Flow Rate and Velocity

EXERCISE OBJECTIVE

- To describe the operation of a flow control valve;
- To establish the relationship between flow rate and velocity;
- To operate meter-in, meter-out, and bypass flow control circuits.

DISCUSSION

Flow rate is the volume of fluid passing a point in a given period of time. Flow rate is often measured in liters per minute (l/min) in metric units. It is usually measured in US gallons per minute [gal(US)/min] in English units. 1 l/min equals 0.264 gal(US)/min.

Figure 2-22 shows an example. If 100 liters (26.4 US gallons) of water flow past the bridge within one minute, then the river has a flow rate of 100 l/min [26.4 gal(US)/min].

Velocity is the average speed of a particle of fluid past a given point. In hydraulics, velocity is often measured in centimeters per min (cm/min) in metric units, or in inches per min (in/min) in English units.
Flow Rate and Velocity

In a hydraulic line, the rate of oil flow is equal to the oil velocity multiplied by the line cross-sectional area. In equation form:

**Metric units:**

\[
\text{Flow rate (l/min)} = \frac{\text{Velocity (cm/min)} \times \text{Area (cm}^2\text{)}}{1000^*}
\]

**Note:** A liter is 1000 cm\(^2\). Therefore, divide the number of cubic centimeters per minute (cm\(^3\)/min) by 1000 to obtain flow rates in l/min.

**English units:**

\[
\text{Flow rate (gal(US)/min)} = \frac{\text{Velocity (in/min)} \times \text{Area (in}^2\text{)}}{231^*}
\]

**Note:** A US gallon is 231 in\(^3\). Therefore, divide the number of cubic inches per minute (in\(^3\)/min) by 231 to obtain flow rates in gal(US)/min.

The above formulas tell us that a constant flow rate will result in a higher velocity when the cross-sectional area decreases or a lower velocity when the cross-sectional area increases. In fact, the velocity of oil is inversely proportional to the cross-sectional area. Figure 2-23 shows an example, in which a constant flow rate is pumped through two pipes of different diameters. The cross-sectional area of pipe B is twice as large as the cross-sectional area of pipe A. Oil velocity in pipe B, then, is only half as fast as oil velocity in pipe A.

![Figure 2-23. Relationship between oil velocity and cross-sectional area.](image)

**Flow rate and rod speed**

The speed at which a cylinder rod moves is determined by how fast the pump can fill the volume behind the cylinder piston. The more flow the cylinder receives, the more quickly the volume behind the piston will fill with oil and the faster the rod will extend or retract.
Flow Rate and Velocity

The speed of a cylinder rod (V) is calculated by dividing the oil flow rate (Q) by the piston area (A) being acted upon. In equation form:

\[
\text{Rod speed (V)} = \frac{\text{Flow rate (Q)}}{\text{Piston area (A)}}
\]

The **extension speed** of a cylinder rod, then, is equal to the oil flow rate divided by the full piston area, as Figure 2-24 shows. The flow rate and piston area are multiplied by multiplication constants for correct numerical results. Figure 2-24 also shows the formula for calculating the extension time of the cylinder rod, which is a variation of the formula used to calculate the extension speed.

![Extension Speed Formula](image)

The **retraction speed** of a cylinder rod is equal to the oil flow rate divided by the **annular** piston area, as Figure 2-25 shows. Since there is less volume to fill during retraction, the rod will retract faster than it extends for any given flow rate.

![Retraction Speed Formula](image)

Figure 2-24. Rod speed during extension.

Figure 2-25. Rod speed during retraction.
Flow Rate and Velocity

Figure 2-25. Rod speed during retraction.

Flow measurement

The rate of oil flow is measured with an instrument called flowmeter. Figure 2-26 shows the Flowmeter provided with your Hydraulics Trainer. Inside the Flowmeter is a red mark on a white indicating ring. The ring slides over a graduated cylinder, indicating the amount of flow. The Flowmeter must be connected for the direction of flow to be measured, the input port being at the bottom of the scale.

The trainer Flowmeter is graduated in liters per minute (lpm) only. As we said at the beginning of the exercise, liters per minute is a metric unit of measurement for flow rates. When working with English units, the measured flow rate in liters per minute must be multiplied by 0.264 for determining the equivalent flow rate in US gallons per minute [gal(US)/min].

Note: The trainer Flowmeter provides a “lpm” reading. Lpm means exactly the same as l/min, that is, “liters per minute”. Since, however, l/min is the metric unit commonly used for measuring flow rates, flow values in liters per minute will be expressed in l/min throughout the manual.
Flow Rate and Velocity

Flowmeters are designed to accurately read the rate of flow at a specific oil temperature. At lower temperatures, the oil is thick, which places extra pressure on the internal parts of the flowmeter and causes the flowmeter reading to be slightly higher than the actual flow rate. As the oil warms and becomes thinner, the flowmeter reading gets closer to the actual flow value.

Flow control valves

A flow control valve is an adjustable resistance to flow that operates very much like a faucet. By adjusting the resistance, or opening, of this valve, you can modify the rate of oil flow to a cylinder and, therefore, the speed of its piston rod.

Since the flow control valve increases the circuit resistance, the pump must apply a higher pressure to overcome this resistance. This may open the relief valve partially, causing some part of the pumped oil to return to the reservoir through the relief valve, and less oil to go to the flow control valve and cylinder.

Figure 2-27 shows an example. The pump in this figure has a constant flow rate of 3.0 l/min [0.8 gal(US)/min]. The sum of the flow rates in the two parallel paths of flow, then, will always be equal to 3.0 l/min [0.8 gal(US)/min]. Decreasing the opening of the flow control valve will cause more oil to go to the relief valve and less oil to go to the cylinder. Conversely, increasing the opening of the flow control valve will cause less oil to go to the relief valve and more oil to go to the cylinder.
A basic rule of hydraulics states that whenever oil flows through a component, there is a pressure difference, or pressure drop ($\Delta P$) across the component, due to frictional resistance, or opposition to the oil flow, of the component. The pressure drop increases as the component resistance increases. In Figure 2-27, for example, the smaller the flow control valve opening, the higher the resistance of the valve, and the greater the pressure drop across the valve. When the valve is open completely, the valve resistance to oil flow is minimum, so the pressure drop across the valve is also minimum.

Figure 2-28 shows the Flow Control Valve supplied with your kit of hydraulic components. It consists of a needle valve and a check valve integrated in one package.

The needle valve is an adjustable orifice restricting the oil flow from the input to the output port. The check valve allows the oil to flow freely from the output to the input port, however it keeps the oil from flowing in the other direction. Turning the Flow Control Valve knob counterclockwise increases the needle valve orifice and allows more oil to pass through the valve, which increases the cylinder speed.

The trainer Flow Control Valve is of non-compensated type. This means that the valve does not compensate for pressure changes in the system, resulting in a different flow rate through the needle valve for the same needle setting.

Some flow control valves compensate for pressure changes in the system by adjusting the pressure drop across the needle valve, which maintains a constant flow rate through the needle valve for the same needle setting. These valves are of pressure-compensated type.
Flow Rate and Velocity

Flow control circuits

There are three ways to meter the oil flow in order to control the speed of a cylinder, which are: meter-in, meter-out, and bypass.

With the meter-in method, the flow control valve is connected in series between the pump and the cylinder, as Figure 2-29 (a) shows. It restricts the working oil flow to the cylinder. The extra flow delivered by the pump is drained back to the reservoir through the relief valve. This method is useful to control cylinders having a load that resists to the pump delivery, as cylinders raising a load.
Flow Rate and Velocity

With the **meter-out** method, the flow control valve is connected in series between the cylinder and the reservoir, as Figure 2-29 (b) shows. It restricts the flow away from the cylinder. The extra flow delivered by the pump is drained back to the reservoir through the relief valve. This method is useful to slow down cylinders having a load that tends to run away, as cylinders lowering a load.

With the **bypass** method, the flow control valve is connected between the pump and the reservoir, as Figure 2-29 (c) shows. The extra flow is diverted directly to the reservoir through the flow control valve. This method is more energy efficient than the meter-in and meter-out methods because the extra flow returns to the reservoir at the load pressure rather than at the relief valve pressure. However, this method is less accurate because it does not provide direct control of the working flow to the cylinder.

**Conversion factors**

Table 2-4 shows the conversion factors used to convert measurements of flow rate, velocity, and area from S.I. (or metric) units to English units, and vice versa.
Flow Rate and Velocity

<table>
<thead>
<tr>
<th>FLOW RATE</th>
<th>VELOCITY</th>
<th>AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liters per minute (l/min)</td>
<td>x 0.264 =</td>
<td>US gallons per minute [gal(US)/min] x 3.79 =</td>
</tr>
<tr>
<td>Centimeters per minute (cm/min)</td>
<td>x 0.394 =</td>
<td>Inches per minute (in/min) x 2.54 =</td>
</tr>
<tr>
<td>Square centimeters (cm²)</td>
<td>x 0.155 =</td>
<td>Square inches (in²) x 6.45 =</td>
</tr>
</tbody>
</table>

Table 2-4. Conversion factors.

REFERENCE MATERIAL

For additional information on flow control valves and flow control circuits, refer to the chapter entitled Flow Control Valves in the Parker-Hannifin’s manual Industrial Hydraulic Technology.

Procedure summary

In this exercise, you will test the operation of meter-in, meter-out, and bypass flow control circuits while noting the actuation times and pressure drops across the trainer Flow Control Valve. Then, you will test the effect of a meter-out circuit on an over-running load.

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

Meter-in flow control circuit

☐ 1. What is the formula for calculating the extension time, t, of a piston rod? (Refer to Figure 2-24.)

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
Flow Rate and Velocity

2. Using this formula, calculate the extension time of the 3.81-cm (1.5-in) bore cylinder rod for the flow rates in Table 2-5. The stroke length, L, is 10.16 cm (4 in). Record your calculations in Table 2-5 under “THEORETICAL”.

3. Connect the circuit shown in Figures 2-30 and 2-31. This circuit meters the oil flow going to the cylinder.

Notice that the Flow Control Valve must be connected so that the arrow points away from the pump.

Figure 2-30. Schematic diagram of a meter-in flow control circuit.
Flow Rate and Velocity

Figure 2-31. Connection diagram of a meter-in flow control circuit.

☐ 4. 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 (turn knob fully counterclockwise).

☐ 5. Close the Flow Control Valve completely by turning its adjustment knob fully clockwise.

☐ 6. Turn on the Power Unit.

☐ 7. Move the lever of the directional valve toward the valve body and observe the pressure reading at gauge A. Since the Flow Control Valve is fully
Flow Rate and Velocity

closed, the pumped oil is blocked at the Flow Control Valve and is now being forced through the relief valve, so gauge A indicates the minimum pressure setting of the relief valve. While keeping the directional valve lever shifted, turn the relief valve adjustment knob clockwise until gauge A reads 2100 kPa (300 psi).

☐ 8. With the lever of the directional valve still shifted toward the valve body, open the Flow Control Valve, 1 turn counterclockwise, to extend the rod. You should observe that the extension speed increases as you increase the opening of the Flow Control Valve.

☐ 9. Move the lever of the directional valve outward from the valve body to retract the rod. Did the rod retract faster than it extended?

☐ Yes ☐ No

☐ 10. Move the lever of the directional valve toward the valve body to extend the cylinder rod. As the rod extends, close the Flow Control Valve completely by turning its adjustment knob fully clockwise. Does the Flow Control Valve provide direct control of the rod speed?

☐ Yes ☐ No

☐ 11. Retract the rod by moving the lever of the directional valve outward from the valve body. Observe that the rod still retracts at full speed even though the Flow Control Valve is completely closed. Explain why.

Note: The trainer Flowmeter provides a "lpm" reading. Lpm means exactly the same as l/min, that is, "liters per minute". Since, however, l/min is the metric unit commonly used for measuring flow rates, flow values in liters per minute will be expressed in l/min throughout this manual.

☐ 12. Open the Flow Control Valve 1 turn counterclockwise.

☐ 13. Now adjust the Flow Control Valve to 1.5 l/min [0.40 gal(US)/min]*. To do so, move the lever of the directional valve toward the valve body to extend the cylinder rod. As the cylinder extends, observe the Flowmeter reading. Adjust the Flow Control Valve so that the Flowmeter reads 1.5 l/min [0.40 gal(US)/min], then retract the rod. Accurate adjustment may require that the cylinder be extended and retracted several times.
Flow Rate and Velocity

☐ 14. Measure the time required for the rod to extend fully using a stopwatch or the second hand on a watch. Record this value in Table 2-5 under “ACTUAL”. Also record the readings of gauges A and B while the rod is extending. When you have finished, retract the rod.

<table>
<thead>
<tr>
<th>FLOW RATE TO CYLINDER</th>
<th>THEORETICAL EXTENSION TIME</th>
<th>ACTUAL EXTENSION TIME</th>
<th>GAUGE A</th>
<th>GAUGE B</th>
<th>ΔP (GAUGE A – GAUGE B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 l/min 0.40 gal(US)/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 l/min 0.53 gal(US)/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 l/min 0.66 gal(US)/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

☐ 15. Repeat steps 13 and 14 for the other flow rates in Table 2-5.

☐ 16. Turn off the Power Unit. Open the Relief Valve completely by turning its adjustment knob fully counterclockwise.

☐ 17. Compare the actual and theoretical extension times registered in Table 2-5. Are these values within 10% of each other?

☐ Yes ☐ No

☐ 18. Does the rod speed increase or decrease as the flow rate decreases?

☐ 19. Calculate the pressure drop (GAUGE A – GAUGE B) across the Flow Control Valve for each flow rate in Table 2-5. Record your results in Table 2-5 under “ΔP”.

☐ 20. According to Table 2-5, does the pressure drop across the valve increase or decrease as the opening of the valve is increased? Why?

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________
Flow Rate and Velocity

**Meter-out flow control circuit**

- 21. Connect the circuit shown in Figure 2-32. This circuit meters the oil flow going out of the cylinder.

  Notice that the Flow Control Valve must be connected so that the arrow points toward the pump.

![Figure 2-32. Meter-out flow control circuit.](image)

- 22. Close the Flow Control Valve completely by turning its adjustment knob fully clockwise.

- 23. Turn on the Power Unit.

- 24. Move the lever of the directional valve outward from the valve body to retract the cylinder rod completely. With the cylinder rod fully retracted, all the oil from the pump now flows through the Relief Valve and gauge B indicates the minimum pressure setting of the Relief Valve. While keeping the directional valve lever shifted, turn the Relief Valve adjustment knob clockwise until gauge B reads 2100 kPa (300 psi).

- 25. Move the lever of the directional valve toward the valve body to extend the cylinder rod. As the rod extends, open the Flow Control Valve 1 turn counterclockwise. You should observe that the extension speed of the rod increases as you increase the Flow Control Valve opening. Retract the rod.
Flow Rate and Velocity

26. Move the lever of the directional valve toward the valve body to extend the cylinder rod. As the rod extends, close the Flow Control Valve completely (turn knob fully clockwise). Does the Flow Control Valve provide direct control of the rod speed?

☐ Yes  ☐ No

27. Retract the rod. Does the setting of the Flow Control Valve have an effect on the retraction speed?

☐ Yes  ☐ No

28. Adjust the Flow Control Valve so that the Flowmeter reads 1.5 l/min [0.40 gal(US)/min] as the rod extends, then retract the rod.

29. Measure the extension time of the cylinder rod. Record this value in Table 2-6 under “EXTENSION”. Also record the readings of gauges A and B while the rod is extending.

<table>
<thead>
<tr>
<th>FLOW RATE FROM CYLINDER</th>
<th>EXTENSION TIME</th>
<th>GAUGE A</th>
<th>GAUGE B</th>
<th>ΔP (GAUGE A - GAUGE B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 l/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.40 gal(US)/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 l/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.53 gal(US)/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 l/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.66 gal(US)/min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

30. Repeat steps 28 and 29 for the other flow rates in Table 2-6.

31. Turn off the Power Unit. Open the Relief Valve completely (turn knob fully counterclockwise).

32. Calculate the pressure drop (GAUGE A - GAUGE B) across the Flow Control Valve for each flow rate in Table 2-6. Record your results in Table 2-6 under “ΔP”.
33. According to Table 2-6, does the pressure drop across the valve increase or decrease as the opening of the valve is increased? Why?

34. Are the pressure drops in Table 2-6 for a meter-out circuit similar to the pressure drops in Table 2-5 for a meter-in circuit? Why?

Bypass flow control circuit

35. Connect the circuit shown in Figure 2-33. This circuit diverts the extra flow directly to the reservoir through the Flow Control Valve. Notice that the Flow Control Valve must be connected so that the arrow points toward the pump.

36. Close the Flow Control Valve completely by turning its adjustment knob fully clockwise.

37. Turn on the Power Unit.

38. Move the lever of the directional valve toward the valve body to extend the piston rod completely. With the Flow Control Valve closed and the cylinder rod fully extended, all the oil from the pump now flows through the Relief Valve and gauge A indicates the pressure setting of the Relief Valve. While keeping the directional valve lever shifted, adjust the Relief Valve so that gauge A reads 2100 kPa (300 psi). Then, retract the rod completely.
39. Move the lever of the directional valve toward the valve body to extend the rod fully. Since there is no bypass flow path between the pump and the reservoir (i.e., since the flow control valve is fully closed), all the oil flow goes to the cylinder and the rod extension time is minimum. Retract the rod, then extend it and measure the rod extension time. Also, note the flowmeter reading while the rod extends. Record your results in the first row of Table 2-7.

<table>
<thead>
<tr>
<th>BYPASS FLOW PATH</th>
<th>ROD EXTENSION TIME</th>
<th>FLOW RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (flow control valve fully closed)</td>
<td>Minimum:</td>
<td></td>
</tr>
<tr>
<td>Open (flow control valve fully open)</td>
<td>Maximum:</td>
<td></td>
</tr>
<tr>
<td>Partially open (flow control valve partially open)</td>
<td>Intermediate:</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-7. Bypass flow control circuit data.

40. Retract the rod, then open the Flow Control Valve completely by turning its adjustment knob fully counterclockwise. Extend the rod fully. Since the bypass flow path is open (i.e., since the Flow Control Valve is open), the oil flow is diverted directly to the reservoir and the rod extension time is...
maximum. Retract the rod, then extend it and measure the rod extension time. Also, note the flowmeter reading while the rod extends. Record your results in the second row of Table 2-7.

41. Retract the rod. Calculate the difference ($\Delta t$) between the maximum and minimum rod extension times recorded in Table 2-7. Then, determine the intermediate rod extension time and record your result in the last row of Table 2-7.

$$\Delta t = \text{maximum extension time (with bypass)} - \text{minimum extension time (no bypass)} = _____ \text{s}$$

$$\text{Intermediate extension time} = \text{minimum extension time (without bypass)} + \frac{\Delta t}{2} = _____ \text{s}$$

42. Extend and retract the rod several times and adjust the flow control valve so that the rod extension time is equal to the intermediate value obtained in step 41. Note and record the Flowmeter reading when the rod extends at the intermediate speed in the last row of Table 2-7.

43. Continue to experiment with bypass flow control by varying the opening of the Flow Control Valve and observing the effect that this has on the rod extension time. Record your observations.

Controlling the speed of an over-running load

44. Disconnect the Power Unit line cord from the wall outlet.

45. Remove the 2.54-cm (1-in) bore cylinder from its adapter. Make sure the cylinder tip (bullet) is removed from the cylinder rod end.

46. Insert the cylinder rod into the cylinder hole in the Power Unit lifting frame, then fasten the cylinder to the lifting frame by tightening its retaining ring securely. Position the lifting frame over the Power Unit, with its open side at the rear of the Power Unit.

47. Connect the two cylinder ports together using a hose full of oil, then pull the piston rod out until it touches the lifting attachment on the Power Unit. Fasten the cylinder to the Power Unit by screwing the lifting attachment onto the threaded end of the cylinder rod. Then, disconnect the hose from the cylinder.
48. Connect the circuit used to lift the Power Unit shown in Figure 2-34. The Flow Control Valve will restrict the flow going out of the cylinder.

CAUTION!

Make sure the hoses and the Power Unit line cord will not become wedged between rigid parts of the trainer when the Power Unit is lifted.

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

50. Plug the Power Unit line cord into a wall outlet, then turn on the Power Unit.

51. Turn the Relief Valve adjustment knob clockwise until gauge A reads 2800 kPa (400 psi).

52. Move the lever of the directional valve outward from the valve body to lift the Power Unit. Then, move the lever of the directional valve toward the valve body. Does the Power Unit returns to ground uncontrolled?

□ Yes  □ No
Flow Rate and Velocity

☐ 53. Move the lever of the directional valve outward from the valve body to lift the Power Unit, then release the lever. Close the Flow Control Valve completely by turning its adjustment knob fully clockwise.

☐ 54. Move the lever of the directional valve toward the valve body. Does the Power Unit return to ground? Why?

☐ 55. Move the lever of the directional valve toward the valve body and slowly open the Flow Control Valve ¼ turn. Does the Power Unit return to ground suddenly or smoothly? Why?

☐ 56. Once the Power Unit has returned to ground, move the lever of the Directional Control Valve outward from the valve body to lift the Power Unit. Is the lifting speed controlled by the Flow Control Valve? Explain why.

☐ 57. Move the lever of the directional valve toward the valve body until the Power Unit has returned to ground.

☐ 58. Turn off the Power Unit. Open the Relief Valve completely (turn knob fully counterclockwise).

☐ 59. Disconnect the Power Unit line cord from the wall outlet, then disconnect all hoses. Wipe off any hydraulic oil residue.

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

☐ 61. 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

By now, you are familiar with flow control valves. The circuits you studied in this exercise show the three basic flow control techniques. As you tested the flow control circuits, you saw how well hydraulic devices can be controlled under different conditions.

In the first part of this exercise, you used meter-in control to change the cylinder extension speed. At the same time, you observed that the setting of the Flow Control Valve had little effect on the speed of retraction. This was due to the check valve inside the valve. The meter-in control is straight-forward. This control works best against a load which does not change direction. Hydraulic presses and positioning equipment are good examples of such a load.

In the second part of the exercise, you used meter-out control to change the cylinder extension speed. The meter-out circuit is useful in controlling loads that might suddenly start pulling on the actuator and tend to run away. Earth moving equipment is designed to lift and dump loads. At the point where the load begins to drop quickly, a meter-out control circuit keeps flow from moving out of the rod end of the cylinder and generates a back pressure to keep the bucket from falling uncontrolled.

In the third part of the exercise, you tested a bypass flow control circuit. It is fairly different from the meter-in and meter-out circuits. The extra flow is diverted directly to the reservoir through the Flow Control Valve. This method is more energy efficient than the meter-in and meter-out controls because the extra flow returns to the reservoir at the load pressure rather than at the relief valve pressure. However, this method is less accurate because it does not provide direct control of the working flow to the cylinder.

Finally, you tested the effect of a meter-out circuit on an over-running load. Without a meter-out circuit, the Power Unit falls uncontrolled to the ground. With a meter-out circuit, the Power Unit smoothly returns to the ground. The speed at which it returns to the ground can be controlled by modifying the Flow Control Valve opening.

REVIEW QUESTIONS

1. What happens to the speed of a piston rod as the diameter of the piston increases but the flow rate remains the same? Explain.

2. Find two ways to decrease the speed at which a cylinder rod extends or retracts.
Flow Rate and Velocity

3. What flow rate is required to make a 10.16-cm (4-in) bore x 3.81-cm (1.5-in) rod x 30.48-cm (12-in) stroke cylinder extend in 6 seconds?

4. Describe the route of hydraulic oil moved by the pump and not metered through the flow control valve in either a meter-in or meter-out circuit.

5. What type of metering circuit is used to control cylinders having a load that resists to the pump delivery, as cylinders raising a load?

6. What type of metering circuit is used to slow down cylinders having a load that tends to run away, as cylinders lowering a load?

7. Name one advantage and one disadvantage of a bypass flow control circuit over the meter-in and meter-out circuits.
EXERCISE OBJECTIVE

- To define the terms "work" and "power";
- To establish the relationship between force, work, and power;
- To calculate the work, power, and efficiency of a hydraulic system.

DISCUSSION

Work

Work is the motion of a load through a distance that results in something useful being done. Work is expressed in units of force multiplied by distance. In hydraulic systems, work is measured in Joules (J) or Newton-meters (N·m) in S.I. units, and in feet-pounds (ft·lb) in English units.

When the exerted force is constant throughout the motion of the load, the amount of performed work is equal to the force exerted multiplied by the distance moved. In equation form:

**S.I. units:**

$$ \text{Work}_{(J)} = \text{Force}_{(N)} \times \text{Distance}_{(m)} $$

**English units:**

$$ \text{Work}_{(ft \cdot lb)} = \text{Force}_{(lb)} \times \text{Distance}_{(ft)} $$

In Figure 2-35, for example, if the cylinder exerted a force of 100 N (22.5 lb) over a vertical distance of 1 m (3.28 ft), then 100 J (73.8 ft·lb) of work was accomplished.