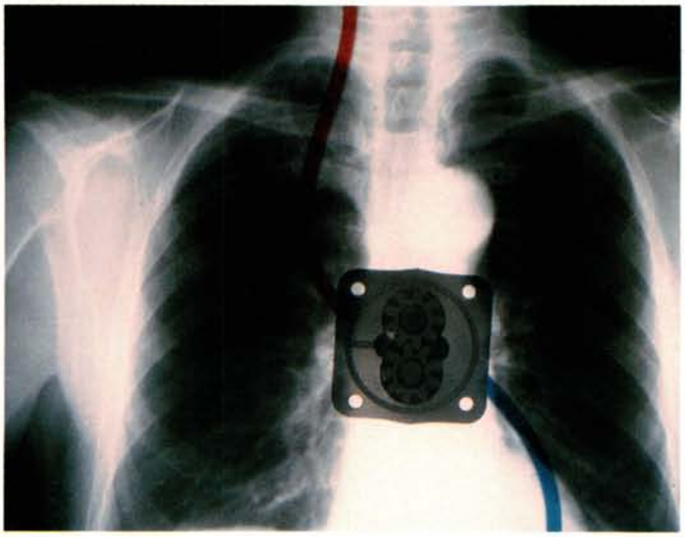
The Heart of Hydraulics



If you underestimate the importance of hydraulic theory, take a moment to feel your own pulse. Your body is using your last meal as fuel for a very important pump—your heart. This morning's eggs and bacon are fueling the mechanical contractions of your heart as it pushes blood through a complex plumbing system of veins and arteries.

Without hydraulics, your body and the car you're working on would never function. In preparation for next month's look at the principles of automatic transmission operation, we thought it was appropriate to start looking at some of the ways pumps and liquids interact to do work for us.

Major Components

A typical hydraulic system has the following major components:

- **A liquid source**, stored in a reservoir like a sump or an oil tank.
- **A pump** to move the liquid through the system.
- **A plumbing system** to carry the liquid. This plumbing may be found in the form of external pipes or hoses, or may be a network of internal drillings or passages like the ones in an automatic transmission valve body.
- **Control valves** or mechanisms to regulate pressure and direct the flow of the liquid.
- **An output device** or "slave" that uses this pressurized liquid to do work.

The Characteristics of Fluids

We all know that matter exists in three basic forms: solids, liquids, and gases. And we're all familiar with the characteristics of these forms from everyday experience. Let's concentrate on the fluids we call liquids and gases, since their similarities and differences are very important to us.

Gases and liquids are fluids, and have no definite shape of their own. They are flexible characters and will conform to the shape of the container in which they are placed. A gas, however, will always fill a closed container while a liquid may not. We're getting warm. But no cigar.

Gases are compressible.

For our purposes, we'll also say that liquids are not compressible. Now we're getting warmer.

This major difference in gases and liquids is the starting point for our understanding of hydraulic action. The non-compressible nature of liquids is the key to making them work for us. Now we're getting hot.

Liquids Under Pressure

If we apply pressure to liquids, we can expect them to act very predictably. A famous French scientist named Blaise Pascal was kind enough to come up with some very important insights about the characteristics of liquids under pressure.

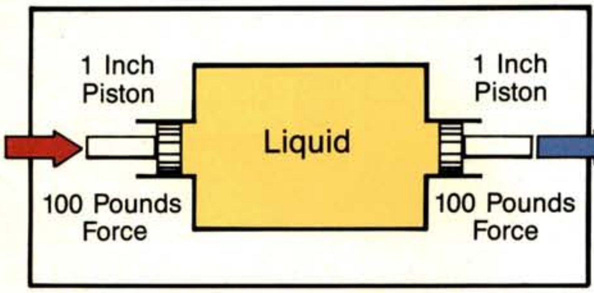
Mister Pascal said that if you had a liquid-filled container with only one opening, and applied force to the liquid through that opening, the force would be evenly distributed throughout the liquid. That means that a molecule of liquid at the closed end of the container is under the same pressure as a molecule at the surface. All those molecules have to share the same work load. (Too bad this doesn't apply to humans!)

Mister Pascal also noted that the molecules being squashed against the walls of the container would try to get out. They would try to take the shortest escape route. They wouldn't hunt for a longer route to safety, but would try to escape directly through the walls of the container. That means that the force they use to escape is always directed at the shortest escape route, and as a result, is applied at right angles to the walls of the container.

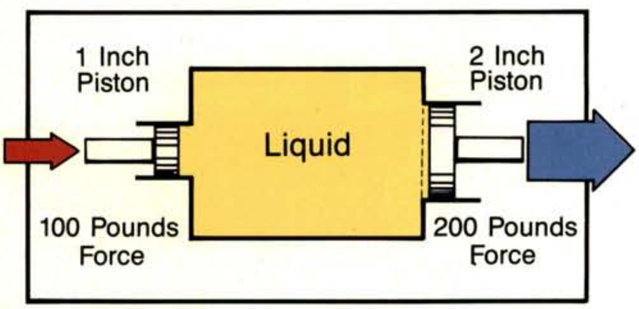
Now we're really getting somewhere. Now we start to understand that pressure applied to the surface of the liquid is applied equally to the entire inner surface of the container. This force is uniform. It's predictable. And most importantly, it's useful.

The rest of our article will look at ways this characteristic of liquids under pressure can be controlled and made to do work.

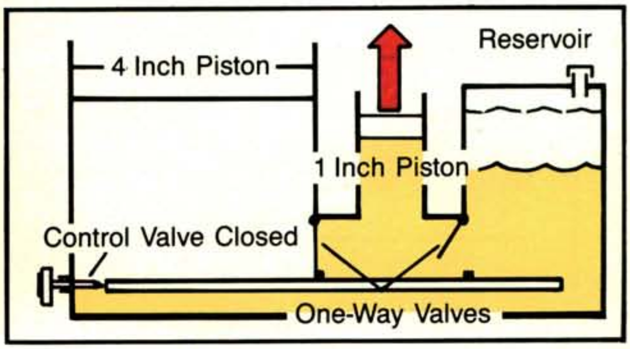
—By Ralph Birnbaum



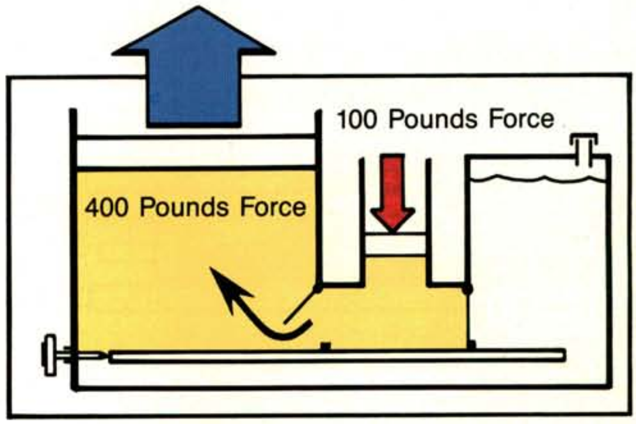
Let's put a one-inch piston exerting 100 pounds of force on the inlet side of the container. Then we'll put a one-inch piston on the outlet side of the container. If you have 100 pounds of force pushing on a one-inch piston, the liquid will exert a 100-pound force on a one-inch piston at the other end of the container.



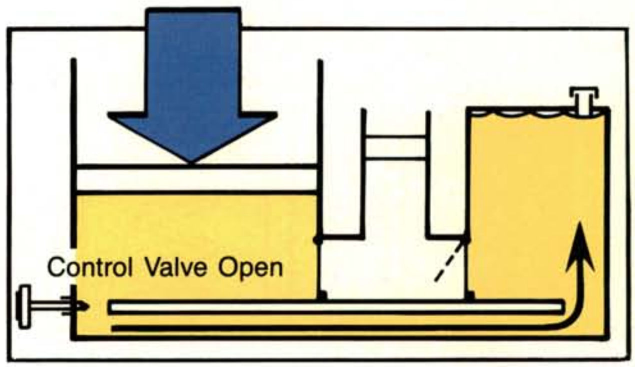
Let's change our container one more time. Let's leave the inlet piston the same size as it was in the previous illustration. But if we use a two-inch piston on the outlet side, the resulting force is also doubled. The larger piston will only move half as far as the one-inch piston did, however, since the volume of liquid displaced is also twice as big.



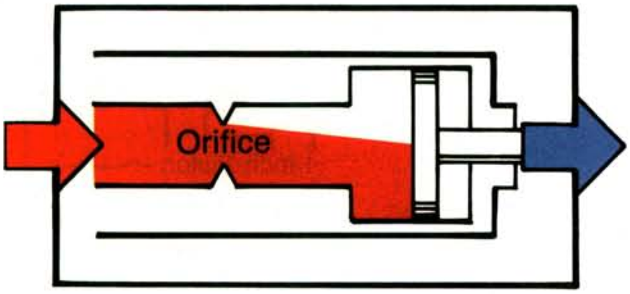
We can use this multiplication of force to make a hydraulic jack. As the small piston moves upward, low pressure opens the one-way valve from the reservoir and the small piston is filled with liquid. The one-way valve to the large piston and the control valve also stay closed.



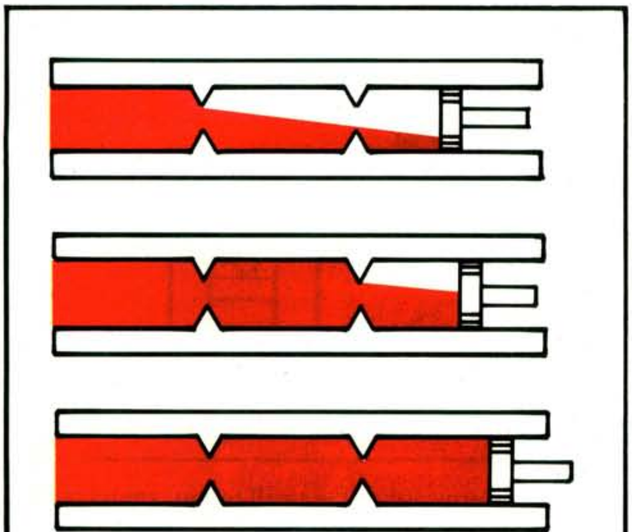
As we push downward on the small piston, applying force to the liquid, the one-way valve at the reservoir closes. The one-way valve feeding liquid to the large piston is pushed open and hydraulic pressure pushes on the large piston. This larger piston magnifies the force applied by the small piston.



Multiplication of force is directly proportional to the difference in piston sizes. But since the larger piston moves only a part of the distance the smaller piston moves, we must repeat the pumping process many times to raise the vehicle. To let the vehicle down? Just open the control valve and vent pressure back to the reservoir.

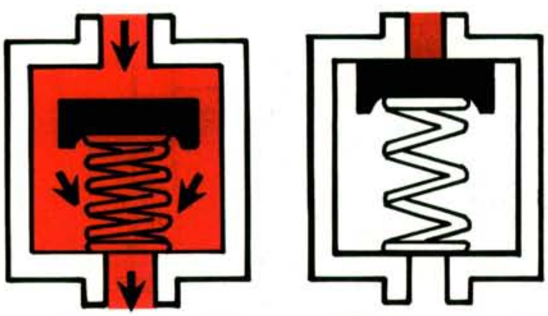


There are a number of ways to regulate the flow of liquid through a passage. This fixed orifice, or restriction in the line, causes pressure to build on the inlet side of the orifice, and slows the movement of liquid toward the piston. When both chambers are filled, pressure equalizes, but the piston is applied more gradually.



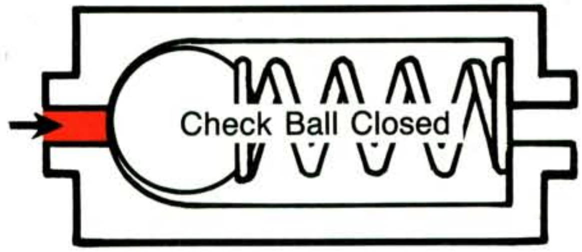
Orifices in Series

Here we have a number of orifices placed in series. These orifices act like hydraulic cushions to allow a more gradual application of pressure to the outlet piston. Any number of these restrictions can be used in series.

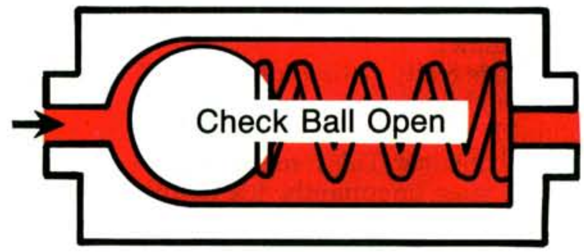


Poppet Valve Open   Poppet Valve Closed

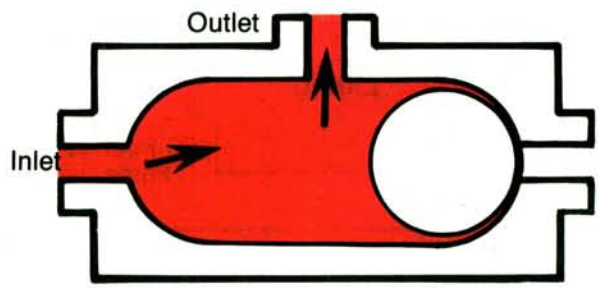
When inlet pressure is greater than the spring tension holding this poppet valve closed, it moves the poppet valve, allowing liquid to flow. When pressure drops to a point where it is less than spring tension, the valve closes. This is a one-way valve.



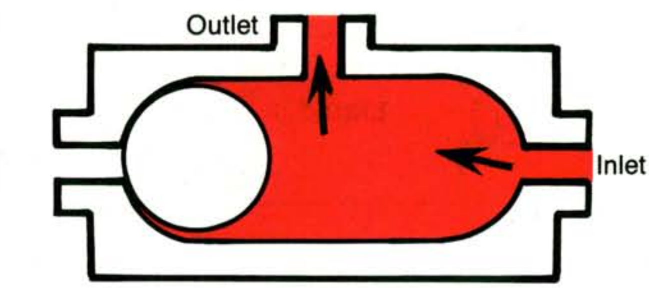
Another type of one-way valve uses a check ball and spring. Like the poppet valve, the check ball is held against the inlet port until the pressure pushing on the ball is greater than spring tension. Pressure on the backside of the ball only closes it more tightly.



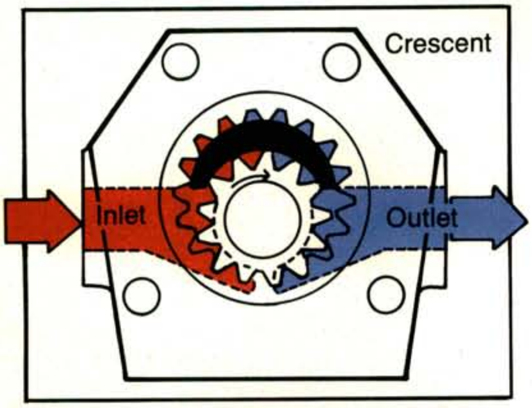
Once pressure gets strong enough to unseat the ball, liquid flows around the ball and through the spring to the outlet. As long as liquid pressure is greater than spring tension, the ball will remain off its seat and allow liquid to pass.



This is a two-way check ball. There is no return spring. Instead, this valve is used to provide hydraulic pressure from one of two different sources to the same outlet port. In this illustration, liquid pressure enters from the left, forcing the ball to the right, closing the right port.

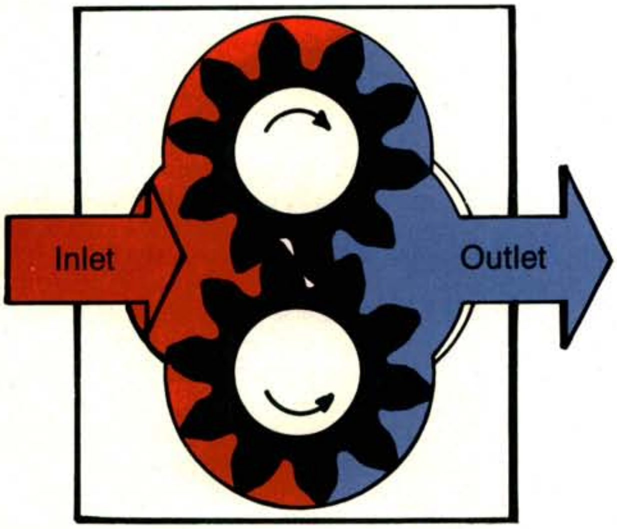


If hydraulic pressure entering the right side port is stronger than pressure at the left side port, the ball moves left. The left port closes. Both valves cannot be open at the same time as a result. Two separate ports can alternately supply liquid to the same outlet port, however.



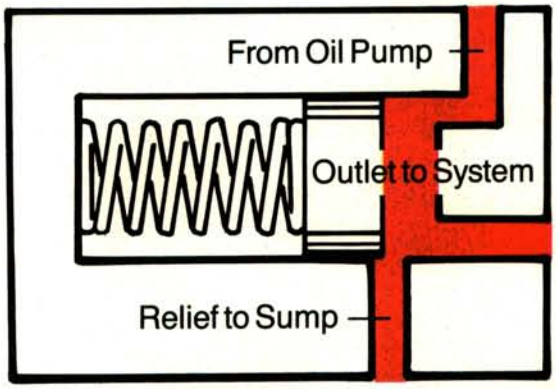
The heart of hydraulics is still the pump. This crescent-style pump is common in many automatic transmissions. A central drive gear rotates, turning a larger driven gear. The gears catch liquid as they turn. The liquid is trapped between the gear teeth and the crescent, and the liquid is compressed and forced through the outlet port as the gears move closer together.

These pumps are made to close tolerances, and assuming there is no excessive wear between its internal parts, this pump will deliver the same amount of liquid each complete cycle. Delivery rates can be changed, however, by increasing or decreasing the speed at which the pump turns, within certain limits.

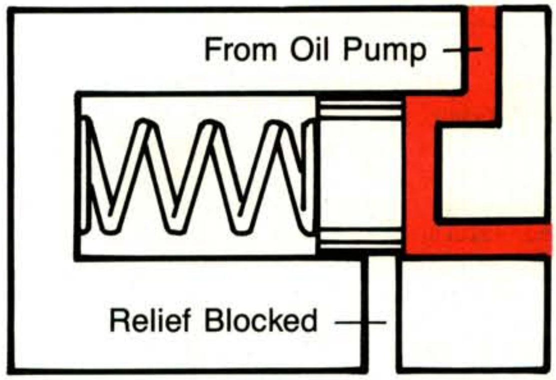


This gear-style rotary pump is also common in automotive applications. Two gears mesh and turn in a housing. One of the gears is powered. The other is driven by the powered gear. The gears rotate in opposite directions. Gear teeth catch liquid drawn from the inlet, or low pressure side. This fluid is trapped between the gear teeth and the walls of the pump housing.

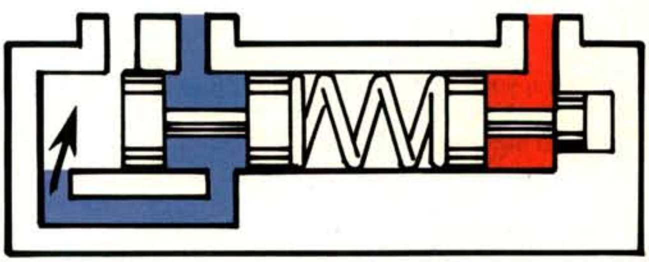
The trapped liquid is discharged through the pressure, or outlet port, of the pump housing. As the gears mesh, they block the flow of liquid back through the inlet passage and act as a one-way valve. This pump is also made to close tolerances. Excessive play between gear teeth, or between gears and the housing or pump cover, will reduce pump efficiency.



We need some way to keep pressure constant when we use pumps like these. Even though pump displacement is the same for each cycle, changes in liquid thickness, and pump speed changes will change pump delivery rates. A pressure relief valve is the answer. Very high pressures overcome spring tension at the relief piston. The piston moves, venting excess pressure back to the reservoir, oil pan, or sump.



When spring pressure is greater than hydraulic pressure, the piston moves back to its closed position, blocking the relief passage. Now all the hydraulic pressure is discharged through the outlet passage and hydraulic pressure is maintained within acceptable limits. Constant changes in pump speed will keep this valve busy, moving back and forth to maintain a stable output pressure, regardless of pressures generated by the pump.



If we combine spring tension and hydraulic multiplication of force, we get a hybrid valve. Spring tension can be changed. Hydraulic pressure on the spool valve at the right causes the valve to move toward the larger piston, increasing spring tension. Hydraulic pressure in the left chamber must now be greater before it can override the spring and move the spool valve at the left.