Chapter 6
Cylinders

Objectives
After studying this chapter, you will be able to:
✓ Describe attributes related to the different types of linear actuators.
✓ Identify the different components used in hydraulic cylinders.
✓ List the different methods manufacturers use to dampen a cylinder’s stroke.
✓ Explain different methods used for sensing a cylinder’s position.
✓ Explain the difference between tension and compression cylinder loads.
✓ Describe how to compute cylinder speeds.
✓ List different types of valves that can be integrated into a cylinder housing.
✓ Explain the principle of cylinder regeneration.
✓ Identify several items that can cause a cylinder to drift.
✓ List the problems that occur when metering-in or metering-out an overrunning load.
✓ Explain the different methods used for synchronizing hydraulic cylinders.
✓ List unsafe actions to avoid when servicing and diagnosing hydraulic cylinders.

Types of Linear Actuators
Hydraulic cylinders are linear actuators that convert fluid energy into linear mechanical energy. Like hydraulic motors, cylinders are the output devices that perform the heavy lifting for mobile equipment. Examples of work performed by the hydraulic cylinders are a haul truck dumping a heavy payload, or an agricultural tractor lifting and moving hay bales, or a combine swinging an unloading auger.

Mobile equipment requires the use of several different types of hydraulic cylinders:
• Single acting.
• Double acting.
• Single rod.
• Double rod.
• Ram.
• Telescoping.

Single-Acting Cylinders
A single-acting cylinder requires only one hydraulic hose and is hydraulically actuated in just one direction. The cylinder uses an outside force to return the cylinder back to its original state. The two common methods for returning a single-acting cylinder is a spring or some type of weight, which is the most common. See Figure 6-1

Figure 6-1. Single-acting cylinders. A—The most common single-acting cylinder application uses fluid pressure to extend the cylinder and some type of external force to retract the cylinder. B—This single-acting cylinder is being used on a combine simulator. Notice the cylinder only has one hydraulic hose, and a heavy weight is used to retract the cylinder. The cylinder is emulating the header raise function. The cylinder could be used as a double-acting cylinder, but a breather is installed in the other hydraulic port.

A single-acting cylinder could be designed so that fluid pressure is used only to retract a cylinder, and a weight is used to extend the cylinder. See Figure 6-2. However, this arrangement is rarely found in mobile equipment. This application is also an example of an overrunning load, which creates problems. Chapter 7 will discuss a pressure control valve that is used to resolve problems with overrunning loads.
Double-Acting Cylinders

A double-acting cylinder uses fluid pressure to extend the cylinder and fluid pressure to retract the cylinder. The most common type of double-acting cylinder is equipped with a single rod. Another name for this actuator is a differential cylinder, due to the piston area differences. See Figure 6-3. The rod side of the piston has less effective area because a portion is displaced by the cylinder’s rod, resulting in an effective area that resembles a ring. The ring’s area is always less than the cap side of the piston.

Another term that is used to frequently describe one side of a cylinder is “head end.” The National Fluid Power Society specifies the rod end of the cylinder as the head end, and the opposite end as the cap end, or blind end. In contrast, Caterpillar and John Deere’s Construction and Forestry (C&F) division frequently label the side that is opposite the rod end as the head end. To avoid confusion resulting from different agencies using the term in different fashions, this text will not use the term “head end.” Instead, it will identify the cylinder ends as the rod end and the cap end.

The difference in areas between a piston’s rod end and cap end affects the cylinder’s output force and output speed. See Figure 6-4. If an equal amount of pressure, such as 1000 psi (69 bar), was applied to both sides of a differential cylinder simultaneously, the cylinder would extend. At first glance it might appear that the cylinder would be statically locked. However, as described by Pascal’s law (Force = Pressure × Area), the difference in areas causes two different forces.

If the cylinder’s piston was three inches in diameter, the cap side area would equal 7.07 in². If the rod’s diameter was 1.5”, the rod would displace 1.77 in² of area from the center of the ring, leaving only 5.3 in² of area on the ring. See Figure 6-5. Notice when 1000 psi is applied to both sides of the cylinder at the same time that the net effective force is a factor of the cylinder’s rod area, in this case 1.77 in².

This principle of different areas within a double-acting cylinder will always result in a stronger extension force than a retraction force for a given system pressure. This principle is also necessary to understand cylinder regeneration, which will be explained later in this chapter.

A similar characteristic exists for cylinder speeds. Chapter 2 explained that, when given a fixed amount of flow, a smaller cylinder area will result in a faster cylinder speed. A larger cylinder area will result in a slower cylinder speed. As a result, anytime a differential cylinder is used in a system with a fixed amount of flow, the cylinder will always retract faster and extend slower.
Excavator manufacturers make use of this inherent principle and maximize it on the boom, stick, and bucket controls. For example, when digging in difficult applications that require high break-out forces, the boom, stick, and bucket cylinders will be extending, which provides maximum cylinder force. See Figure 6-6. However, after the excavator has loaded the bucket, high speed is more desirable, and the extra force is not necessary. Therefore, to dump the bucket, to extend the stick, or to extend the boom, the excavator will retract a hydraulic cylinder for the fastest cylinder speeds at a reduced force.

### Double-Acting, Double-Rod Cylinders

When manufacturers want a cylinder that delivers the same speed and same force in both directions, a second rod is added to the cylinder. See Figure 6-7. The most common application for double-acting, double-rod cylinders is steering.

### Rams

A ram is a single-acting cylinder that uses a cylinder rod that is the same diameter as the cylinder’s piston. Rams are used in applications that require long stroke and must maintain the rigidity of the rod. Some combines use rams to lift the header. See Figure 6-8.

As previously mentioned, single-acting cylinders are retracted using an outside force, something other than fluid pressure. When rams are used to lift a header, the weight of the header must retract the rams. If the feeder house (the housing that feeds crop from the header into the combine and is used for lifting the header) has extra rams added to gain extra lift force, and if the header is removed from the feeder house, the feeder house might be too light to overcome the back pressure in the return circuit. This concern is especially true if the hydraulic system is an open-center system with a fixed-displacement pump. Chapter 16 will explain open-center hydraulic systems in greater detail. To overcome this problem, some manufacturers use double-acting cylinders in place of single-acting rams. Note that the double-acting cylinders can also improve a cylinder’s retraction speed, which can be critical if the machine is operating at fast speeds.

### Telescoping Cylinders

A telescoping cylinder is a linear actuator that contains up to six cylinder tubes that extend to provide a very long cylinder stroke. During retraction, the tubes (also known as sleeves) collapse into a compact cylinder. The cylinder can retract to a length that is 20–40% of the overall extended stroke, compared to the traditional cylinder, which can only be retracted to 50% of the cylinder’s overall length.

### Components

The individual components consist of a barrel, one to four intermediate stages, and a final stage called a plunger. See Figure 6-9. When retracted, the barrel houses all of the collapsed stages.
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Application

The telescoping cylinders can be single acting or double acting. An example of a single-acting telescoping cylinder application is a haul truck’s dump bed. See Figure 6-10. A traditional cylinder would not be able to provide the overall stroke length nor the necessary compactness of the retracted cylinder.

Figure 6-9. A single-acting telescoping cylinder contains a large-diameter barrel, one to four tubes, and a smaller-diameter plunger.

Figure 6-10. Telescoping cylinders are commonly used in dump bed applications, providing very long strokes and very short retraction lengths.

Operation and Inherent Benefit

The cylinder extends in stages. The cylinder’s operation has benefits that are inherent to its design. The larger-diameter stages extend first, because they have the most effective area. The smaller stages extend last. During the initial extension the cylinder extends at the slowest speed and with the most force. This operation is beneficial in a dump truck because it provides smooth and safe extension while the bulk of the load begins to move. A smaller-diameter stage will extend next, causing the cylinder to extend faster with less force. This operation is beneficial because the bulk of the load has been dumped, and an increase in speed is more desirable than greater force as the remaining payload is dumped.

Trash trucks use double-acting telescoping cylinders to actuate the compactor. This cylinder provides the inherent benefit of large forces during compaction. The cylinder also provides a fast retraction speed with a reduced force. The compactor needs little force for retraction because the load exists only during extension. See Figure 6-11.

Figure 6-11. Double-acting telescoping cylinders have the oil routed internally through the cylinder. The effective area for retraction is small, resulting in fast retraction speeds with reduced force.

Cylinder Components and Nomenclature

A hydraulic cylinder contains several individual components: piston, gland, rod, barrel, and seals. The cylinder’s piston is secured to the cylinder’s rod by a nut or a bolt. See Figure 6-13.

Piston Rings and Seals

Pistons have multiple rings and seals installed around their outside circumference. A piston wear ring prevents the piston from rubbing the barrel. A piston
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A piston seal is installed around the outside circumference of the piston. The piston seal's job is to maintain a fluid-tight seal between the barrel and piston as the piston slides in and out of the barrel. Piston seals vary in composition and design. A few factors that manufacturers must consider when choosing a seal is the compatibility of the oil, fluid temperature, seal longevity, cylinder speed, and pressure. Piston seals designs can be categorized into three groups:

- Metal seals.
- Double-acting seals.
- Lip seals.

Seal design and composition determine the effectiveness, durability, and leakage potential of the piston seal. For example, metal seals will leak the most, but are more durable and longer lasting. Metal seals can be steel, cast iron, or chrome-plated steel.

Figure 6-12. This articulated dump truck uses two double-acting telescoping cylinders to dump the bed. The fluid passageways are drilled through the plunger and stages.

A double-acting piston seal holds fluid in both directions. It provides improved sealing over metal seals, but is less durable. O-ring piston seals can be used in double-acting applications. However, the soft rubber O-ring requires the use of a stiff plastic backup ring. The more popular type of double-acting seal uses an outer seal ring made of polytetrafluoroethylene (PTFE), commonly known as Teflon. The Teflon reduces friction, enabling the seal to easily slide between the barrel and the piston. However, Teflon is fairly rigid and requires the use of a rubber ring underneath the Teflon ring. The rubber ring, sometimes known as an expander, places pressure on the sliding Teflon ring.

In Figure 6-15A, the piston seals have been removed. The red ring is the rigid Teflon seal, and the neighboring black ring is the soft rubber ring that holds pressure against the Teflon seal as it rides against the barrel. Figure 6-15B shows the piston with the seal ring installed.

A single-acting piston's lip seal, U-shaped or V-shaped, is designed to hold fluid in one direction. If used in a double-acting cylinder, the piston will require two lip seals. They are less durable than metal seals, but are less likely to leak. Fluid pressure forces the lip to seal against the barrel and piston, providing a snug connection. See Figure 6-16.

Follow the manufacturer's service literature during assembly. The manufacturer might state to coat the seal with petroleum jelly prior to assembly. One service manual recommended heating a piston seal ring prior to installation by placing the ring in 180°–200°Fahrenheit (80°–90°C) water.

Gland

The cylinder's rod is guided by a gland, which acts like a cylinder rod bearing or bushing. See Figure 6-13 and Figure 6-17. The gland is usually removable, providing the technician the ability to disassemble the cylinder.

Cylinder glands are removed with a spanner wrench. A spanner wrench is designed to grip the gland by attaching to the gland's key slots or dowel holes. If a spanner wrench is unavailable, and if the gland has an exterior lip, a large pipe wrench can be used to grip the gland's lip and back the gland out of the cylinder. See Figure 6-18. However, to prevent damage to the gland's outside surface, a spanner wrench should be the first choice for removing the gland.

Figure 6-14. This double-acting cylinder piston has a wide wear ring.
Note
If a spanner wrench is unavailable, and if a pipe wrench does not fit on the gland, it is possible to fabricate a spanner wrench. A spanner wrench can be made by welding properly spaced dowel pins to a piece of steel.
A gland contains an internal wear ring that prevents the cylinder rod from rubbing on the gland. An external O-ring seal is also located on the threads of the gland. This static seal prevents leakage between the gland and the barrel.

**Barrel**

After a gland has been removed, the barrel can be honed. A Flex-Hone® is an attachment placed on a lathe or a drill and is used to machine the inside surface of the barrel. See Figure 6-19. The hone deglazes the surface removing rust and small blemishes. If a cylinder is rebuilt and not honed, it is possible that the piston seals will leak because the barrel's surface is too slick. The hones are offered in eight different material compositions. One of the most popular hones used for hydraulic cylinders is made of silicon-carbide.

Cylinder housings vary in design. Some cylinders cannot be rebuilt, because they are welded together from the factory. A tie bolt cylinder is designed to be repairable. The housing contains four long bolts that mate the rod end with the cap end. See Figure 6-20. These cylinders are commonly found on agricultural implements. The cylinders can be easier to rebuild and contain an O-ring seal between the cylinder's barrel and the end plates. The cylinders are also known as tie rod cylinders.

**Cylinder Rod**

The cylinder's rod must also be considered during a rebuild. If the rod has cracks, nicks or is bent, it will cause leakage. The rod's surface can be rechromed. If repair parts are unavailable because the cylinder is too old, a hydraulic repair shop can fabricate a rod, or even an entire cylinder, using materials they have on hand.

**Cylinder Loads, Damping, and Speeds**

As machines are manufactured, the type of cylinder load, potential shocks, and cylinder speeds must all be factored into the machine's design. Loads exerted on cylinders are classified as thrust loading and tension loading. A **thrust load** occurs anytime a cylinder must push a load. This is also known as compression loading. A **tension load** occurs any time a cylinder pulls a load. It is also known as shear loading.

**Cylinder Dampening**

Hydraulic cylinders can exert shock loads to machines. Shock loads occur when the cylinder's piston harshly hits the cylinder barrel as it reaches the end of travel. The shock loads jar machine components and linkages causing potential damage. Manufacturers use different techniques to reduce the shock loads placed on the machine:
- Cushioned cylinders.
- Orifices.
- Accumulators.
- Programmable kick-outs.

A cylinder cushion consists of an internal plunger that blocks off a larger portion of the cylinder's flow as the cylinder reaches the end of travel. See Figure 6-21. When the plunger reaches its cavity, the cylinder's remaining oil must flow through the cushioned oil passage. A threaded adjustment is often placed in the cavity providing some adjustment to the cushion.

Cylinder cushions can be designed as fixed, variable, cushioned in just one direction, or cushioned in both directions. A reverse flow check is used when the cylinder is actuated in the opposite direction. It routes oil to the piston allowing the fluid to act on the entire piston area, not just the area of the plunger.

An orifice can be used to dampen the stroke of a cylinder. The schematic in Figure 6-22 shows a cylinder that is cushioned and dampened. The orifice restricts and limits the rush of fluid into the cylinder's inlet. Only after the cylinder reaches its end of travel will the cylinder's supply pressure reach the full system pressure. The result is a dampened cylinder. The orifice can be located at the DCV or it can be integrated at the cylinder.

Accumulators are frequently used in mobile machinery to dampen a cylinder's shock loads. Chapter 13 will explain accumulator fundamentals and applications.
A cushioned cylinder consists of a plunger that blocks off the cylinder’s oil flow as the cylinder reaches the end of travel, which slows the cylinder as it reaches its end of travel. Figure 6-21.

The schematic shows that the cylinder contains a cushion in both directions, an orifice in both directions, and pilot-operated check valves in both directions. Figure 6-22.

Cylinder Speeds

Today’s electronic controls can also be used to reduce cylinder shock loads. Construction wheel loaders use programmable kick-outs. The operator accesses the programmable option in the machine’s monitor. The operator places the bucket in the desired position then presses the monitor’s key to have the bucket “kicked out” once it reaches that set position. Kick-out is a term used to indicate that the cylinder has stopped moving. A kick-out can be set for the lower position and the raise position. The monitor can have several other features allowing the operator to set the kick-out for a specific work tool being used, such as pallet forks or bucket. The kick-out can be set for tilting, or curling, the bucket as well.

The machine’s ECM determines the cylinder’s position through a sensor. As the cylinder reaches the end of travel, the ECM will slow the cylinder by varying the electronically controlled DCV.

A cylinder stroke can be mechanically limited. A stop tube is sometimes placed inside a cylinder, which limits the overall stroke of the cylinder. See Figure 6-23. Stop tubes are sometimes used when a cylinder has a long rod, and the rod has a tendency to buckle or bend. The stop tube will prevent the rod from fully extending.

Agricultural implements frequently use an external depth stop that consists of an aluminum clamp that fits around the cylinder’s rod. See Figure 6-24. These types of depth stops are readily available at farm equipment stores. The clamps are available in a variety of thicknesses and are used to adjust the individual wings on implements. The clamps are easily installed and can be quickly removed from the cylinder.

A cylinder’s speed can be calculated if the cylinder’s area is known and the quantity of oil flow into the cylinder is known. The speed is measured in feet per minute (ft/min), feet per second (ft/sec), or meters per second (m/sec). The speed of a cylinder is computed by multiplying the flow rate times a factor, and dividing that product by the cylinder’s area:

\[
\text{Speed (ft/min)} = \frac{\text{Flow (gpm)} \times 19.25}{\text{Area (in}^2\text{)}}
\]

\[
\text{Speed (ft/sec)} = \frac{\text{Flow (gpm)} \times 0.3208}{\text{Area (in}^2\text{)}}
\]

\[
\text{Speed (m/sec)} = \frac{\text{Flow (lpm)} \times 0.167}{\text{Area (cm}^2\text{)}}
\]

If a cylinder was supplied a 20 gpm of oil, and if the cylinder had an area of 7.07 in², the cylinder would extend at a rate of 54 feet per second. A factor
of 19.25 is used. It was derived by dividing the quantity of a gallon (231 in³) by 12” (foot), which equals 19.25. The same factor can be converted to solve for feet per second by dividing the 19.25 by 60 seconds, equaling 0.3208.

The same cylinder can be computed in metric units of measurement. A flow rate of 75.7 lpm and an area of 45.6 cm² would equal a cylinder speed of 0.277 m/sec.

Cylinder Electronic Sensing

Electronically controlled machines use a variety of sensors to measure a cylinder’s position and the load on a cylinder. Sensing the position and/or cylinder load provides inputs for two types of systems: automatic implement controls and automatic guidance systems. Some examples of automatic implement controls are:

• Automatic header height on a combine.
• Load control for an agricultural tractor’s three-point hitch.
• Slope control on a motor grader.
• Grade control on an excavator.
• Grade control on a dozer.

Two common technologies used for sensing a cylinder’s position are potentiometers and magnetostrictive transducers. A potentiometer is a three-wire sensor that provides a variable resistance based on the location of the signal wiper. See Figure 6-25. Potentiometers provide an indirect method of measuring a cylinder’s position. The sensor is often located on the implement away from the cylinder, as on a combine’s feeder for example. As the lift cylinders are actuated, the feeder moves, causing the potentiometer to rotate. This provides the ECM with an indirect input of the position of the feeder cylinders.

A magnetostrictive cylinder sensor is an internal linear-displacement transducer (LDT) that directly measures a cylinder’s position. The cylinder’s piston and rod have a passageway drilled through their center. The sensor has a shaft that fits inside the rod’s passageway. See Figure 6-26. A magnet is located in the cylinder’s piston. As the piston is actuated, a pulse-width modulated signal is transmitted through two wires located inside the sensor’s shaft. The magnet moves in relation to the shaft, allowing the sensor to gauge how far the cylinder has been extended. Magnetostrictive cylinders are used for steering cylinders on combines and motor graders. The sensors are used for automatic guidance systems.
Cylinders can contain pressure sensors that measure a load placed on a cylinder. The feeder lift cylinders on a combine have a pressure sensor connected in parallel with the lift cylinders. The machine has a float setting, which measures the load on the cylinders using the pressure sensor. The combine’s header float is designed to allow the header to float across the ground by means of sensing the feeder cylinders’ pressure.

Agricultural tractors are frequently equipped with three-point hitches. The hitches often are configured with a three-point hitch rockshaft potentiometer and a hitch pin strain gauge sensor. The two sensors measure the position of the hydraulically controlled hitch and the draft load exerted on the hitch. The ECM will raise and lower the hitch’s hydraulic cylinder based on input from those two sensors plus operator inputs, such as sensitivity and commanded position.

The ECM that monitors these various cylinder inputs will require a calibration process. The calibration is typically required after a sensor has been replaced, or if an error has occurred. Some calibrations take place every time the key has been cycled and the lift function is initiated.

Valving Designed for Cylinders

Machine manufacturers incorporate different valve technologies within mobile equipment to protect and control cylinders. Designers sometimes integrate valves directly into the cylinder housing. Some examples of pressure-control valves that can be mounted inside cylinder housings are pilot-operated check valves, counterbalance valves, thermal-relief valves, or pressure-relief valves. Chapter 7 will detail the purpose and operation of pressure-control valves.

Regeneration

One valve technology that is designed specifically for a double-acting differential cylinder is regeneration. Cylinder regeneration takes place when an unloaded differential cylinder is extending and its return oil is rerouted to the cylinder’s inlet. See Figure 6-27. The principle is similar to the way a positive-displacement pump generates a low pressure in a cavity that has an expanding volume and a higher pressure in a cavity with a decreasing volume.

When the two cylinder ports are connected together, the cylinder will extend due to the larger area on the cap side of the piston. Plus the cylinder will extend at a faster speed, because it is regenerating use of the oil that is normally routed to the reservoir.

Regeneration is sometimes used on loader circuits to increase the speed for dumping a bucket. A DCV in the regeneration position is illustrated in Figure 6-28. The regeneration portion of the spool is highlighted in yellow.

Cylinder Drift

Cylinder drift occurs when a rod leaks down over an extended period of time. Several different types of valves can cause this problem if the valves are leaking or malfunctioning:

- Thermal-relief valves.
- Cylinder port relief valves.
- Pilot-operated check valves.
- Counterbalance valves.
- Lift check valves.
- Secondary poppet valves.

The operation of these valves will be detailed in Chapter 7 and Chapter 9.
One misconception related to cylinder drift is that it is usually the result of a bad piston seal. However, a failed piston seal can cause a cylinder to drift only if the cylinder rod is pointing toward the ground. In Figure 6-29, the cylinder's rod is pointing upward. For this example, consider the cap side of the cylinder has an area of 10 in² and the cylinder's ring area is 9 in². If the piston's seal had a failure or was even removed, before the cylinder could drift back into the barrel one inch, it would require displacing 10 in³ of oil from the cap side, and it would have to place that 10 in³ in a 9 in³ cavity in the rod side of the cylinder. As a result, a cylinder that has the rod facing upward cannot drift due to a piston seal failure.

However, if the double-acting cylinder has the rod facing toward the ground, a piston seal failure can cause the cylinder to drift. See Figure 6-30. Presuming the cylinder has the same areas, 10 in² on the cap side and 9 in² on the rod side, if the cylinder moved one inch, then 9 in³ of oil from the rod side would easily fit in a 10 in³ cavity on the cap side, and the cylinder would be allowed to drift. As the cylinder moved, the voided 1 in³ cavity on the cap side would drop to a vacuum state.

The dozer in Figure 6-31 has two double-acting cylinders used to raise the blade. The blade has been removed. Notice the cylinder on the left has leaked down and the cylinder on the right remains secure in its barrel. Chapters 21 and 22 will detail equipment and methods used for diagnosing cylinders.

Figure 6-29. A double-acting cylinder cannot drift back into the barrel due to a bad piston seal if the rod is pointing upward. The amount of oil that is displaced from the cap side cannot fit into the smaller cavity in the rod side.

Figure 6-30. A double-acting cylinder that has the rod facing toward the ground can drift out of the barrel due to a faulty piston seal.

Figure 6-31. The dozer blade cylinder on the left has drifted and the cylinder on the right remains secure. Because the rods are pointing toward the ground, a faulty piston seal can cause the cylinder to drift.
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Metering-In and Metering-Out Overrunning Loads

Manufacturers choose different methods for controlling the speed of hydraulic cylinders. Metering-in and metering-out are two methods used for controlling cylinder speeds. If a cylinder is actuating an overrunning load, then both metering-in and metering-out will cause problems.

A metering-in circuit will restrict the oil flowing into a cylinder. If the cylinder has an overrunning load, the weight of the cylinder can cause the rod to extend faster than the pump can supply oil, resulting in cavitation. See Figure 6-32. Make-up valves and counterbalance valves provide solutions to resolve this problem. Those valves will be explained in Chapter 7 and Chapter 8.

If the needle valve was placed in the other working line of the cylinder to limit the cylinder’s return oil, the cylinder’s speed would be controlled in a metering-out fashion. See Figure 6-33. When a restriction is placed in the return line of an extending double-acting cylinder, the cap side of the cylinder will cause pressure on the rod side to intensify. The pressure can intensify enough to damage components. As mentioned, Chapter 7 will explain counterbalance valves, which are used to resolve this problem.

Synchronizing Cylinders

Hydraulic circuits frequently require multiple cylinders to extend simultaneously to lift a single load. Depending on how the cylinders are plumbed, they can rise at different rates, causing the implement to lift unevenly. If the cylinders are plumbed in parallel, without any additional provision, the cylinders will extend at different rates due to variations in load. See Figure 6-34.

Mobile machinery uses multiple methods for keeping cylinders synchronized and for rephasing the cylinders back into synchronization. The most common method of extending two cylinders simultaneously is to plumb the cylinders in a master/slave series configuration. See Figure 6-35.

The master and slave cylinders must have a specific area relationship. The slave cylinder’s piston area must equal the difference of the master cylinder’s area minus the rod’s area. See Figure 6-36. For example, a planter that uses a 3.25” diameter master cylinder with a 1.25” diameter rod, will require a slave cylinder with a 3” diameter piston.

Three common applications for series cylinder configurations are reel lift on a combine header, reel fore and aft on a combine header, and lift cylinders on agricultural implements such as planters.
Two cylinders that are plumbed in parallel will not extend simultaneously, due to the differences in friction and loads on the cylinders. Figure 6-34.

Mobile machinery that uses two or more double-acting cylinders commonly connect the cylinders in series. Cylinder A (master cylinder) and Cylinder B (slave cylinder). Figure 6-35.

If the series cylinders leak or get out of synchronization, it can be challenging to resynchronize the cylinders, also known as rephasing. Some planters have rephasing orifices in the cylinders. The operator rephases the cylinders by holding the DCV in the raise position until the cylinders are placed back in sync. See Figure 6-37.

Some implements have the cylinders in parallel and use rephasing relief valves. If one of the parallel cylinders reaches its end of travel and the operator continues to hold the DCV in the raise position, the rephasing relief valve supplies oil to the other cylinder that is continuing to extend. The rephasing valves are commonly used in conjunction with a flow divider valve. The flow divider valve is used to proportion oil to different sized implement cylinders that are plumbed in parallel. See Figure 6-38. Proportional flow divider valves will be explained in Chapter 8.

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<td>7.065</td>
</tr>
</tbody>
</table>

Figure 6-36. This table shows that the difference in areas between the master cylinder’s piston and rod must equal the slave cylinder’s piston area.

Rephasing orifices are commonly used in planter lift cylinders. They allow an operator to place the cylinders back into synchronization by holding the DCV in the raise position until the cylinders are synchronized. Figure 6-37.
Figure 6-38. Some planters use rephasing relief valves when the cylinders are connected in parallel. When one cylinder reaches the end of travel, the operator can continue to hold the DCV control valve in the raise position, and the remaining oil will be routed to the other cylinder that is continuing to extend.

Cylinder Safety

Technicians are frequently tasked with repairing a hydraulic cylinder. It is common for the cylinder's piston or gland to be seized, making it difficult to remove, even after the snap ring has been removed and the gland has been unthreaded. Do not attempt to use compressed air or heat the cylinder's barrel with a torch.

A September 2001 Hydraulics and Pneumatics Journal article by Rory McClaren recommends placing the hydraulic cylinder with the rod downward inside a bucket. See Figure 6-39. A vise might be needed to hold the cylinder in place. At the opposite end, fill the cylinder with hydraulic oil. With the cylinder's snap ring removed, use a hydraulic hand pump to slowly push the piston rod and gland assembly out of the barrel. Observe the pressure gauge while applying pressure with the hand pump. If the pressure exceeds the cylinder's specification, the cylinder must be scrapped. The bucket is used to catch the oil when the rod is freed from the cylinder. Use only a hand pump; do not use a running hydraulic system.

Do Not Attempt to Stall a Hydraulic Cylinder or Motor under Pressure

While diagnosing and servicing hydraulic machines, technicians have at times been tempted to mechanically limit or prevent an actuator from moving while the actuator receives full hydraulic pressure and flow. This action must be strictly avoided. While hydraulic components might appear to be small, their output power can be tremendous. A small hydraulic motor can easily produce 10 hp. Considering that a single horsepower is the equivalent to 550 foot pounds per second, any attempt to stall an actuator puts personnel at serious risk of injury. For this reason, technicians must never attempt to mechanically stall, bind, or hold a hydraulic cylinder or motor to prevent it from moving.

Do Not Attempt to Mechanically Actuate a Cylinder or Motor while It Is under Pressure

Other injuries have occurred when technicians have attempted to mechanically assist a stuck hydraulic motor to rotate while the motor is under pressure, or assist a seized cylinder that is under pressure. These actions should also be strictly avoided. If an actuator is inoperable, pressures and flows should be checked, but technicians should never attempt to mechanically assist a hydraulic actuator to move.

Figure 6-39. A seized cylinder piston or gland can be difficult to remove. Hold the cylinder in a vise. Fill the cylinder with oil. Install a pressure gauge and use a hydraulic hand pump to push the seized piston or gland out of the cylinder. If the pressure reaches the cylinder's limit, a new cylinder will need to be ordered and the old cylinder will need to be scrapped.
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Summary
✓ Single-acting cylinders use fluid pressure in only one direction.
✓ A double-acting, single-rod cylinder exhibits different forces when extending and retracting under a given pressure and different speeds when extending and retracting using a given flow.
 ✓ Telescoping cylinders provide long strokes, and compact lengths when retracted.
✓ A ram’s cylinder rod is the same diameter as the cylinder’s piston.
✓ The gland guides the cylinder rod during extension and retraction.
✓ Wear rings prevent metal-to-metal contact during cylinder operation.
✓ Piston seals can be metal, Teflon, lip design, or O-ring.
✓ Rod seals retain the cylinder’s fluid.
✓ Rod wipers prevent outside contaminants from entering the cylinder.
✓ Cylinder shock loads can be dampened with cushioned cylinders, orifices, accumulators, or programmable kick-outs.
✓ Computing a cylinder’s speed requires knowing the cylinder’s area and input flow.
✓ Potentiometers and magnetostrictive sensors measure the position of a cylinder.
✓ When the cap end and rod end of a double-acting cylinder are plumbed together, the cylinder will regenerate.
✓ Cylinders can drift due to a bad pressure control valve.
✓ A bad piston seal can cause cylinder drift only if the rod points toward the ground.
✓ Manufacturers use master/slave series designs to synchronize two cylinders.
✓ Rephasing orifices and rephasing relief valves are used to place cylinders back into synchronization.
✓ Compressed air and heat should never be used to remove a seized cylinder piston or gland.
✓ Do not mechanically restrict or stall an operating actuator.
✓ Do not mechanically assist an actuator that is under pressure.

Technical Terms

- cap end
- cushion
- differential cylinder
- double-acting cylinder
- gland
- head end
- lip seal
- magnetostrictive cylinder sensor
- metering-in
- metering-out
- potentiometer
- programmable kick-outs
- ram
- regeneration
- rod seal
- single-acting cylinder
- spanner wrench
- telescoping cylinder
- tension load
- thrust load
- tie bolt cylinder
- wear ring
- wiper

Review Questions

1. A double-acting, single-rod cylinder has 500 psi pressure applied simultaneously to both the rod and cap side of the cylinder. What will the result be?
   A. The cylinder will retract.
   B. The cylinder will be hydraulically locked.
   C. The cylinder will extend.
   D. Answer varies, depending on the type of rod seal installed.

2. During the extension of an excavator’s boom, stick, or bucket, which of the following will occur?
   A. The boom, stick, and bucket will exhibit maximum force.
   B. The boom, stick, and bucket are extended by extending the cylinder.
   C. The boom, stick, and bucket will exhibit the slowest speed.
   D. The boom, stick, and bucket will have reduced force while the arms are extending.

3. If a needle valve is used to meter oil into a hydraulic cylinder with an overrunning load, what will occur?
   A. Cavitation.
   B. Pressure intensification.
   C. Both A and B.
   D. Neither A nor B.

4. If a needle valve is used to meter oil into a cylinder with an overrunning load, which of the following could occur?
   A. Cavitation.
   B. Pressure intensification.
   C. Both A and B.
   D. Neither A nor B.

5. Which of the following terms refers to a plunger blocking off a portion of a cylinder’s flow at the end of its travel?
   A. Main relief valve.
   B. Rejuvenation.
   C. Cushion.
   D. Regeneration.

6. If a cylinder pulls a load, what type of load is it?
   A. Tension.
   B. Stress.
   C. Thrust.
   D. Inertia.

7. If a cylinder pushes a load, what type of load is it?
   A. Tension.
   B. Stress.
   C. Thrust.
   D. Inertia.

8. Which of the following should be used to remove a seized piston from a cylinder?
   A. Acetylene torch with rosebud tip.
   B. Compressed air.
   C. Hydraulic hand pump.
   D. Fluid from a running tractor.

9. Technician A states that it is okay to use a lever to extend a frozen cylinder while applying full system pressure to the cylinder. Technician B states that it is okay to check for cylinder leaks at mid-stroke by holding the cylinder using a stop. Who is correct?
   A. Technician A.
   B. Technician B.
   C. Both A and B.
   D. Neither A nor B.

10. Which of the following terms refers to a master cylinder used to position and synchronize two cylinders?
    A. Main relief valve.
    B. Rejuvenation.
    C. Cushion.
    D. Regeneration.

11. Which of the following terms refers to routing the oil from the rod side of a differential cylinder to the cap side?
    A. Main relief valve.
    B. Rejuvenation.
    C. Cushion.
    D. Regeneration.
12. As a cylinder rod moves back and forth, it is guided and supported by which of the following?  
A. Gland.  
B. Piston.  
C. Barrel.  
D. Cap.

13. What is the advantage of connecting two cylinders in series?  
A. Keeps the cylinders synchronized.  
B. Prevents cavitation.  
C. Generates higher lifting force with less input pressure.  
D. Lowers the system’s pressure.

14. Which of the following cylinders has a rod with the same diameter as the piston?  
A. Single acting.  
B. Double acting.  
C. Telescoping.  
D. Ram.

15. Which of the following cylinder input devices sends a pulse-width modified signal through the center of the rod and uses a magnet inside the piston?  
A. Potentiometer.  
B. Rheostat.  
C. Thermistor.  
D. Magnetostrictive sensor.

16. The length of a fully collapsed telescopic cylinder can be as little as _____ of its extended stroke length?  
A. 10 to 20%  
B. 20 to 40%  
C. 40 to 60%  
D. 60 to 80%

17. All of the following are used to dampen a cylinder to prevent shock loads, EXCEPT:  
A. orifice.  
B. programmable kick-out.  
C. cushion.  
D. wear ring.

18. Technician A states that cylinder glands contain a wear ring. Technician B states that cylinder pistons contain a wear ring. Who is correct?  
A. Technician A.  
B. Technician B.  
C. Both A and B.  
D. Neither A nor B.

19. Technician A states that telescoping cylinders can be double acting. Technician B states that telescoping cylinders can only be single acting. Who is correct?  
A. Technician A.  
B. Technician B.  
C. Both A and B.  
D. Neither A nor B.

20. What type of speed will a telescoping cylinder exhibit during the initial extension?  
A. Slow.  
B. Medium.  
C. Fast.

21. What type of force will a telescoping cylinder exhibit during the final stage of extension?  
A. Small.  
B. Medium.  
C. Large.

22. Which of the following has the responsibility of preventing a cylinder from leaking oil?  
A. Piston seal.  
B. Rod seal.  
C. Rod wiper.  
D. Wear ring.

23. Which of the following has the responsibility of preventing contaminants from entering a cylinder?  
A. Piston seal.  
B. Rod seal.  
C. Rod wiper.  
D. Wear ring.

24. A piston seal is being installed; the service manual states to heat the seal prior to installation. What method is used to heat the seal?  
A. Butane torch.  
B. Acetylene torch.  
C. Heat gun.  
D. Hot water.

25. Technician A states that pipe wrenches are sometimes used to remove a cylinder’s gland. Technician B states spanner wrenches should never be used to remove cylinder glands. Who is correct?  
A. Technician A.  
B. Technician B.  
C. Both A and B.  
D. Neither A nor B.

26. Prior to assembly of a rebuilt cylinder, what should be used to machine the cylinder’s barrel?  
A. 1000-grit sandpaper.  
B. Emery cloth.  
C. Flex hone.  
D. Die grinder.

27. External aluminum clamp-on stops are commonly used in what application?  
A. Motor graders.  
B. Backhoes.  
C. Agricultural implements.  
D. Agricultural combines.

28. A cylinder with a five-centimeter diameter is receiving 30 lpm. What is the cylinder’s extension speed?  
A. 0.255 m/sec  
B. 0.355 m/sec  
C. 0.455 m/sec  
D. 0.555 m/sec.

29. Rephasing relief valves are used in what type of cylinder circuit?  
A. Cylinders in series.  
B. Cylinders in parallel.  
C. Both A and B.  
D. Neither A nor B.

30. Rephasing orifices are used in what type of cylinder circuit?  
A. Cylinders in series.  
B. Cylinders in parallel.  
C. Both A and B.  
D. Neither A nor B.