercise

from

Hydraulics Applications – PLC

Exercise 6

Counting of Hydraulic Actuator Cycles

EXERCISE OBJECTIVE

- To connect and test a PLC-controlled hydraulic system that makes a motor rotate 1000 turns and then reciprocates a cylinder 10 times.

DISCUSSION

Counting of hydraulic actuator cycles is required when a portion of the system must be activated or deactivated after an actuator has made a definite number of cycles. A typical application is an automated packing machine that stacks and counts production items into groups. The usual method is for a cylinder to continuously extend and retract, picking and stacking one item on each cycle, and for a counter to count the number of cycles which have been made by the cylinder. When the required count is reached, a switching signal causes another cylinder to push the stack away.

Counting of hydraulic actuator cycles is also required for machine maintenance scheduling. The PLC keeps track of when each machine part should be replaced based on the number of items it manufactures.

The PLC counter instructions are ideally suited to count the number of cycles made by an actuator. They allow monitoring automatic production machines at higher efficiency rates.

Procedure summary

In this exercise, you will connect a PLC-controlled hydraulic system that makes a motor rotate 1000 turns and then reciprocates a cylinder 10 times.

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

☐ 1. Get the hydraulic motor and flywheel from their storage location. Install the flywheel onto the shaft of the motor and tighten the set screw. Make sure the set screw is completely screwed into its hole.

CAUTION!

Make absolutely certain the flywheel is firmly secured to the motor shaft.

☐ 2. Get the photoelectric switch from your storage location and clamp it to the work surface. Place the hydraulic motor in front of the photoelectric switch at a distance of 10 cm/4 in (2 rows of perforations) from it, aligning the motor axis with the beam of the switch. Clamp the motor into place.

☐ 3. Connect the PLC-controlled hydraulic system shown in Figure 6-1. Mount magnetic proximity switches PX1 and PX2 so that they are activated when the cylinder rod is fully extended and fully retracted, as Figure 6-1 a) shows.

Counting of Hydraulic Actuator Cycles

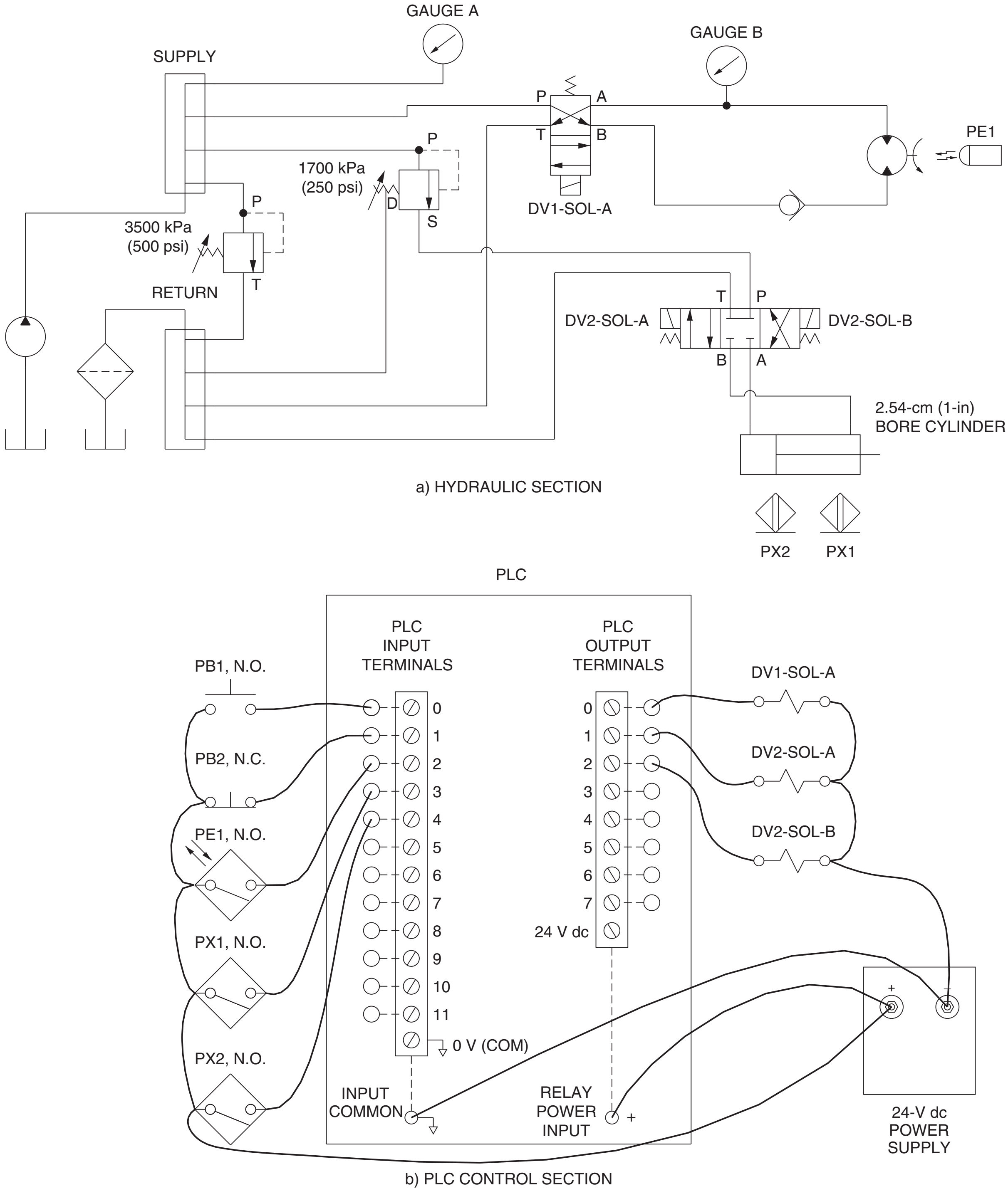

Figure 6-1. PLC-controlled hydraulic system to connect.

☐ 4. Enter the PLC ladder program in Figure 6-2.

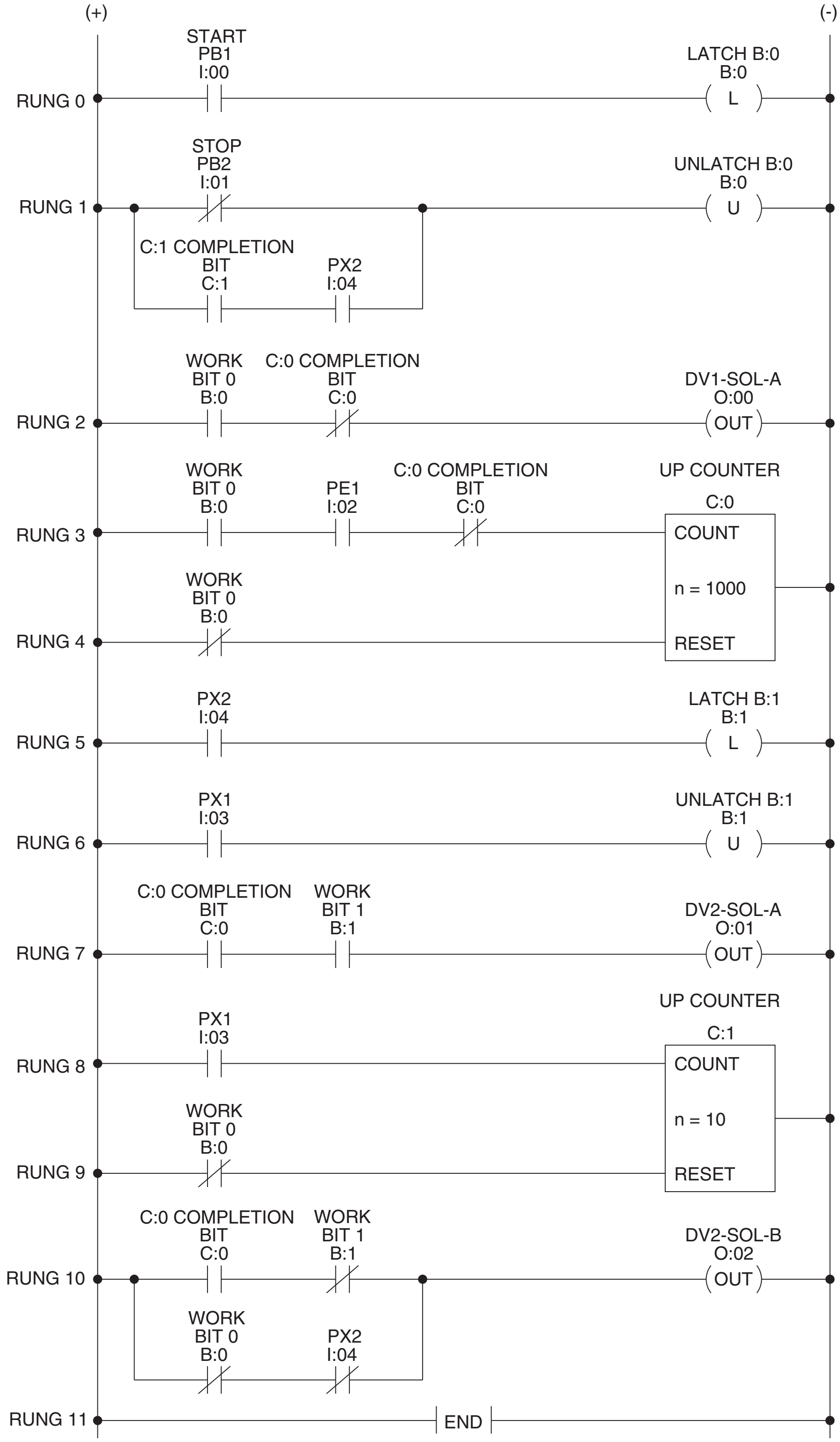

Figure 6-2. PLC ladder program used to make a motor rotate 1000 turns and then reciprocate a cylinder 10 times.

☐ 5. Before starting the hydraulic 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 pressure relief valve completely by turning its adjustment knob fully counterclockwise.

CAUTION!

Ensure that the electrical leads and components are not placed in a position where they may become wedged or confined between rigid parts of the trainer when the cylinder rod extends or the motor rotates. Damage to the trainer could result.

☐ 6. Close the sequence valve completely.

☐ 7. Turn on the hydraulic power unit. Then, turn on the 24-V dc power supply.

☐ 8. Adjust the maximum system pressure to 3500 kPa (500 psi).

☐ 9. Adjust the sequence valve operating pressure to 1700 kPa (250 psi).

☐ 10. Test the operation of the system, using the following verification steps:

a. Momentarily press the START pushbutton, PB1. The motor should start rotating, while the cylinder rod should remain immobile.
b. Monitor PLC counter instruction C:0 on ladder rung 3. When the counter accumulated value reaches 1000, the motor should stop, while the cylinder rod should start to reciprocate (extend and retract).
c. When the cylinder rod has reciprocated 10 times, it should stop in the fully retracted position, allowing a new cycle to be initiated.

Do not proceed with the exercise if any of the above conditions was not met. Instead check the circuit connections and the PLC program. Perform the required modifications, then verify that the system operates correctly.

☐ 11. Cycle the system a few times and monitor the PLC program as it is executed. What causes the motor to start rotating when PB1 is pressed? Explain by referring to the PLC ladder program in Figure 6-2.

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☐ 12. What causes counter instruction C:0 on rung 3 to increment its accumulated value when the motor rotates? Explain.

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☐ 13. What causes the motor to stop and the cylinder rod to start reciprocating when the accumulated value of counter instruction C:0 reaches 1000? Explain.

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☐ 14. What causes counter instruction C:1 on rung 8 to increment its accumulated value every time the cylinder rod becomes fully extended?

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☐ 15. What causes the cylinder rod to stop in the fully retracted position after it has reciprocated 10 times? Explain.

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☐ 16. Start the system by pressing PB1, then press PB2 while the motor is rotating. Does the motor stop immediately when PB2 is pressed? Why?

____

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☐ 17. Start the system by pressing PB1, then press PB2 while the cylinder rod is extending and in mid-stroke. Does the rod return to the HOME (fully retracted) position before it stops? Why?

____

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☐ 18. Draw in Figure 6-3 the timing diagram of the system.

Figure 6-3. Timing diagram for the PLC-controlled hydraulic system.

☐ 19. Modify your PLC program so that the system will operate as follows:

– Pressing the START pushbutton causes the cylinder rod to start reciprocating, while the motor remains stopped.
– When the rod has reciprocated 10 times, it stops, while the motor starts to rotate.
– When the motor has rotated 1000 turns, it stops and the system becomes ready for a new cycle.

Draw the modified program in Figure 6-4. Enter your program and test system operation.

☐ 20. When you have finished, turn off the hydraulic power unit, the PLC, and the 24-V dc power supply. Turn off the host computer, if any.

☐ 21. Disconnect all hydraulic hoses and electrical leads. Remove all components from the work surface. Return all hoses, leads, and components to their storage location.

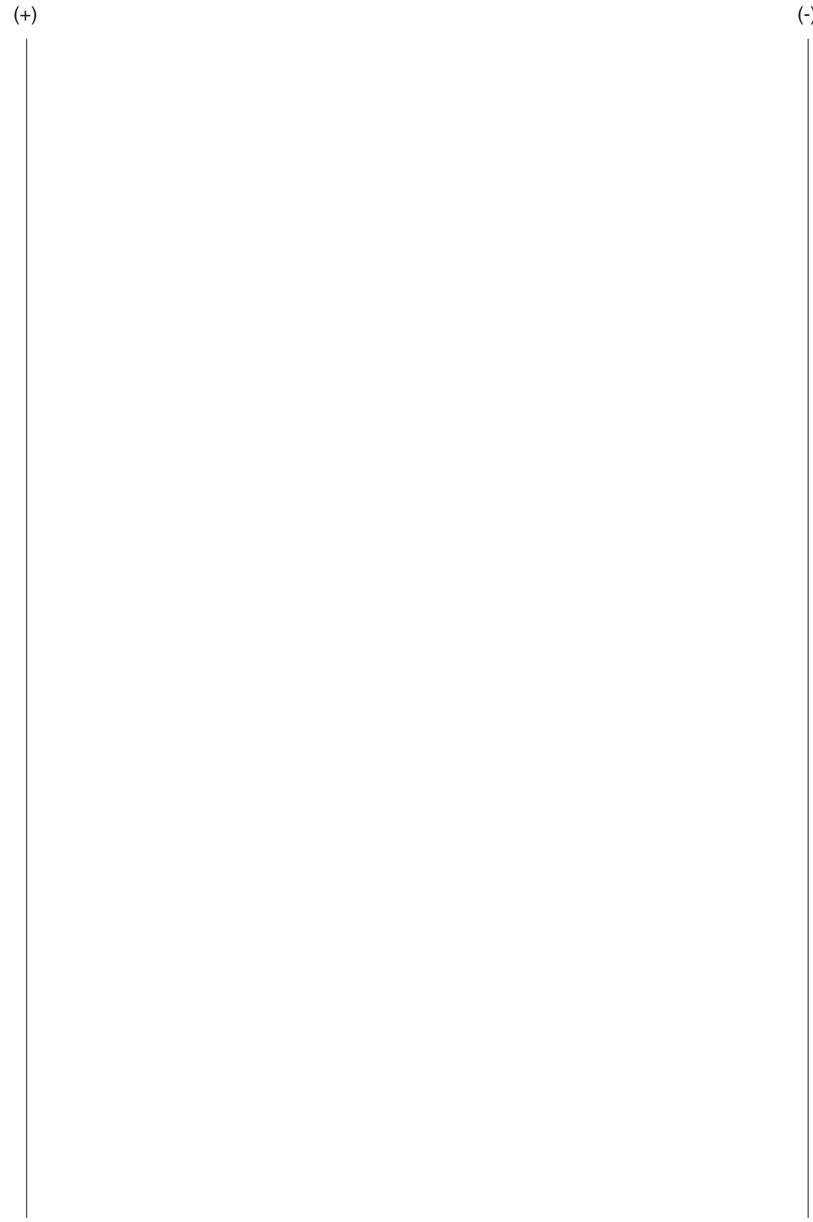


Figure 6-4. New modified program.

CONCLUSION

In this exercise, you connected a PLC-controlled hydraulic system that makes a motor rotate 1000 turns and then reciprocates a cylinder 10 times. You saw that the PLC counter instruction is incremented by false-to-true rung transitions of the counter rung. These rung transitions are caused by events occurring in the system, such as a cylinder piston traveling past a magnetic proximity switch or a motor flywheel activating a photoelectric switch. After a definite number of events has occurred, the counter completion bit turns on, which activates or deactivates a directional valve solenoid.

REVIEW QUESTIONS

1. When is counting of hydraulic actuator cycles required?

2. Describe a typical hydraulic application where counting of actuator cycles is required.

3. How can the PLC counter instruction be used to activate a directional valve solenoid after a cylinder has reciprocated a definite number of times?

4. In the PLC ladder program of Figure 6-2, what purpose is served by N.C. contact instruction C:0 on rung 3?

5. In the PLC ladder program of Figure 6-2, what purpose is served by N.C. contact instruction B:0 on rung 4?

Sample Exercise

from

Hydraulics Applications –

Servo-Proportional Control

Exercise 1

Proportional Directional Control Valves

EXERCISE OBJECTIVE

- To describe the design and operation of a proportional directional control valve;
- To plot the flow rate/voltage curve of the trainer Proportional Directional Control Valve.

DISCUSSION

Proportional directional control valves

In hydraulics, the speed of an actuator is controlled by regulating the volume of oil entering and discharging from it. This can be accomplished by using, among others, a conventional flow control valve or a proportional directional control valve:

The **flow control valve** is rugged, simple in construction, and relatively inexpensive. However, there are several disadvantages to using this type of valve:

– The valve knob setting must be readjusted each time a new actuator speed is desired.

– In applications requiring the actuator speed to change at certain moments of the cycle, several flow control valves must be used, which complicates the circuit and increases the number of required adjustments.

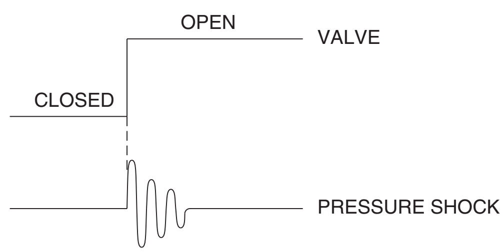
– A flow control valve cannot control the direction of motion of the actuator. Therefore, a directional control valve must be added to the circuit to provide for direction control. Since a directional control valve is an on/off switching valve, the system may be subject to shocks caused by the sudden closing or opening of the directional valve and by load impact on the actuator. These shocks can result in leakage or destruction of the valve, pump, actuator, and plumbing.

The **proportional directional control valve** is more expensive than the flow control valve and it requires an electrical signal for its control. However, it eliminates the problems related to the flow control valve:

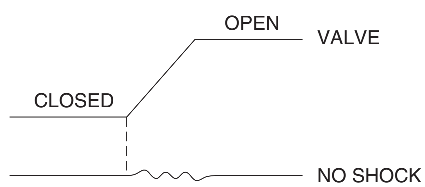
– The proportional directional control valve allows simultaneous control of both the actuator speed and direction, using a single valve.

– The actuator speed and direction can be changed at any moment of the cycle simply by modifying the level and polarity of the electrical control signal, which can be done automatically by a remote control circuit.

– The electrical control signal can be ramped to shift the spool of the proportional directional control valve **smoothly** and suppress hydraulic pressure shocks, as Figure 1-1 shows.



a) Conventional directional control valve



b) Proportional directional control valve

Figure 1-1. The proportional directional control valve can eliminate shocks from the hydraulic circuit.

Applications

Proportional directional control valves are used in numerous industrial applications, including injection and blow molding, metal cutting, fatigue testing, die casting, steel making, steam and gas turbine operation, press, heavy industry, paper, lumber processing, plastics, robotics, material handling, mobile equipment, and computer-controlled machine tools. A typical application of a proportional directional control valve is to provide rapid, smooth, and accurate transfer of parts from one work station to another in a transfer line. Another application is to control a die punch at high cycle rates and high inertial forces without excessive mechanical wear on the shearing mechanisms. A third application is to control a hydraulic lift and provide slow acceleration and deceleration of the lift.

Construction and operation of proportional directional control valves

The construction of proportional directional control valves may vary slightly from manufacturer to manufacturer. However, proportional directional control valves have the following parts in common: electronic circuit, spool actuating mechanism, spool, and centering springs.

As an example, Figure 1-2 shows the construction of the Proportional Directional Control Valve supplied with your hydraulics trainer. As the figure shows, a permanent-magnet **linear force motor** directly drives the valve spool. The spool, which is of the **blocked-center** type, has V-shaped control edges that open up very gradually, allowing accurate control of the flow rate. A **control voltage** between –10 and 10 V is applied to the electronic circuit inside the valve to control the valve spool and, therefore, the valve opening. A **LVDT** is attached to the valve spool to provide feedback on the position of the spool.

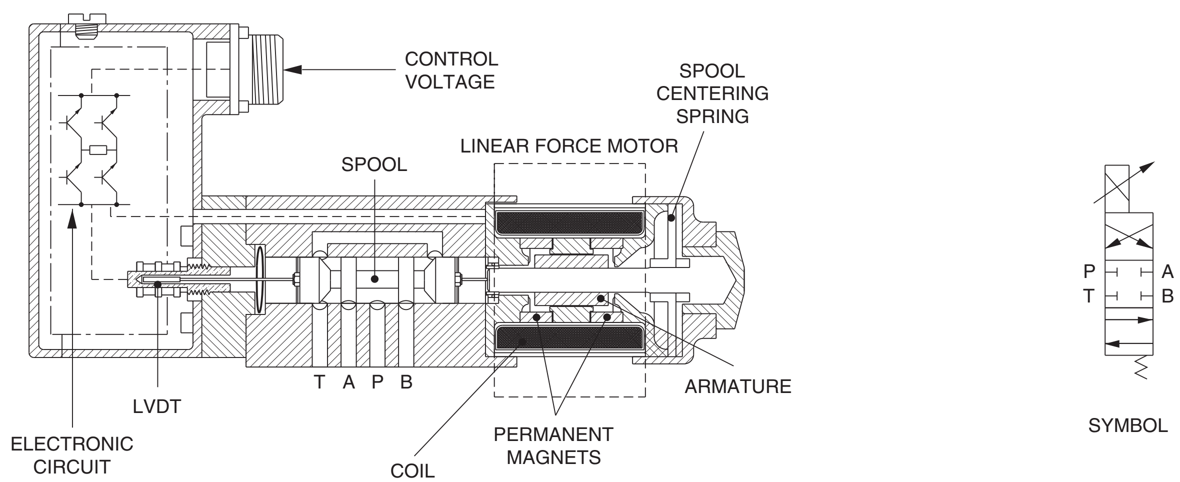


Figure 1-2. Proportional valve using a linear force motor for actuation of its spool.

Detailed valve operation is as follows:

- The **electronic circuit** converts the control voltage into a current used to drive the linear force motor.

- The **linear force motor** moves the spool according to the polarity and level of the control voltage. The **polarity** of the control voltage, which is either positive (+) or negative (−), determines whether the spool is moved to the straight-arrows or crossed-arrows position. The **level** of the control voltage determines the distance over which the spool moves:

  – When a **positive** control voltage is applied to the valve, the electronic circuit causes a proportional current to flow through the motor coil. This creates a magnetic field around the coil, causing the motor armature to move the spool to the left. This compresses the spool centering spring. This also connects port P to port A and port T to port B, which is the **straight-arrows** condition. The distance over which the spool is shifted to the left is directly proportional to the current and, therefore, to the control voltage. The higher the control voltage is, the further the spool will move towards the leftmost, fully-open position.

  – When a **negative** control voltage is applied to the valve, the electronic circuit causes the current through the motor coil to change direction. This reverses the direction of the magnetic field around the coil, causing the armature to move the spool to the right. This compresses the spool centering spring. This also connects port P to port B and port T to port A, which is the **crossed-arrows** condition. The higher the control voltage is, the further the spool will move towards the rightmost, fully-open position.

– If the control voltage is removed or set at 0 V, the centering spring will automatically return the spool to the center position, blocking all valve ports.

- The **LVDT**, or linear variable differential transformer, produces a voltage proportional to the spool position. This voltage is fed back to the electronic circuit and compared to the control voltage. If the voltages are unequal, the electronic circuit will cause a current to flow through the motor coil to correct the spool position until it corresponds to the desired position. In this way, the LVDT provides internal closed-loop control of the spool position.

Proportional valves having a built-in LVDT are used in applications where the spool position must accurately correspond to the control voltage. However, models without LVDT are also available for applications where the position error is not so important, such as when the operator is visually monitoring the actuator movement.

Figure 1-3 shows another type of proportional directional control valve that uses two proportional solenoids for the actuation of its spool. When the control voltage is positive, solenoid A is energized and the spool is moved a proportional distance to the right, which is the straight-arrows position. When the control voltage is negative, solenoid B is energized and the spool is moved a proportional distance to the left, which is the crossed-arrows position. When the control voltage becomes null, the centering springs automatically return the spool to the center position, blocking all valve ports.

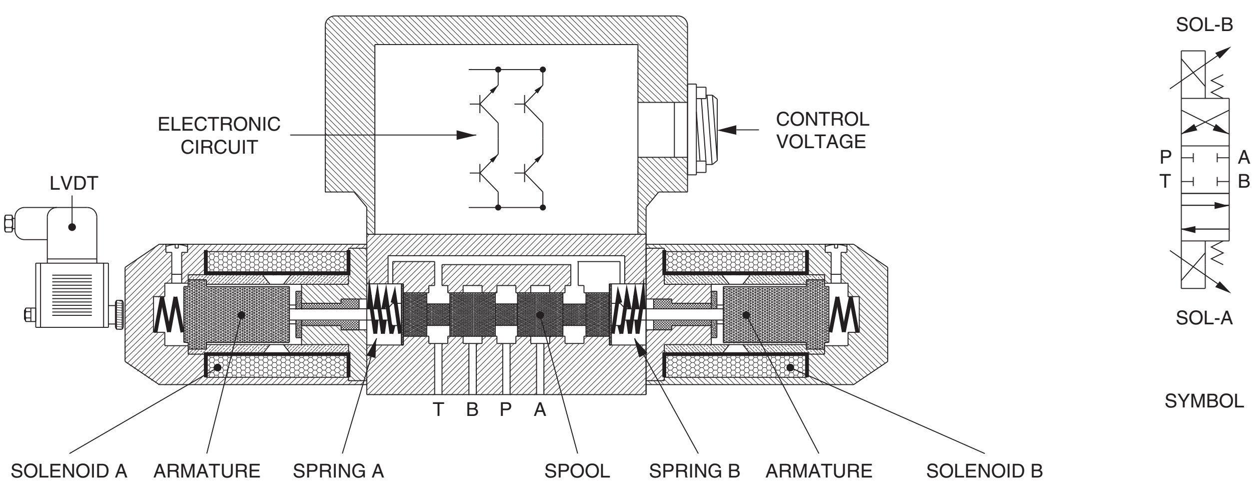


Figure 1-3. Proportional directional control valve using two solenoids for actuation of its spool.

Direct- and pilot-operated proportional valves

The proportional valves illustrated in Figures 1-2 and 1-3 are **direct-operated** because their actuating mechanism acts **directly** upon the spool to provide the desired flow rate. As pressures and flow rates increase, the force required to move the spool increases. As a result, direct-operated proportional valves have a limit of practicality which is around 75 l/min [20 gal(US)/min]. For higher flow rates, **pilot-operated** proportional valves must be used.

Figure 1-4 shows a pilot-operated proportional solenoid valve. A **pilot** spool generates a **hydraulic** force used for actuation of the **main** spool, allowing high flow rates to be controlled. When, for example, solenoid A is energized, the pilot spool is moved to the right, directing pilot oil to the right of the main spool. This moves the main spool to the left over a distance proportional to the pressure of the pilot oil.

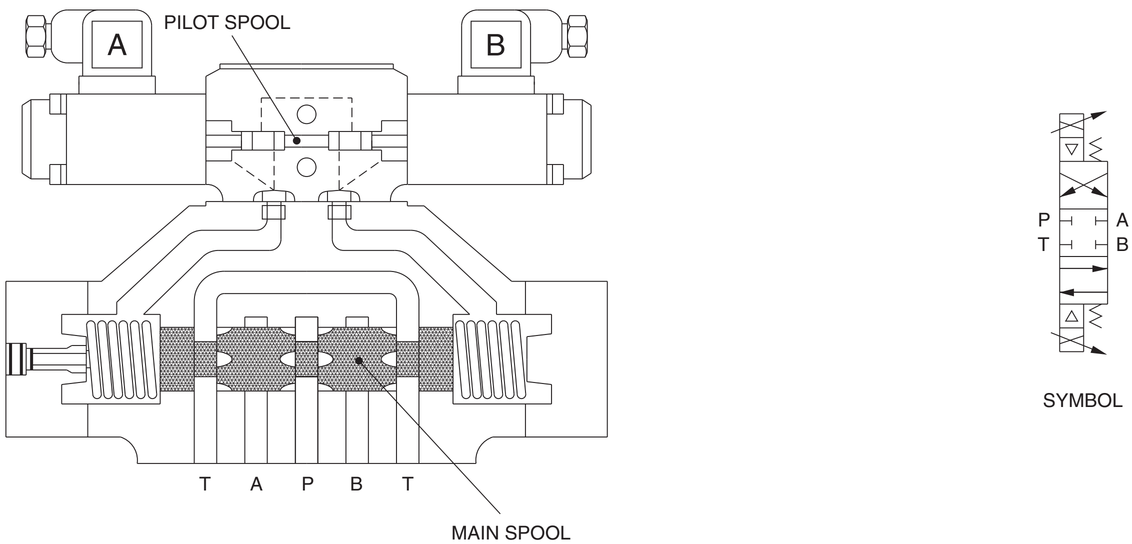


Figure 1-4. Pilot-operated, two-stage proportional solenoid valve.

The valve illustrated in Figure 1-4 has two stages, which are the pilot stage and the main stage. However, pilot-operated proportional valves are also available as three-stage for very high flow applications.

Flow rate/voltage curve of a proportional directional control valve

The flow rate/voltage curve of a proportional valve is obtained by varying the valve control voltage and measuring the output flow rate at port T of the valve, with ports A and B connected to each other, as Figure 1-5 (a) shows. When recording the flow measurements, it is important that the pressure drop ΔP across the valve be kept constant because the flow rate through the valve will increase not only with an increase in control voltage but also with an increase in pressure drop across the valve.

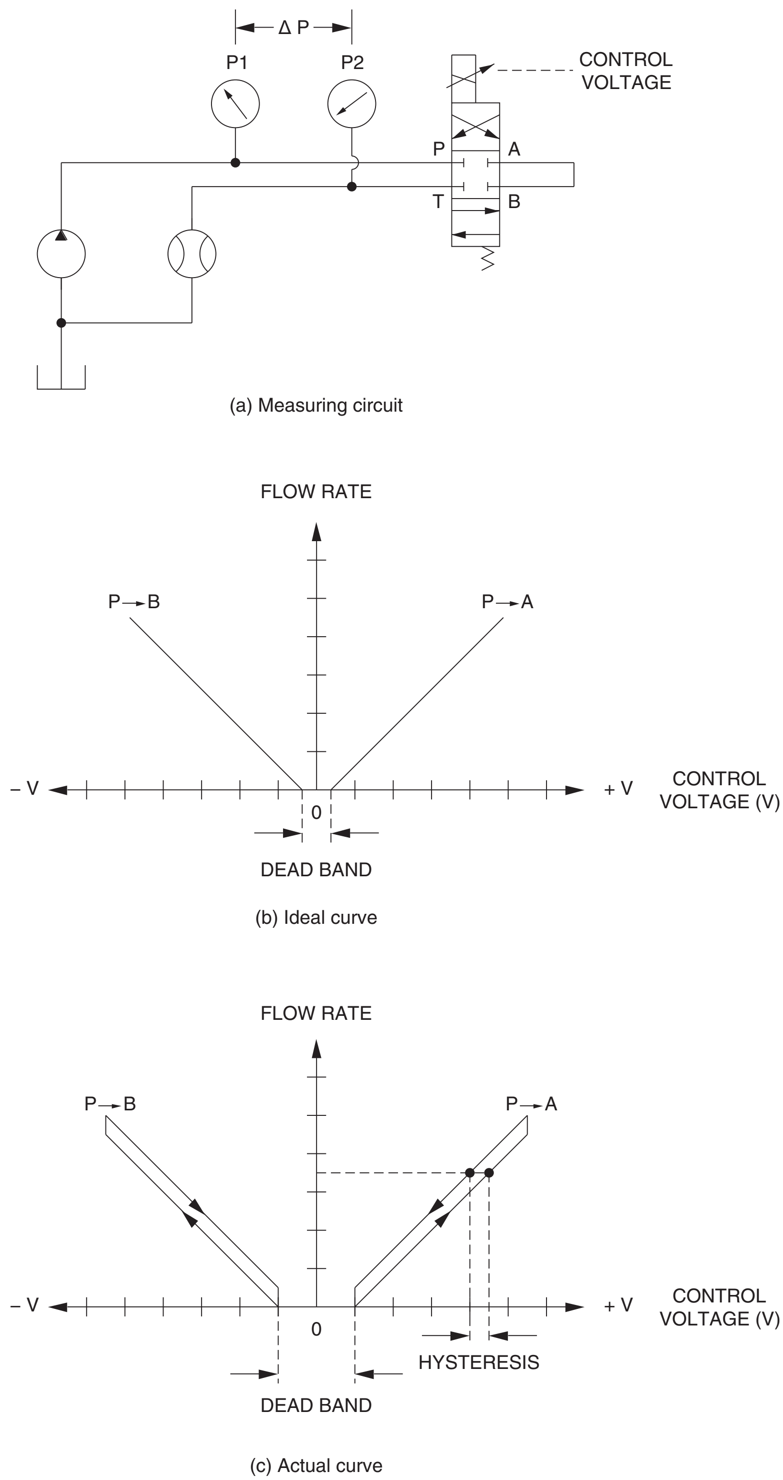


Figure 1-5. Flow rate/voltage curve of a proportional valve.

Figure 1-5 (b) shows the ideal flow rate/voltage curve of a proportional valve. The curve is actually a straight line, indicating that the flow rate is directly and linearly proportional to the control voltage. The flat zone near the 0-V area of the curve is called the **dead band**. Within the dead band, the flow rate remains null even if the control voltage is changed. This means a minimum control voltage must be applied before the valve actually begins to open.

A dead band is caused by the fact that the spool lands of the valve are machined slightly wider than the body grooves. This condition, called spool overlap, is required to have all ports blocked when the spool is centered.

Figure 1-5 (c) shows the actual flow rate/voltage curve of a proportional valve. This curve differs fairly from the previous one in that it has a wider dead band, as well as **hysteresis**. Hysteresis is a difference in control voltage required to obtain a given flow rate when the valve spool moves in one direction and then in the other direction. **Hysteresis** is mainly due to spool friction, magnetizing effects, and oil contamination. Hysteresis can be reduced substantially with a LVDT.

Null adjustment

Most proportional directional control valves have a null adjustment screw that can be used to compensate for load drift when the control voltage is null. The null is adjusted slightly off true center in order to provide more pressure on one end of the actuator and prevent any motion of the load. Temperature changes, pressure changes, and valve age may cause the null to drift slightly, so that null readjustment may be required to maintain the load stationary.

Filtering

In order for a proportional directional control valve to provide consistent operation and high reliability, it is important to have good oil filtering in the entire hydraulic system. Proportional directional control valves often come with a small built-in filter that provides coarse filtration of the oil which goes into their pilot spool. But it is important to install an additional high pressure filter just upstream of the valve, particularly in systems operating at high pressures and high cycling rates. Failure to do so may result in the valve gradually deteriorating in performance.

The SETPOINTS section of the trainer P.I.D. Controller

Your trainer comes with a P.I.D. Controller, model 6367, made of controls and circuits that can be used to accurately operate the trainer Proportional Directional Control Valve.

As Figure 1-6 shows, the P.I.D. Controller has a SETPOINTS section that can produce **two** adjustable DC voltages called **setpoints**. Adjustment of SETPOINT 1 is by means of potentiometer 1, while adjustment of SETPOINT 2 is by means of potentiometer 2. Each setpoint can be adjusted between –10 and 10 V, which corresponds to the control input range of the trainer Proportional Directional Control Valve when the valve switch is set to the –10 V - +10 V position.

The SETPOINTS section has two outputs, labeled "1" and "2":

– SETPOINT output 1 will be used for control of the trainer Proportional Directional Control Valve. The voltage present at this output is either SETPOINT 1 or SETPOINT 2, depending on which setpoint is selected. Selection of a setpoint is either by means of toggle switch S1 or by means of an external 24-V DC voltage from an electromechanical relay or PLC, in which case the toggle operator of switch S1 must be set to the A position.

– SETPOINT output 2 will be used in applications requiring an adjustable DC voltage source. This output provides the voltage set by SETPOINT potentiometer 2.

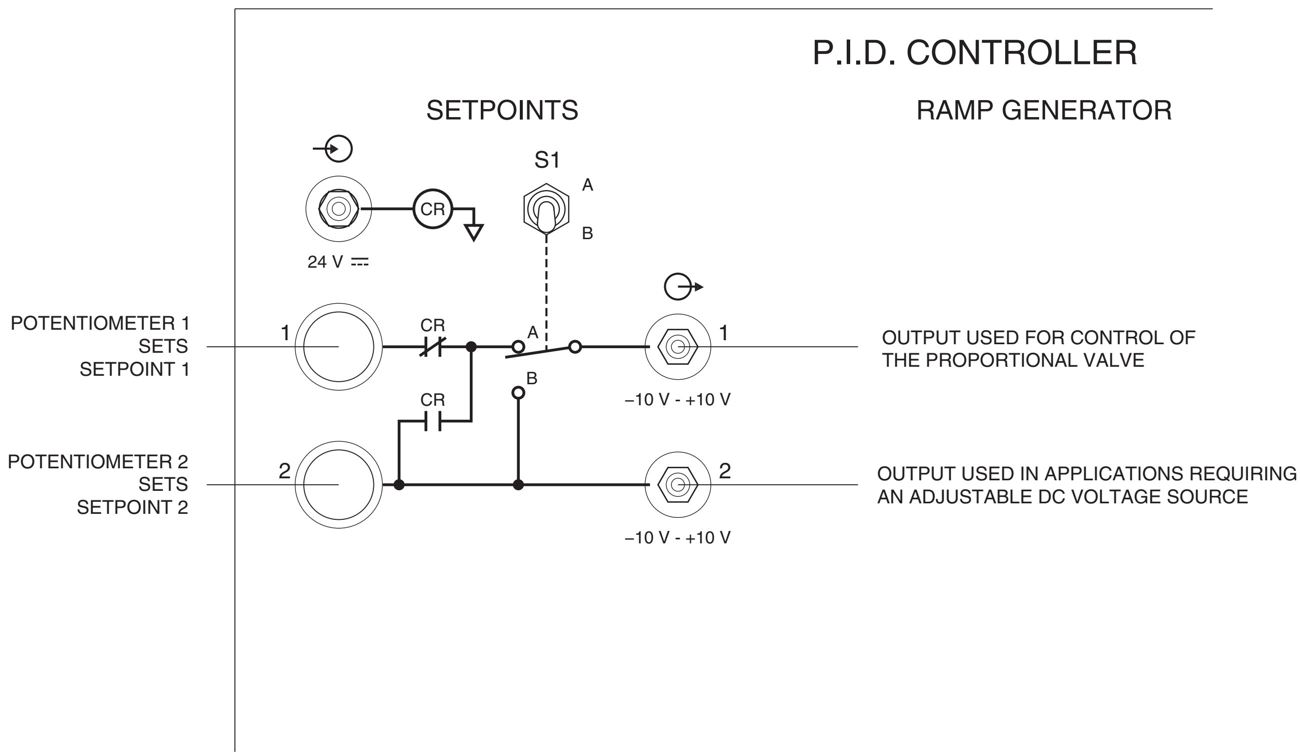


Figure 1-6. The SETPOINTS section of the P.I.D. Controller.

Procedure summary

In this exercise, you will plot the flow rate/voltage curve of the trainer Proportional Directional Control Valve. To do so, you will measure the flow rate at port T of the valve for several different voltages.

EQUIPMENT REQUIRED

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

PROCEDURE

☐ 1. Connect the system shown in Figure 1-7. In this system, SETPOINT output 1 of the P.I.D. Controller will be used to apply a variable voltage to the control input of the Proportional Directional Control Valve.

> **Note:** *The proportional valve has an output terminal, labeled –10 V - +10 V, which can be used to monitor the actual position of the valve spool throughout the exercise. The voltage generated at this output corresponds to the actual spool position, and should be approximately equal to the valve control voltage at all times.*

☐ 2. Turn on the 24-V DC Power Supply and P.I.D. Controller by setting their POWER switch to the I position. **Do not turn on the hydraulic Power Unit yet.**

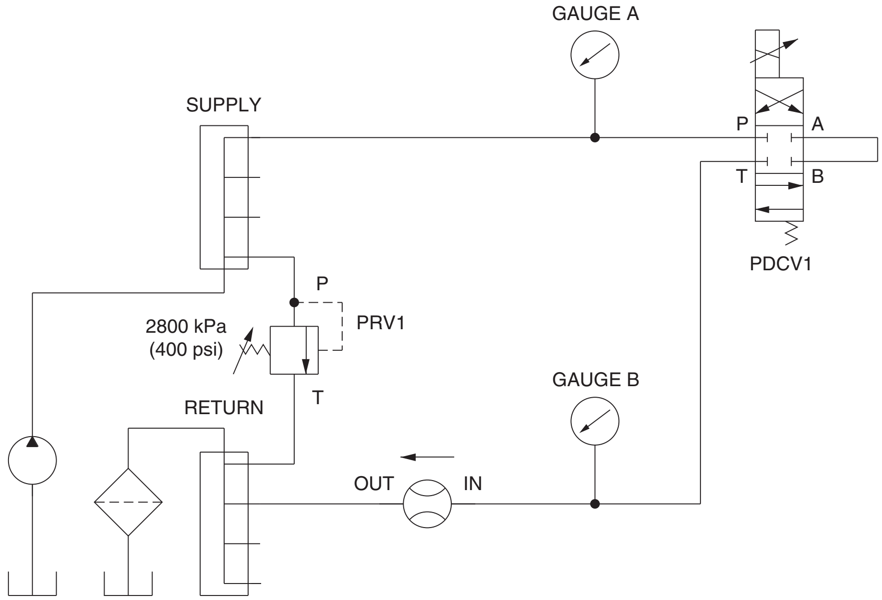
☐ 3. On the Proportional Directional Control Valve, set the control input range switch to the –10 V - +10 V position.

☐ 4. In the SETPOINT section of the P.I.D. Controller, select SETPOINT 1 by setting SETPOINT switch S1 to the A position.

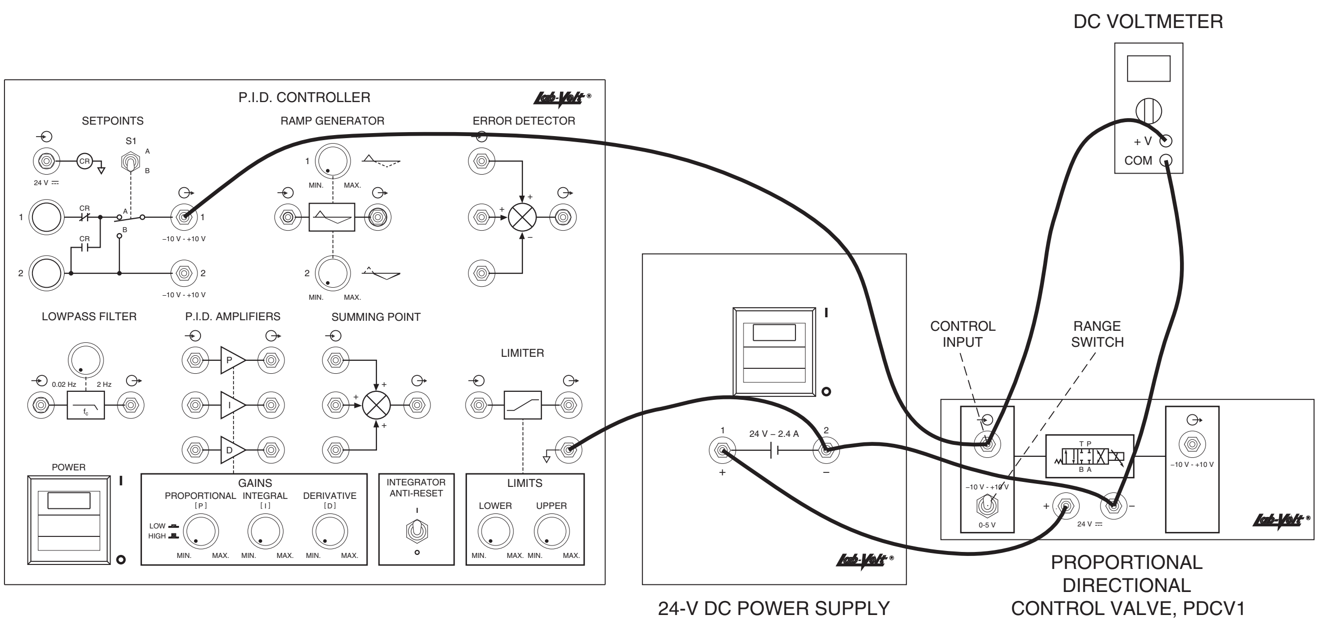
Adjust the knob of SETPOINT 1 potentiometer until the DC voltmeter reads 0.00 V at the control input of the Proportional Directional Control Valve.

☐ 5. Before turning on the hydraulic Power Unit, perform the following start-up procedure:

a. Put on safety glasses;
b. Make sure the hydraulic hoses are firmly connected;
c. 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;
d. Open the Relief Valve completely by turning its knob fully counterclockwise.



(a) Hydraulic section



(b) Electrical section

Figure 1-7. Plotting the flow rate/voltage curve of the trainer Proportional Directional Control Valve.

☐ 6. Turn on the hydraulic Power Unit. With a control voltage of 0.00 V applied to the Proportional Directional Control Valve, the valve is in the closed-center condition and all the pumped oil is dumped back to the reservoir at the Relief Valve pressure setting.

☐ 7. Adjust the Relief Valve knob until the system pressure at gauge A is 2800 kPa (400 psi).

☐ 8. While observing the Flowmeter piston, very slowly turn the knob of SETPOINT 1 potentiometer clockwise and stop turning it as soon as the piston begins to move.

Note the voltage indicated by the DC voltmeter. This is the positive control voltage at which the Proportional Directional Control Valve begins to open. Record this voltage in Table 1-1 next to "VALVE OPENS AT". Also, record the readings of pressure gauges A and B for this voltage.

CONTROL VOLTAGE (+)	FLOW RATE	GAUGE A PRESSURE	GAUGE B PRESSURE	PRESSURE DROP (GAUGE A – GAUGE B)
Valve opens at ________ mV	≅ 0 l/min [0 gal(US)/min]			
1.00 V				
3.00 V				
5.00 V				
7.00 V				
9.00 V				
10.00 V				
9.00 V				
7.00 V				
5.00 V				
3.00 V				
1.00 V				
Valve closes at _______ mV	≅ 0 l/min [0 gal(US)/min]			

Table 1-1. Flow rate versus positive (+) control voltage.

☐ 9. Slowly turn the knob of SETPOINT 1 potentiometer clockwise until the DC voltmeter reads 1.00 V. In Table 1-1, record the Flowmeter reading for this voltage. Also, record the readings of pressure gauges A and B.

☐ 10. Repeat step 9 for each of the other control voltages listed in Table 1-1.

Note: *Once you have reached a control voltage of 10.00 V, turn the knob of SETPOINT 1 potentiometer counterclockwise to decrease the control voltage.*

☐ 11. Adjust the knob of SETPOINT 1 potentiometer until the DC voltmeter reads 0.00 V at the control input of the Proportional Directional Control Valve.

☐ 12. Very slowly turn the knob of SETPOINT 1 potentiometer counterclockwise and stop turning it as soon as the Flowmeter piston begins to move. In Table 1-2, record the voltage indicated by the DC voltmeter next to "VALVE OPENS AT". Also, record the readings of pressure gauges A and B for this voltage.

CONTROL VOLTAGE (−)	FLOW RATE	GAUGE A PRESSURE	GAUGE B PRESSURE	PRESSURE DROP (GAUGE A – GAUGE B)
Valve opens at – _______ mV	≅ 0 l/min [0 gal(US)/min]			
–1.00 V				
–3.00 V				
–5.00 V				
–7.00 V				
–9.00 V				
–10.00 V				
–9.00 V				
–7.00 V				
–5.00 V				
–3.00 V				
–1.00 V				
Valve closes at – _______ mV	≅ 0 l/min [0 gal(US)/min]			

Table 1-2. Flow rate versus negative (−) control voltage.

☐ 13. Slowly turn the knob of SETPOINT 1 potentiometer counterclockwise until the DC voltmeter reads –1.00 V. In Table 1-1, record the Flowmeter reading for this voltage. Also, record the readings of pressure gauges A and B.

☐ 14. Repeat step 13 for each of the other control voltages listed in Table 1-2.

> **Note:** *Once you have reached –10.00 V, turn the knob of SETPOINT 1 potentiometer clockwise to increase the control voltage.*

☐ 15. In Figure 1-8, plot the flow rate/voltage curve of the Proportional Directional Control Valve, based on the data recorded in Tables 1-1 and 1-2.

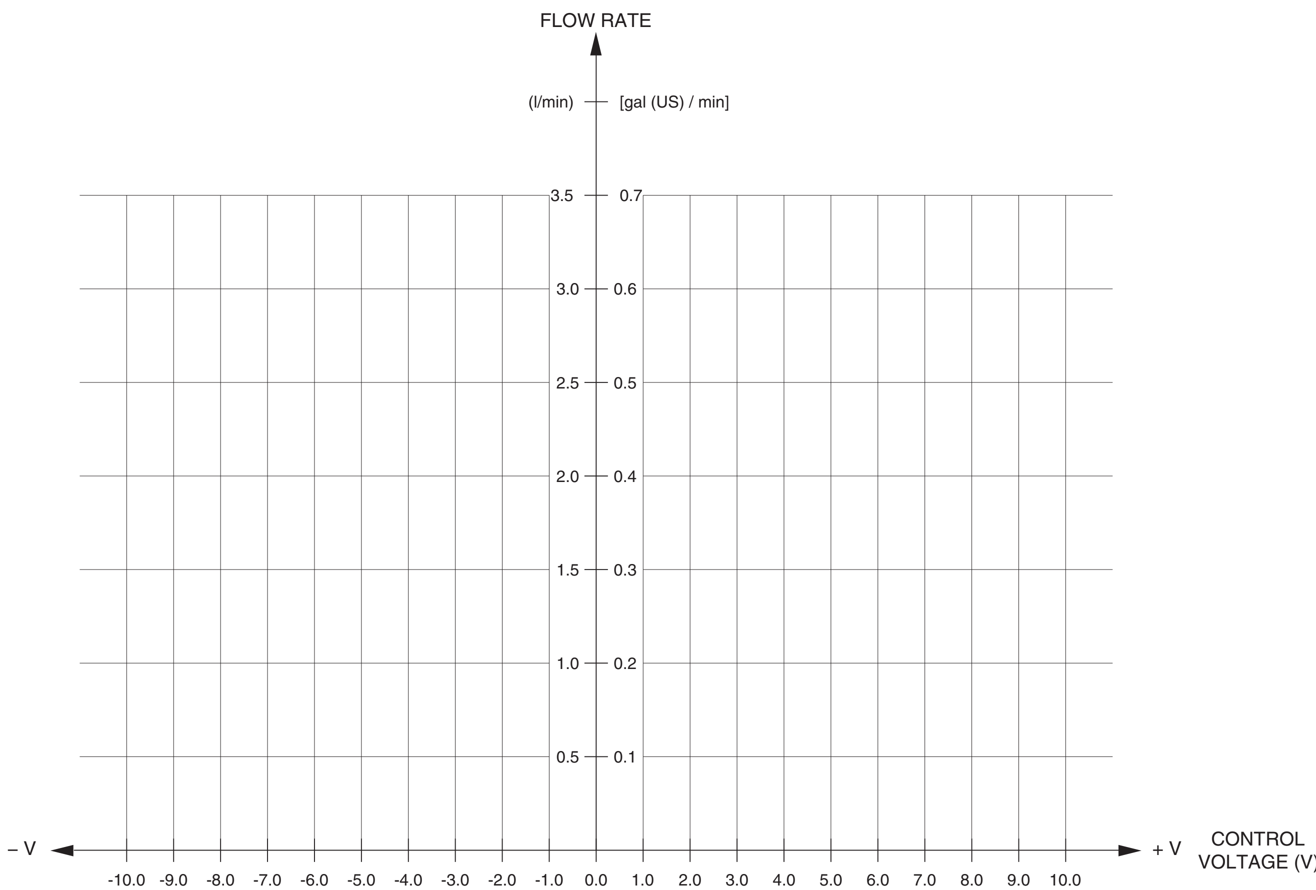


Figure 1-8. Flow rate/voltage curve of the proportional valve.

☐ 16. Describe the curve you obtained in Figure 1-8 in terms of dead band, linearity, and hysteresis.

____

____

____

☐ 17. Complete the column “PRESSURE DROP” of Tables 1-1 and 1-2. Did the pressure drop across the valve remain approximately constant and equal to the system pressure of 2800 kPa (400 psi) regardless of the size of the valve opening (control voltage)? Why?

____

____

____

☐ 18. Then turn off the P.I.D. Controller and 24-V DC Power Supply.

☐ 19. Disconnect all hoses and electrical leads. Return all hoses, leads, and components to their storage location.

CONCLUSION

In this exercise, you learned that proportional directional control valves are precision spool-type valves with electronic actuation. You plotted the flow rate/voltage curve of the trainer Proportional Directional Control Valve. You saw that there is a narrow dead band near the 0-V area of the curve within which the valve remains closed. Beyond that zone, the flow rate is directly and linearly proportional to the control voltage. You also saw that there is a small difference in flow rate for a given control voltage when the valve spool moves in one direction and then in the other direction. This difference is due to hysteresis.

You saw that the pressure drop across the proportional valve remains approximately constant and equal to the relief valve pressure setting regardless of the size of the proportional valve opening. This happens because under any control voltage, the proportional valve output flow rate is less than the flow rate delivered by the pump, so that part of the pumped oil is forced to return to the reservoir through the relief valve.

REVIEW QUESTIONS

1. What parts do proportional directional control valves have in common?

____

____

2. Name two types of spool actuating mechanisms.

____

3. What happens to the flow rate allowed by a proportional valve when the pressure drop across the valve decreases?

____

4. In the exercise, why did the pressure drop across the proportional valve remain approximately constant and equal to the relief valve pressure setting regardless of the size of the proportional valve opening?

____

____

5. What is hysteresis? How can hysteresis be minimized on direct-operated proportional valves?

____

____

____

Other Samples

Extracted from

Electrical Control

of Hydraulic Systems

Unit Test

1. The main function of a sequencing circuit is

   a. operating actuators in a particular order;
   b. cycling a cylinder many times;
   c. cycling a cylinder one time;
   d. monitoring system pressure.

2. Similar to the pressure relief valve, the sequence valve is

   a. normally open and it senses the pressure downstream.
   b. normally closed and it senses the pressure upstream.
   c. normally open and it senses the pressure upstream.
   d. normally closed and it senses the pressure downstream.

3. As long as the pressure upstream of a sequence valve is lower than the valve cracking pressure, the valve will

   a. remain wide open and oil will be allowed to flow through the valve.
   b. remain closed and oil will be allowed to flow through the valve.
   c. remain closed and oil will not be allowed to flow through the valve.
   d. remain in some intermediate position to maintain the downstream pressure at its operating pressure.

4. What is the purpose of a limit switch in an electrically-controlled cycling system?

   a. Maintaining the position of a cylinder.
   b. Monitoring the position of a cylinder.
   c. Adjusting the position of a cylinder.
   d. Energizing and de-energizing valve solenoids.

5. What is the function of a pressure switch in an electrically-sequenced clamp and work circuit?

   a. Preventing the clamp cylinder from over-tightening the workpiece.
   b. Maintaining a constant pressure behind the piston of the clamp cylinder.
   c. Ensuring that the workpiece is clamped correctly.
   d. Allowing the pump to unload to reservoir at minimum pressure.

6. The difference between the actuation pressure and the reset pressure of a pressure switch is called the

   a. proof pressure.
   b. pressure differential.
   c. ambient pressure.
   d. actuation point.

Unit Test (cont'd)

7. Pressure-compensated flow control valves maintain a constant flow rate

   a. as the upstream pressure varies.
   b. as the downstream pressure varies.
   c. by keeping a constant pressure drop across their internal needle valve;
   d. all the above.

8. What is the function of a sequence valve in a hydraulic motor braking circuit?

   a. To immediately stop the motor by creating a back pressure at the motor inlet.
   b. To stop the motor gradually and smoothly by limiting the back pressure created at the motor outlet.
   c. To allow the oil to flow directly from the reservoir into the rotating motor when it is braking.
   d. To decrease the braking time and increase the pressure spikes generated.

9. Cylinder dwell is a function used to

   a. allow a cylinder to retract immediately after contacting the workpiece.
   b. allow a cylinder to retract immediately after reaching the end of the extension stroke.
   c. prevent a cylinder from extending immediately after reaching the end of the retraction stroke.
   d. prevent a cylinder from retracting immediately after reaching the end of the extension stroke.

10. Which one of the following describes the operation of a solid-state ON-DELAY relay?

    a. It shifts its contacts to the activated state immediately when the coil is energized. It returns them to the normal state after a preset time has passed.
    b. It shifts its contacts to the activated state after a preset time has passed after the coil has been de-energized. It returns them to the activated state immediately when the coil is re-energized.
    c. It does not shift its contacts to the activated state until a preset time has passed after the coil has been energized. It returns them to the normal state immediately when the coil is de-energized.
    d. It does not shift its contacts to the deactivated state until a preset time has passed after the coil has been energized. It returns them to the activated state immediately when the coil is de-energized.

Instructor Guide Sample

Extracted from

Hydraulics Fundamentals

EXERCISE 2-1 PRESSURE LIMITATION

ANSWERS TO PROCEDURE QUESTIONS

☐ 3. Gauge A should read between 200 and 700 kPa (between 30 and 100 psi).

☐ 4. Gauge A should read about 2900 kPa (420 psi) @ 38°C (100°F).

☐ 5. Because increasing the spring compression makes the oil flow path provided by the relief valve more restrictive, so that the pump must apply more pressure to overcome the resistance.

☐ 6. No. As soon as the relief valve pressure setting becomes higher than 6200 kPa (900 psi), the main relief valve inside the power unit, which is set to 6200 kPa (900 psi), provides a path of least resistance, so that all the pumped oil passes through this path.

☐ 8. The valve will start to open around 3000 kPa (440 psi).

☐ 14. Gauge A should read about 500 kPa (75 psi) @ 38°C (100°F).

☐ 15. About 1400 kPa (200 psi).

☐ 18. Gauge A should read about 300 kPa (40 psi) @ 38°C (100°F).

☐ 19. About 2100 kPa (300 psi).

☐ 22. During cylinder extension, gauge A showed the pressure needed to overcome the resistance of the piston seals and that of the oil flowing back to the reservoir. The pressure did not change because these resistances are not affected by the relief valve settings.

☐ 23. Circuit pressure increases when the cylinder is fully extended because the resistance of the cylinder becomes very high. Further movement would require the piston rod to “break out” of the cylinder. System pressure at this point is determined by the relief valve which allows all the oil coming from the pump to return directly to the reservoir.

ANSWERS TO REVIEW QUESTIONS

1. To limit the maximum system pressure.

2. These two relief valves are identical. They are both used to limit the maximum system pressure. However, the main relief valve in the power unit is factory-set at a higher pressure than the secondary relief valve provided with the Hydraulics Trainer. It is used as an additional safety device for backing up the secondary relief valve. It should not be readjusted or tampered with.

3. A pilot-operated relief valve.

4. The pressure relief valve will be ineffective because it will not limit the system pressure. The system pressure will rise to the pressure setting of the main relief valve, if any. Otherwise, pressure will rise until oil leaks from the hose connections or the pump motor is stalled.

5. The cracking pressure is the minimum pressure required to “open” a pressure relief valve and start flow through it.

6. During cylinder extension, gauge A would read 600 kPa (85 psi). Once the cylinder fully extended, the system pressure would rise to 6900 kPa (1000 psi) instead of 3400 kPa (500 psi).

EXERCISE 2-2 PRESSURE AND FORCE

ANSWERS TO PROCEDURE QUESTIONS

☐ 1. S.I. units: $F_{(N)} = \dfrac{P_{(kPa)} \times A_{(cm^2)}}{10}$

English units: $F_{(lb)} = P_{(psi)} \times A_{(in^2)}$

☐ 2. $A_f = 11.4\ cm^2\ (1.77\ in^2)$

☐ 3.

PRESSURE APPLIED ON FULL PISTON AREA	THEORETICAL CYLINDER FORCE	ACTUAL CYLINDER FORCE
3500 kPa (500 psi)	3990 N (885 lb)	3750 N (850 lb)
2800 kPa (400 psi)	3192 N (708 lb)	3000 N (675 lb)
2100 kPa (300 psi)	2394 N (531 lb)	2250 N (510 lb)

Table 2-2. Cylinder force versus pressure.

☐ 14. The actual forces may be somewhat less than the theoretical forces because of pressure drops across connectors and of spring rate accuracy. However, the actual and theoretical values should be within 20% of each other.

☐ 15. Force increases as pressure increases.

☐ 17. The full side of the piston.

☐ 18. The cylinder rod will extend.

☐ 21. The cylinder rod should move toward the rod side (extend) because the force generated on the rod side of the piston is lower than the force generated on the cap side. The difference in force is caused by the difference in effective area of the two sides of the piston. The piston area available for the pressure to act on is lower on the rod side because the cylinder rod covers a portion of the piston.

☐ 24. Gauge B will read the most pressure. Since A_f is greater than A_a, P_a must be greater than P_f for the equation $P_f \times A_f = P_a \times A_a$ to be true.

☐ 25.

PART A	INPUT PRESSURE AT GAUGE A (P_f)	OUTPUT PRESSURE AT GAUGE B (P_a)	INPUT/OUTPUT PRESSURE RATIO (P_f/P_a)	RECIPROCAL OF AREA RATIO (A_a/A_f)
INPUT PRESSURE APPLIED ON FULL PISTON AREA	1400 kPa (200 psi)	1800 kPa (260 psi)	0.77	0.61
	2100 kPa (300 psi)	2800 kPa (400 psi)	0.75	

PART B	INPUT PRESSURE AT GAUGE A (P_a)	OUTPUT PRESSURE AT GAUGE B (P_f)	INPUT/OUTPUT PRESSURE RATIO (P_a/P_f)	RECIPROCAL OF AREA RATIO (A_f/A_a)
INPUT PRESSURE APPLIED ON ANNULAR AREA	400 kPa (200 psi)	800 kPa (110 psi)	1.82	1.64
	100 kPa (300 psi)	1100 kPa (160 psi)	1.88	

Table 2-3. Pressure distribution in the cylinder of Figure 2-20.

☐ 29. Gauge A will read the most pressure. This is because the pressures in the rod and cap sides will build until the forces exerted on both sides of the piston are exactly equal. Since the annular piston area is smaller than the full piston area, the required annular pressure must be greater than the full area pressure to obtain equilibrium of forces.

☐ 35. In theory, the input/output pressure ratio should be equal to the reciprocal of area ratio. However, the measured values may differ slightly because of pressure drops across hoses and connectors.

☐ 43. About 2200 kPa (320 psi).

☐ 46. S.I. units:

$$F_{(N)} = \frac{P_{(kPa)} \times A_{(cm^2)}}{10}$$

$$= \frac{2200\ \text{kPa} \times [(2.54\ \text{cm})^2 - (1.59\ \text{cm})^2] \times 0.7854}{10}$$

$$= 678\ \text{N or } 69.2\ \text{kg}$$

English units:

$$F_{(lb)} = P_{(psi)} \times A_{(in^2)}$$

$$= 320\ \text{psi} \times [(1\ \text{in})^2 - (0.625\ \text{in})^2] \times 0.7854$$

$$= 153.2\ \text{lb}$$

ANSWERS TO REVIEW QUESTIONS

1. S.I. units:

$$F_{(N)} = \frac{P_{(kPa)} \times A_{(cm^2)}}{10}$$

$$P_{(kPa)} = \frac{F_{(N)} \times 10}{A_{(cm^2)}}$$

English units:

$$F_{(lb)} = P_{(psi)} \times A_{(in^2)}$$

$$P_{(psi)} = \frac{F_{(lb)}}{A_{(in^2)}}$$

2. $A = \pi \times r^2 = D^2 \times \pi/4 = D^2 \times 0.7854$

3. S.I. units:

   The required force is: 728 N/cm × 5.08 cm = 3698 N

   Therefore,

$$P_{(kPa)} = \frac{3698\text{ N} \times 10}{A_{(cm^2)}} = \frac{3698\text{ N} \times 10}{(2.54\text{ cm})^2 \times 0.7854} = 7298\text{ kPa}$$

   English units:

   The required force is: 416 lb/in × 2 in = 832 lb

   Therefore,

$$P_{(psi)} = \frac{832\text{ lb}}{A_{(in^2)}} = \frac{832\text{ lb}}{(1\text{ in})^2 \times 0.7854} = 1059\text{ psi}$$

4. $P_a = P_f \times \frac{A_f}{A_a} = P_f \times \frac{D^2 \times 0.7854}{(D^2 - d^2) \times 0.7854}$

   S.I. units:

$$P_a = 3500\text{ kPa} \times \frac{(2.54\text{ cm})^2 \times 0.7854}{[(2.54\text{ cm})^2 - (1.59\text{ cm})^2] \times 0.7854} = 5755\text{ kPa}$$

   English units:

$$P_a = 500\text{ psi} \times \frac{(1\text{ in})^2 \times 0.7854}{[(1\text{ in})^2 - (.625\text{ in})^2] \times 0.7854} = 820\text{ psi}$$

5. $P_f = P_a \times \frac{A_a}{A_f} = P_a \times \frac{(D^2 - d^2) \times 0.7854}{D^2 \times 0.7854}$

   S.I. units:

$$P_f = 3500\text{ kPa} \times \frac{[(2.54\text{ cm})^2 - (1.59\text{ cm})^2] \times 0.7854}{(2.54\text{ cm})^2 \times 0.7854} = 2128\text{ kPa}$$

   English units:

$$P_f = 500\text{ psi} \times \frac{[(1\text{ in})^2 - (.625\text{ in})^2] \times 0.7854}{(1\text{ in})^2 \times 0.7854} = 304\text{ psi}$$

EXERCISE 2-3 FLOW RATE AND VELOCITY

ANSWERS TO PROCEDURE QUESTIONS

☐ 1. S.I. units:

$$t_{(s)} = \frac{A_{f\ (cm^2)} \times 60 \times L_{(cm)}}{Q_{(l/min)} \times 1000}$$

English units:

$$t_{(s)} = \frac{A_{f\ (in^2)} \times 60 \times L_{(in)}}{Q_{[gal(US)/min]} \times 231}$$

☐ 9. Yes.

☐ 10. Yes.

☐ 11. During rod retraction, the oil coming from the cap end of the cylinder is bypassed to the reservoir through the check valve inside the flow control valve. Therefore, the retraction time is determined by the full pump flow, and not by the flow control valve setting.

☐ 14.

FLOW RATE TO CYLINDER	THEORETICAL EXTENSION TIME	ACTUAL EXTENSION TIME	GAUGE A	GAUGE B	ΔP (GAUGE A − GAUGE B)
1.5 l/min [.40 gal(US)/min]	4.6 s	4.6 s @ 38°C (100°F)	1900 kPa (280 psi)	100 kPa (15 psi)	1800 kPa (265 psi)
2.0 l/min [.53 gal(US)/min]	3.5 s	3.5 s @ 38°C (100°F)	1800 kPa (260 psi)	100 kPa (15 psi)	1700 kPa (245 psi)
2.5 l/min [.66 gal(US)/min]	2.8 s	2.8 s @ 38°C (100°F)	1700 kPa (240 psi)	100 kPa (15 psi)	1600 kPa (225 psi)

Table 2-5. Meter-in flow control circuit data.

☐ 17. The actual and theoretical extension times should be within 10% of each other. If the actual extension times are greater than the theoretical times, this is probably because the flow rates required for this experiment were adjusted at an operating temperature below 38°C (100°C). The trainer flowmeter is designed to accurately read the flow rate at 38°C (100°F). Below this temperature, the oil is thicker, placing extra pressure on the internal parts of the flowmeter and causing the flowmeter reading to be slightly higher than the actual flow rate.

☐ 18. The rod speed decreases as the flow rate decreases.

☐ 20. As the valve opening is increased, the pressure drop decreases because the valve resistance to oil flow decreases. This increases the flow to the cylinder and decreases the flow to the relief valve.

☐ 26. Yes.

☐ 27. No.

☐ 29.

FLOW RATE FROM CYLINDER	EXTENSION TIME	GAUGE A	GAUGE B	ΔP (GAUGE A − GAUGE B)
1.5 l/min [.40 gal(US)/min]	4.0 s @ 38°C (100°F)	2100 kPa (300 psi)	0 kPa (0 psi)	2100 kPa (300 psi)
2.0 l/min [.53 gal(US)/min]	3.1 s @ 38°C (100°F)	2000 kPa (290 psi)	0 kPa (0 psi)	2000 kPa (290 psi)
2.5 l/min [.66 gal(US)/min]	2.4 s @ 38°C (100°F)	1900 kPa (280 psi)	0 kPa (0 psi)	1900 kPa (280 psi)

Table 2-6. Meter-out flow control circuit data.

☐ 33. As the valve opening is increased, the pressure drop decreases because the valve resistance to oil flow decreases. This increases the flow to the cylinder and decreases the flow to the relief valve.

☐ 34. Yes, because the resistance of the flow control valve for a given flow rate is fixed. The pressure required to overcome this resistance, therefore, is fixed, whether the valve is positioned before or after the cylinder.

☐ 40. No. The piston rod extends at less than full speed because the flow control valve diverts some of the oil flow directly to the reservoir and less flow goes to the cylinder.

☐ 41. No, since the piston rod still retracts at full speed.

☐ 43.

FLOW RATE	EXTENSION TIME	GAUGE A	GAUGE B	ΔP (GAUGE A − GAUGE B)
1.0 l/min [.26 gal(US)/min]	2.4 s @ 38°C (100°F)	150 kPa (20 psi)	75 kPa (10 psi)	75 kPa (10 psi)
1.25 l/min [.33 gal(US)/min]	2.8 s @ 38°C (100°F)	150 kPa (20 psi)	75 kPa (10 psi)	75 kPa (10 psi)
1.5 l/min [.40 gal(US)/min]	3.2 s @ 38°C (100°F)	150 kPa (20 psi)	75 kPa (10 psi)	75 kPa (10 psi)

Table 2-7. Bypass flow control circuit data.

☐ 46. The extension time increases as the opening of the control valve increases, because more flow is diverted to the reservoir and less flow goes to the cylinder.

☐ 48. The pressure drops in the bypass flow control circuit are much lower than in the meter-in and meter-out circuits because the extra oil is diverted to the reservoir at the load pressure rather than at the relief valve pressure.

☐ 57. Yes.

☐ 59. No, because the oil cannot move out of the rod end of the cylinder, due to the flow control valve being closed.

☐ 60. The power unit should smoothly return to the ground because the flow control valve restricts the oil flow returning to the reservoir, which slows down the power unit.

☐ 61. The lifting speed is not controlled by the flow control valve. During retraction of the cylinder rod, all the oil from the pump goes to the rod end of the cylinder through the check valve inside the flow control valve. Therefore, the cylinder retracts at full speed.

ANSWERS TO REVIEW QUESTIONS

1. The speed of the piston rod will decrease. This is because the speed of a piston rod is inversely proportional to the piston area. The larger the diameter of the piston, then, the lower the speed of the rod.

2. Rod extension and retraction speeds can be decreased by decreasing the flow rate into the cylinder. Flow rate can be easily decreased by the use of a flow control valve in the system. A second method to decrease the speed of a cylinder rod is to use a cylinder of greater size without changing the flow rate to the cylinder.

3. 24.7 l/min [6.52 gal(US)/min]

4. The oil flow from the pump that is not metered through the flow control valve is returned to the reservoir through the pressure relief valve.

5. Meter-in.

6. Meter-out.

7. The bypass flow control circuit is more energy efficient than the meter-in and meter-out circuits because the extra flow is returned to the reservoir at the load pressure rather than at the relief valve pressure. However, this circuit is less accurate because it does not provide direct control of the working flow to the cylinder.

EXERCISE 2-4 WORK AND POWER

ANSWERS TO PROCEDURE QUESTIONS

☐ 10.

RETRACTION TIME	ANNULAR PRESSURE	DEVELOPED FORCE	CYLINDER WORK	CYLINDER POWER
0.8 s @ 38°c (100°F)	2200 kPa (320 psi)	681.9 N (153.3 lb)	69.2 J (51.1 ft·lb)	86.5 W (0.116 hp)

Table 2-9. Cylinder work and power.

☐ 22. The flowmeter should read about 3.4 l/min [0.9 gal(US)/min] at 38°C (100°F).

☐ 23.

CIRCUIT PRESSURE (GAUGE A)	FLOW RATE	PRESSURE AT GAUGE B	PUMP OUTPUT POWER	POWER DISSIPATED BY VALVE
1400 kPa (200 psi)	3.3 l/min [0.87 gal(US)/min] @ 38°C (100°F)	70 kPa (10 psi)	75.7 W (0.101 hp)	71.9 W (0.096 hp)
2100 kPa (300 psi)	3.2 l/min [0.85 gal(US)/min] @ 38°C (100°F)	70 kPa (10 psi)	110.9 W (0.149 hp)	107.2 W (0.144 hp)
2800 kPa (400 psi)	3.15 l/min [0.83 gal(US)/min] @ 38°F (100°F)	70 kPa (10 psi)	144.4 W (0.194 hp)	140.8 W (0.189 hp)
3500 kPa (500 psi)	2.9 l/min [0.77 gal(US)/min] @ 38°C (100°F)	70 kPa (10 psi)	167.0 W (0.224 hp)	164.1 W (0.220 hp)

Table 2-10. Power dissipation versus pressure drop.

☐ 26.

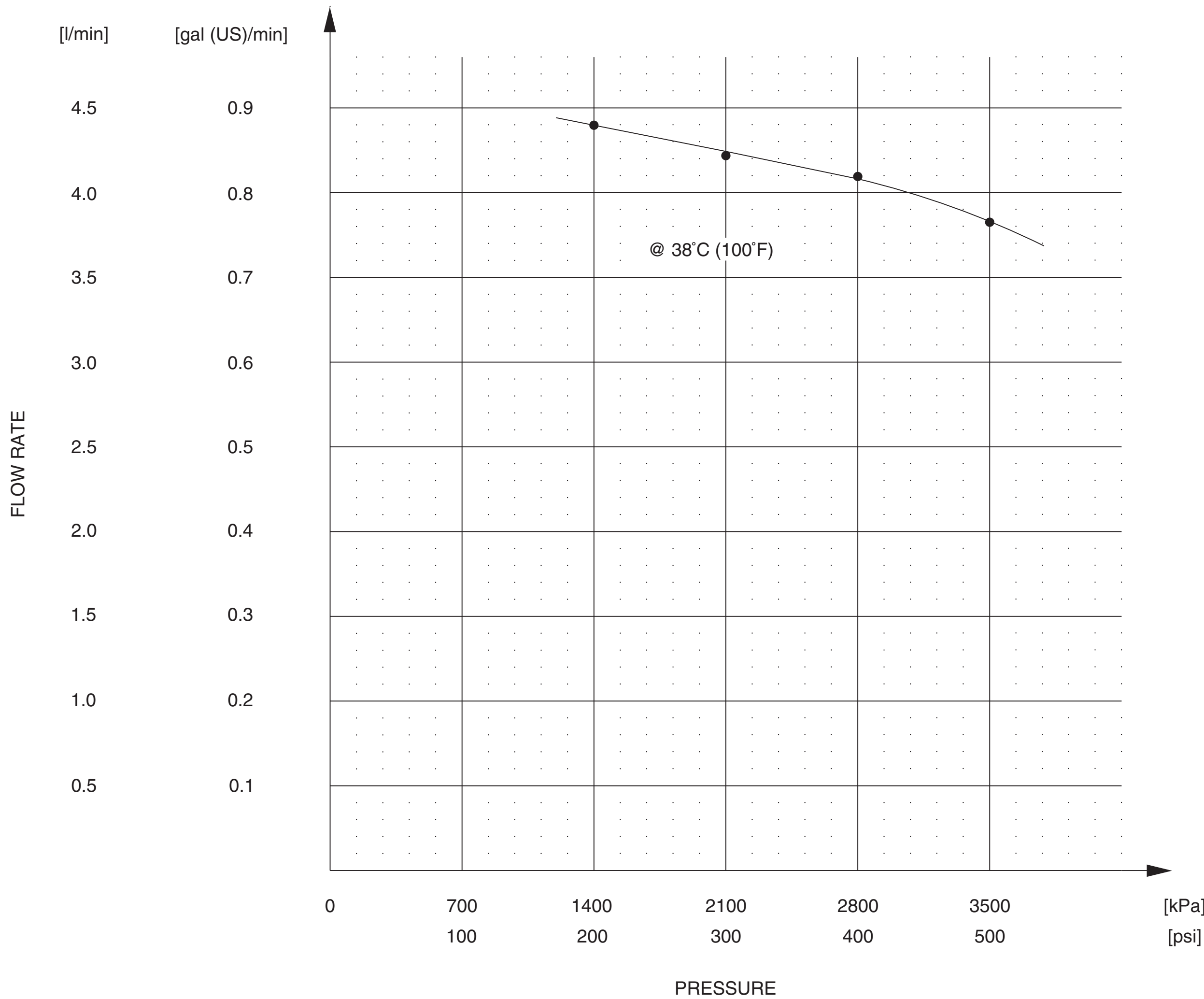


Figure 2-41. Flow rate versus circuit pressure.

☐ 27. Yes. The flow rate of a pump varies according to the circuit pressure, due to internal leakage. As the system pressure increases, the amount of internal leakage increases, which reduces the actual pump flow rate. The relationship between pump flow rate and system pressure will be studied in a later exercise.

☐ 29. Yes. As the flow control valve opening is decreased, the pump must develop more power to overcome the increased circuit resistance.

☐ 31. Yes. As the flow control valve opening is decreased, the pressure drop across the valve increases, causing more power to be dissipated as heat by the flow control valve.

☐ 32. The annular pressure required to lift the power unit is about 2200 kPa (320 psi).

☐ 33. The pump flow rate at a pressure level of 2200 kPa (320 psi) is approximately 3.2 l/min [0.85 gal(US)/min].

☐ 34.

PUMP OUTPUT POWER	CYLINDER OUTPUT POWER	EFFICIENCY
118.3 W (0.159 hp)	86.5 W (0.116 hp)	73.0%

Table 2-11. Circuit efficiency.

☐ 37. No, because some power was lost as heat by frictional resistance of the hoses, directional valve, and cylinder seals.

ANSWERS TO REVIEW QUESTIONS

1. The dissipated power doubles.

2. Both cylinders accomplished the same amount of work.

3. $$P_{(hp)} = \frac{F_{(lb)} \times D_{(ft)}}{t_{(s)} \times 550} = \frac{5000 \text{ lb} \times 3 \text{ feet}}{4 \text{ s} \times 550} = 6.8 \text{ hp}$$

4. 1 hp = 745.7 W
   Cylinder power = 6.8 hp
   System efficiency = 75%
   Electrical power input = $\frac{745.7 \times 6.8 \text{ hp}}{0.75} = 6.76 \text{ kW}$

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