Hydraulic Valves

Purpose

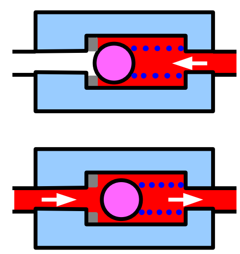
A valve controls one of three things.

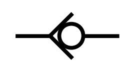
- **Direction**. If we want to send fluid to one place or another, or prevent flow from going in reverse, we use a *directional control valve* (DCV).
- **Pressure.** If we want to control the pressure in the downstream flow, we use a *pressure control valve* (PRV). This is the type of valve we use on the pneumatic test stand to vary the pressure in the system.
- **Flow**. If we want to control the amount of fluid flowing past the valve, we use a *flow control valve* (FCV). This is the type of valve you have in your kitchen sink.

Directional Control Valves

Check Valves

Check valves allow flow in one direction only. The simplest way to build a check valve for fluid power systems is to use a ball bearing and a spring. The spring (blue dots, in cross section) pushes the ball (pink) against a seat (gray). In this cartoon, hydraulic fluid is red. When fluid tries to flow through the valve, the ball presses against the seat, and fluid won't flow.



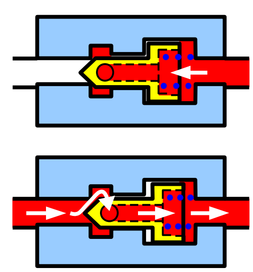


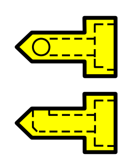
When fluid tries to flow in the other direction, it pushes against the ball, compressing the spring. The ball moves, and fluid can flow past. The fluid must develop enough pressure to counteract the spring force…so check valves can be designed to prevent very low pressure flow, while allowing higher pressure flow.

The symbol of a check valve is a cartoon of a ball and seat. The ball can move to the right, but it can't move to the left because of the V-shaped seat.

There are check valves built in to all the hoses and fittings on the hydraulic stand, so if you don't completely seat a hose on a fitting, it won't spew hydraulic fluid all over your shirt when you turn the pump on. Instead, fluid won't flow. Check valves are useful to protect the safety of operators.

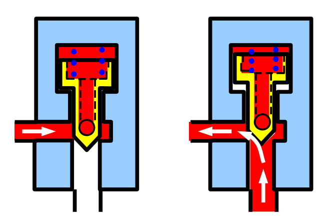
Think about a check valve the way you think about an electrical diode…it passes electrical current one way, but not the other way.





If you want direct flow through the valve, you can use a hollow *poppet* instead of a ball bearing. The poppet has a transverse hole drilled in the side, and a longitudinal hole drilled from one end. When the fluid tries to flow through the valve, the poppet seats against the housing, stopping flow. When the fluid flows the other direction, the poppet moves, and you get flow through the core of the poppet, and out the other side.

One of the drawbacks of this type of valve is that, as the flow increases, the pressure drop across the valve also increases. You can limit this effect by redesigning the valve to allow better flow.



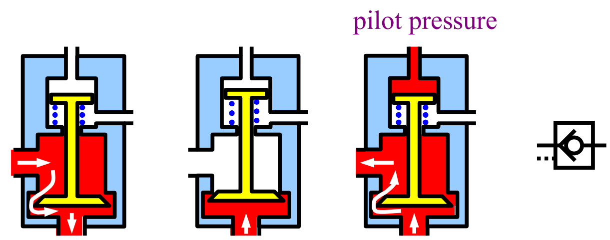
If you design your check valve to operate through a right angle, you can get higher flows with less pressure drop…because the fluid doesn't have to go through the poppet itself. If the flow comes in from the left, the poppet is seated, and fluid doesn't flow through the valve.

If the flow comes up through the bottom of the valve, it pushes the poppet up against the spring, and flows around the bottom of the poppet and out the left side port.

You can get valves like this rated up to 300 gpm. A top-loading washing machine typically has a capacity of 50 gallons. A valve that handles 300 gpm can handle the volume of 6 large washing machines in a minute…that's a pretty good flow rate.

Although the main flow doesn't go through the poppet, the poppet still needs holes because it's got a little fluid behind it. If the poppet moves up, that fluid has to go somewhere…so you can either run it to drain, which means extra lines, or you can use a hollow poppet, so the excess goes back into the main flow.

The check valves described above use fluid acting directly on the poppet or ball. Another way to build a check valve is to apply a secondary pilot pressure to part of the valve. With a *pilot-to-open check valve* we get free flow of fluid in one direction, and no flow in the other direction, *unless* a pilot signal opens the valve.

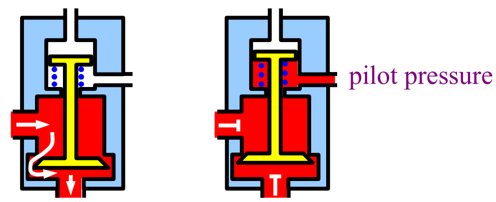


If we have flow from the left, it pushes on the poppet, overcoming the spring force, and the valve opens. If flow goes the other way, the spring pushes the poppet upwards, and the valve closes. However, if we apply pressure to the pilot port at the top, this pressure pushes on the piston, compresses the spring, and opens the valve.

You could use this type of valve to hold a hydraulic cylinder locked in place until a main directional control valve is shifted.

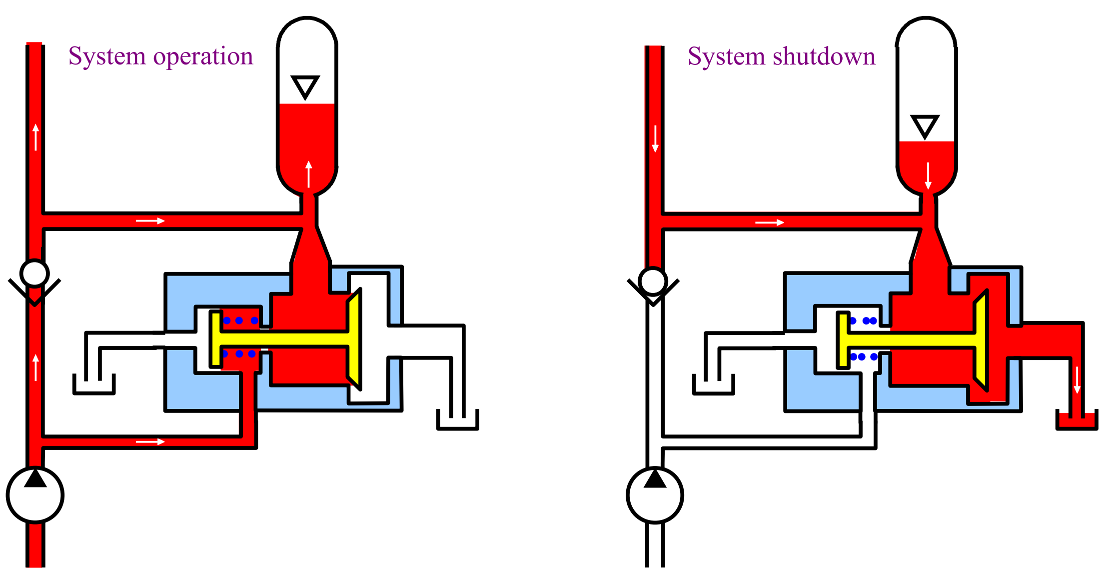
The symbol looks like a conventional check valve symbol, with a dashed line representing the pilot line.

We can turn this into a *pilot-to-close check valve* by applying pilot pressure the other way…so the valve is locked, and there's no flow in either direction.



What we have is a valve which operates automatically to keep flow moving only in one direction, or it can be opened by remote control to allow flow in both directions, or it can be closed by remote control to prevent flow in any direction. This is a pretty useful flow control device.

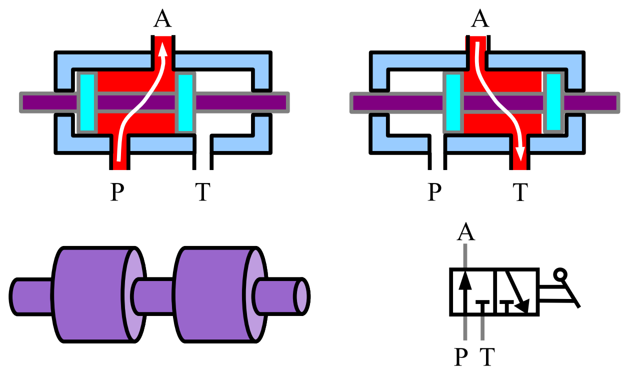
One application of this type of valve is for pressure relief from a gas-charged accumulator when a machine is shut down. The accumulator is like the tank on a well pump…it's got pressurized gas over a membrane, and it evens out the pressure spikes in the system.



A hydraulic pump sends flow to the system, to the accumulator, and to the pilot line of the pilot-to-close check valve. When the pump is running, the accumulator builds up gas pressure. The pilot-to-close check valve is in the closed position. When the pump shuts down, we lose pressure to the pilot, so the pressure from the accumulator opens the valve to drain the accumulator and the rest of the system to tank. Notice the level in the accumulator is going down, and the gas expands.

Directional Control Valves

Directional Control Valves control where we send the fluid to. In Lab #1, we used a DCV to send fluid either to the left end of the cylinder, or to the right end of the cylinder. Internally, a DCV has a spool inside it. The spool can move left and right to control the flow.

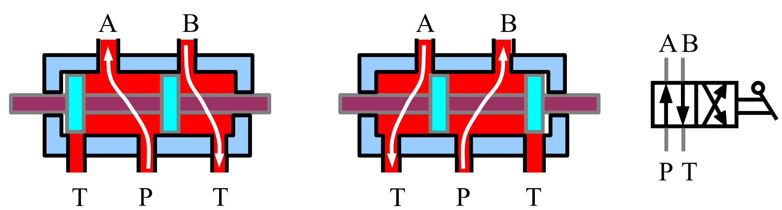


If we set the spool in a cylindrical chamber, with 3 ports drilled into the sides, then we can make a valve. When the spool is shifted to the left, flow goes from the pump to port A. There's no flow to the Tank, port T. When the spool is shifted to the left, flow goes from port A to the Tank. There's no flow from the pump, port P.

There are 2 positions and 3 connections, so we call this a 2-position, 3-way DCV.

The symbol for this valve has two squares, indicating the 2 positions. The handle is at the right…so this is valve has a manual control. There are 3 ports on the valve, indicating it's a 3-way valve. Internally, arrows indicate flow, and Tees indicate no flow.

Let's drill another hole for port B. When the spool is shifted to the left, flow goes from the pump to port A, returns to port B, and finally to tank. When the spool is shifted to the right, flow goes from the pump to port B, returns to port A, and finally to tank.

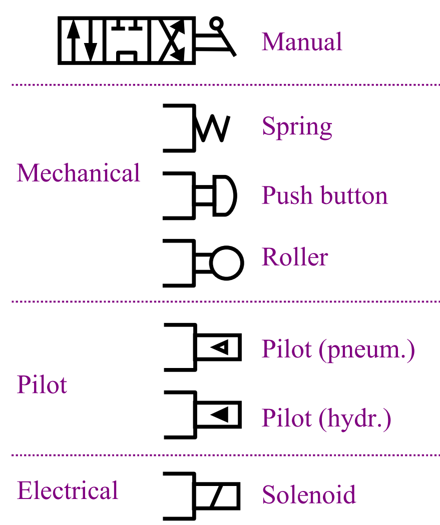


The symbol represents the flow paths inside the valve. In a hydraulic valve, the two tank ports are connected internally to a single fitting, so you only have one connection to make to your hydraulic line to tank.

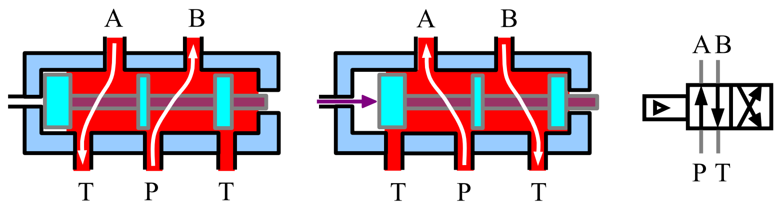
The valve has 2 positions, and 4 connections, so we call it a 2-position, 4-way valve. If you add a neutral position, you can build a 3-position, 4-way valve, like we have on the hydraulic stand.

There are four control methods for moving the spool in a DCV:

- **Manual control**. Move the spool by hand, with a lever.
- **Mechanical control.** The spool is pushed mechanically by a spring, push button, or cam with a roller. We used a spring return valve on the pneumatic stand, and we will be using push button and cam-activated valves in future labs. This is the type of valve we use on the pneumatic test stand to vary the pressure in the system.
- **Pilot control**. Either hydraulic fluid or air pushes on the spool. A hollow triangle is use for a pneumatic pilot; a solid triangle is used for a hydraulic pilot.
- **Electrical control**. An electromagnet (solenoid) pushes the spool. We will use solenoid-controlled valves on the pneumatic stand in upcoming labs.



This cartoon shows how a pilot control works. A pneumatic pilot signal controls one side of a hydraulic valve. Before we apply the pilot pressure, we have flow from the pump to port B, and from port A to the tank. When we pressurize the pilot line with air, it moves the spool to the right, changing the hydraulic flow pattern. Now we have flow from the pump to port A, and port B drains to tank.



This valve needs some method to move it back to the left…it could be another pilot control, or it could be a cam, or a spring, or some other method.

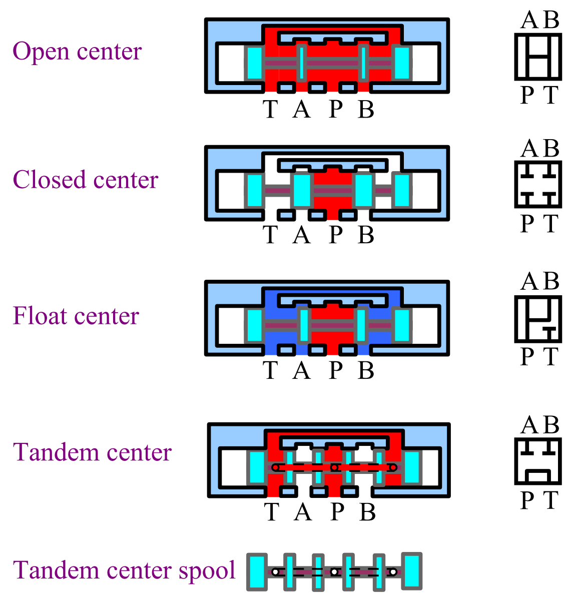
The textbook shows a variety of center flow paths for 3-position, 4-way valves. We have 4 ports: tank, A (to the system), pressure (from the pump), and B (to the system).

If we design the valve with skinny pistons, we have an open center control valve. In this position, fluid flows freely between all lines, so actuators like motors and cylinders are free to move.

If we change the design of the pistons on our spool, we can build a closed center valve. Now, all the ports are isolated. Actuators in the system are locked…motors won't move, cylinders won't move. The pump is working hard, because its output can't get to the tank.

The float center valve lets us maintain pressure while cylinders are free to move. This type of valve is often used in circuits that have a pilot-operated check valve, like we discussed in last week's lecture.

The tandem center valve can save the pump if there are long idle times when we're not actually using the pump output. This is the type of center we have on the hydraulic stand upstairs. We can make this valve by drilling holes in the spool, so fluid flows through the spool from the pressure port to the tank port, therefore pressure doesn't build up. When pressure builds up, oil gets hot, and can oxidize & break down. Oxidation raises acidity (pH drops), and acid attacks metal components. Also, maintaining pressure costs money...if you can unload the pump when it's not needed, you can save money, wear & tear, oil life, etc.



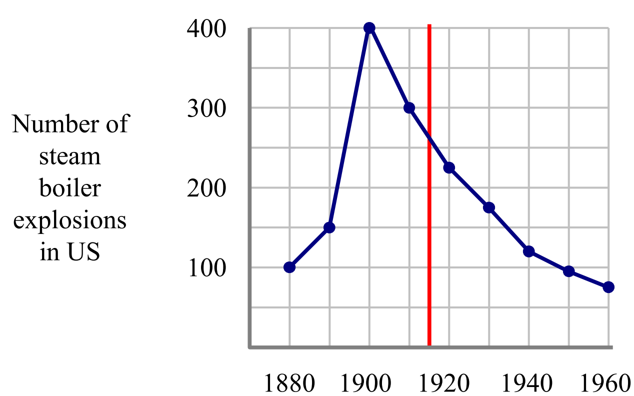
Pressure Control Valves

Pressure Relief Valves

The most common method of controlling pressure is with a *pressure relief valve* (PRV).

In 1803, lead plugs were used in U.K. for steam boilers. If the pressure gets too high, the plug deforms and blows out. This device is difficult to calibrate. Sometimes the plug lets loose too soon, and sometimes it doesn't let loose when it's supposed to. By the 1850s, steam boiler explosions occurred at a rate of 1 every 4 days.

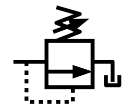
In 1865, one explosion on a Mississippi River steamboat killed 1,800 people. Hundreds of them were Union soldiers recently released from prison camps, heading home.



This was the worst boiler disaster in world history, at a time when the US population was about 10% of what it is today. Compare it with a disaster that kills 18,000 Americans all at once, and you get a sense of scale (4.5× worse than 9/11).

So what happened in 1915 that ensured a reduction in boiler explosions? The American Society of Mechanical Engineergs (ASME) published its famous *Boiler Code*, which establishes requirements for materials and dimensions of steam boilers. The *Boiler Code* is what put ASME on the map as a professional society.

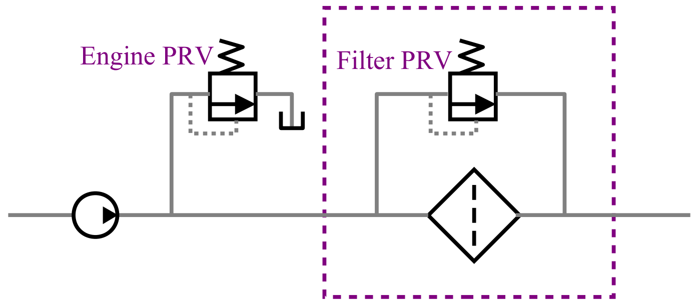
A *direct-acting* pressure relief valve consists of a ball or a poppet, with a spring behind it. When the fluid pressure is high enough to move the poppet and compress the spring, fluid flows through the valve and pressure is relieved. The hydraulic symbol for this valve shows the flow path is controlled by a spring (on top) and a pilot line (dashed line on bottom). The arrow through the spring shows that the spring is adjustable. You adjust the spring force by rotating the handle.



There are two PRVs in the lubrication system in your car. One is built into the engine; the other is in the oil filter itself.

A brand-new oil pump produces more pressure than the lubrication system needs, so excess oil goes to the sump. When this fails, the filter can inflate and pop off the engine. The second PRV is called a “bypass valve” in the filter industry. It’s designed to protect the engine in case oil won’t flow through the filter element. You can lose flow through the filter for 2 reasons:

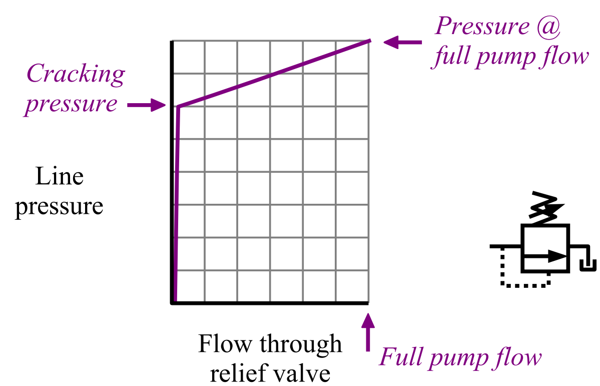
- Cold oil won’t flow easily through the filter.
- Oil won’t flow through a dirty filter element.



If you lose lubrication, you also lose bearings. The PRV in the filter is either a leaf spring or a coil spring that pushes a disk of paper or rubber against a hole.

If we plot the pressure in the line vs. the flow through the valve, we get a curve that looks like this. The *cracking pressure* is the pressure it takes to crack open the valve. As the pressure gets higher than that, the valve opens more, so the flow through the valve increases.

Let’s say the cracking pressure is 1000 psi. An inexperienced technician installs this pressure relief valve in a system such that it drains into a 200 psi line. What pressure does the valve actually crack open? It depends on construction, probably about 1200 psi…which could be dangerous. You want to make sure that a relief valve dumps to tank under 0 pressure…otherwise it might not open when you expect it to.

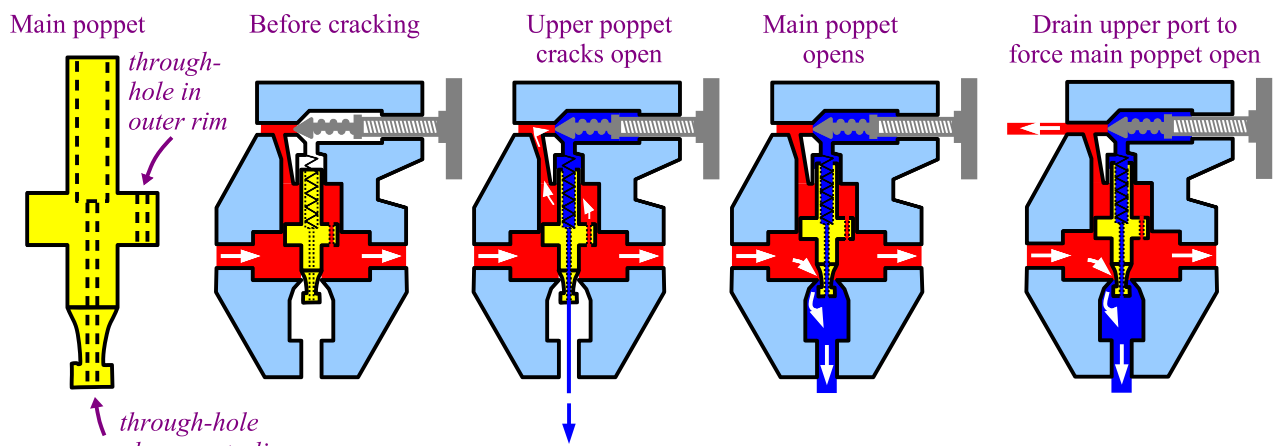


Compound Pressure Relief Valves

There’s a series of pictures of a compound PRV in the textbook. It’s a little hard to understand because the original picture from Vickers was in three colors: black for the hardware, red for the incoming fluid, and blue for the fluid as it leaves the valve. The textbook shows the incoming fluid as gray, but the outgoing fluid isn’t shown.

Before the valve cracks, fluid comes in on the left and out on the right. The poppet in this valve is hollow, and it has two holes drilled through it. The hole in the outer surface of the piston allows fluid to travel into the upper part of the valve. So now we have pressurized fluid on both sides of the piston, and the piston doesn’t move…the spring holds the piston closed.

Sometimes you’ll see this type of valve called a *balanced piston* pressure relief valve, because initially the equal pressure on both sides of the piston hold it in balance. When the pressure becomes high enough, it cracks the upper poppet open. Now we get a little leakage through the hole in the center of the poppet.

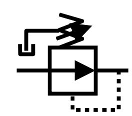


Now that we've relieved the pressure above the poppet by venting the fluid, there's a pressure differential across the poppet. The valve in your book opens up when this pressure differential reaches 20 psi.

The operation of this valve depends on fluid being able to move through small diameter holes. This is one of the reasons that it's important to keep hydraulic fluid clean. Otherwise, the valve would not operate. If pressure relief is part of a safety system, then people's lives and limbs are at risk if you don't filter the crud out of the hydraulic fluid.

The port on the upper left of the valve can be plugged, and the valve will operate normally. If you drain off fluid through this port, then the pressure above the piston drops. If it drops to 20 psi lower than the line pressure, then the valve will open. This feature allows you to control the valve remotely.

Pressure-Reducing Valves

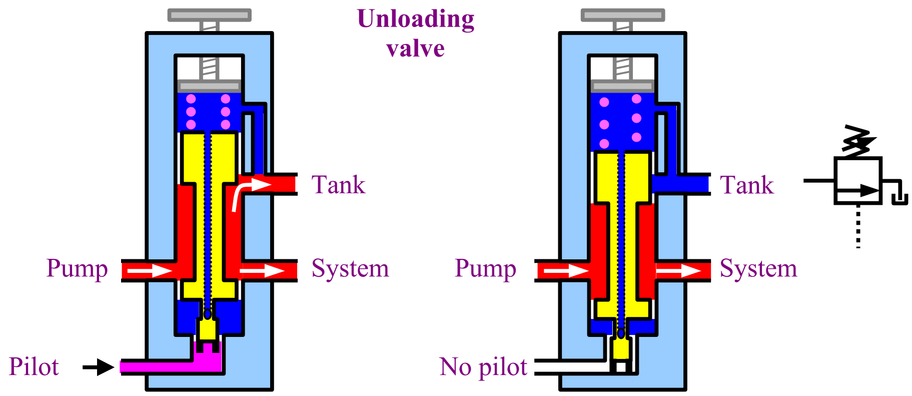


Pressure relief valves open to relieve excess pressure by draining fluid. Another type of pressure control valve is the *pressure-reducing valve*. The symbol in the book 281 has an error…the arrow that indicates the direction of flow is drawn backwards. You can tell, because the pilot line comes from the downstream side (outlet).

An adjustable spring pushes on a spool that has a small diameter hole running through it. When the pressure on the downstream side gets high enough, it will shift the spool to the right, which reduces flow through the valve. We call this a *direct acting* pressure-reducing valve because the fluid acts directly on the spool.

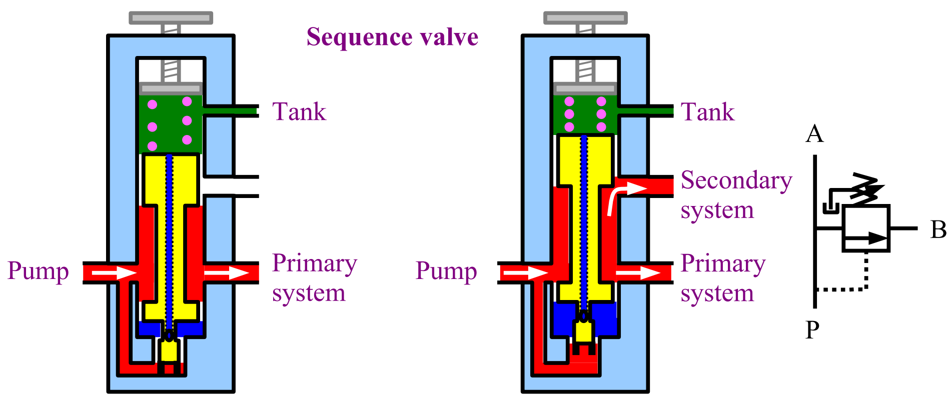
You can build pressure-reducing valves in different ways. A *pilot-operated pressure reducing valve*, which is not in the book (illustrated in the class handout), offers more control and is more accurate than a direct-acting pressure-reducing valve. The lower part of the valve looks like a direct-acting pressure-reducing valve, but the adjustable spring is in the pilot stage in the upper part of the valve.The symbol is the same…the pilot signal is from the downstream side, the spring is adjustable, and we're bleeding off fluid through the adjustment to tank.

We can use a type of pressure-reducing valve to reduce wear and tear on a hydraulic pump. When you first turn on the pump, you don't want to have to fight the full system pressure from a dead stop. So, you install an *unloading valve* to take the load off the pump until it gets up to speed and full pressure. An unloading valve allows the pump to deliver full flow at zero pressure. When the unloading valve receives pilot pressure, the spool moves up, and allows full pump flow to go to tank.



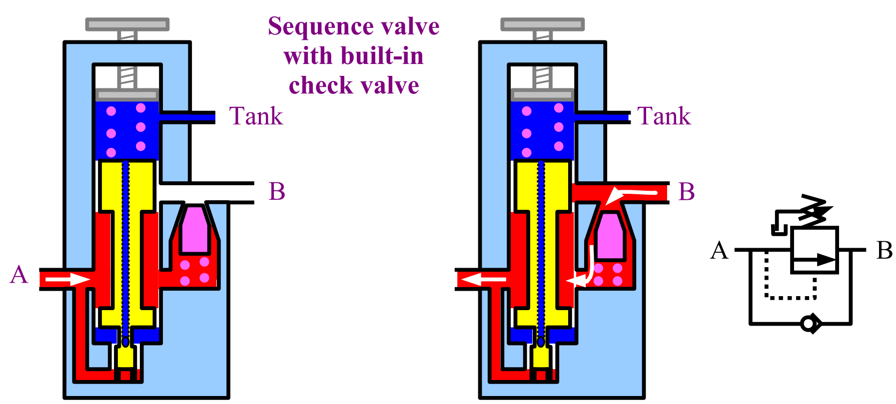
When the pilot pressure drops below a certain value, the spool is pushed down by the spring, and flow to the tank stops. All the flow goes to the system. The spool is hollow, so we can relieve the pressure above and below the spool as it moves up and down. The spring is adjustable, so we can set the required pilot pressure.

We can also use pressure to control the sequence of events in a hydraulic circuit. In the lab, we use a *sequence valve* to make one action occur before another. A pilot line from the pressure side supplies fluid to one side of the spool. We send fluid to the primary circuit, marked **A** on the hydraulic symbol. In the lab, this circuit is one of the cylinders. When the cylinder bottoms out, pressure in the system rises.



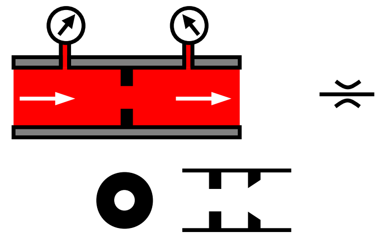
This symbol is a little different from the one in the book. The textbook symbol doesn't show both circuits, A and B. The increased pressure in the pilot line pushes the spool up, and opens flow to a secondary circuit, marked "B" on the hydraulic symbol. In the lab, circuit B is the second cylinder.

The sequence valve we use in the lab has three ports: intake, output, and drain (to tank). It's got a built-in check valve, so you can have free-flow in the reverse direction. The valve is closed at the left; reverse flow is shown at the right, through the check valve.



Flow Control Valves

Orifices

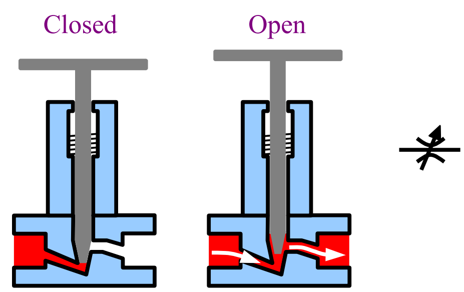


We've looked at valves designed to control the pressure in a system, and valves that open or close due to pressure in the system. Now we'll look at valves designed to control the *flow* of hydraulic fluid.The simplest type of flow control is a plate with a hole in it. In hydraulic terminology, a hole is called an *orifice*, so the plate is called an *orifice plate*. The symbol for an orifice plate is a pair of curved lines around a hydraulic line…it represents a restriction in the flow.

If we install a pressure gauge on either side of the plate, we'll find that the pressure drops as the fluid flows through the plate.

The flow rate is proportional to the area of the opening times the square root of the pressure drop over specific gravity: $Q \sim A\sqrt{\frac{\Delta p}{SG}}$. The textbook lists the exact equation, with constants, for US and metric units. There's also a constant in the equation that accounts for the shape of the plate opening…whether it's got a square edge, like the one in the pipe, or a sharp edge. For example, let's calculate the flow rate of water passing through a ½" diameter orifice with a square edge. The pressure drop is measured at 0.2 psi. By definition, the specific gravity of water is 1. From the textbook, a square edge has a constant of 0.6 in the textbook equation, so $Q = \frac{38.1\text{ gpm}}{\text{in.}\cdot\text{lb.}^{0.5}} \frac{0.6\pi(0.5\text{ in.})^2}{4}\sqrt{\frac{0.2\text{ lb.}}{\text{in.}^2\,1}} = 2.0\text{ gpm}$.

Needle Valves

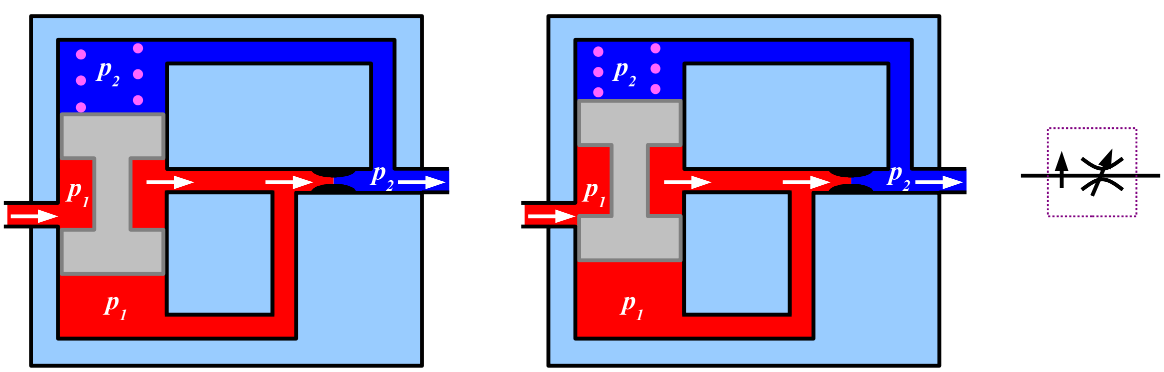


The simplest adjustable flow control valve is a *needle valve*. A tapered needle seats against a conical seat. You can get very fine control over flow through small diameter piping.

The symbol looks like an orifice…we have two curvy lines around our hydraulic line, but there's also a diagonal arrow, which shows that the valve is adjustable.

Pressure-Compensated Flow Control Valves

Orifices and needle valves do not compensate for pressure changes…so they are best used when pressures are stable. You know this from your house…the flow control valve on the shower only delivers constant flow if the water pressure is constant. If the water pressure in your house drops because someone starts to fill the washing machine, flow in the showerhead drops.



There are other types of valves that can compensate for pressure and temperature changes. This valve compensates for pressure. The fluid is flowing from left to right, past a spool, and through an adjustable throttle. The pressure upstream from the throttle is p_1, shown in red. The pressure downstream is p_2, shown in blue. We want to maintain pressure p_2.

If the upstream pressure p_1 goes up, then the spool will move upward, reducing flow through the valve. The symbol for this valve shows a diagonal arrow, indicating it's adjustable. It includes an arrow perpendicular to the flow direction, which means it's pressure-compensated. The cartoon doesn't show that the valve is adjustable…I left that out so you can see the flow pattern. We can add an adjustment screw to the spring to adjust the desired downstream pressure.

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