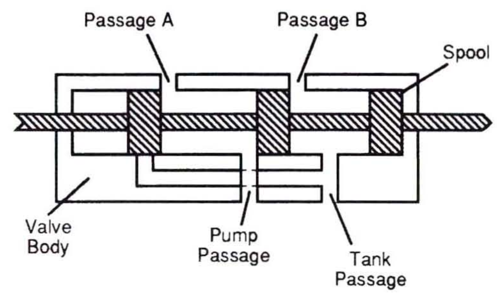
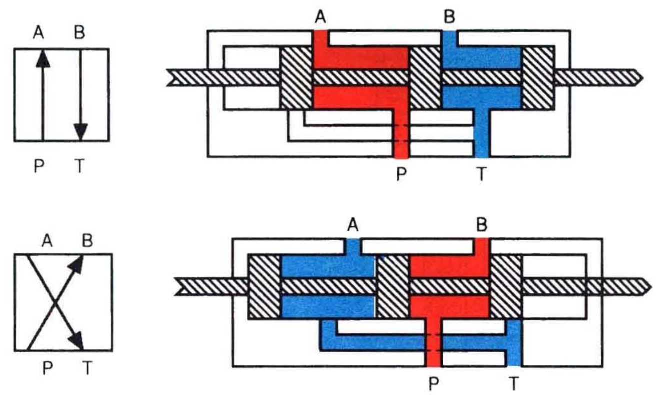
CHAPTER 10

Directional Control Valves



A directional control valve consists of a body with internal passages which are connected and disconnected by a movable part. In directional valves, and in most industrial hydraulic valves we have seen previously, the movable part has been a spool. Spool valves are by far the most common type of directional valve used in industrial hydraulics. For this reason, we will concentrate on these valves - their types and operation.

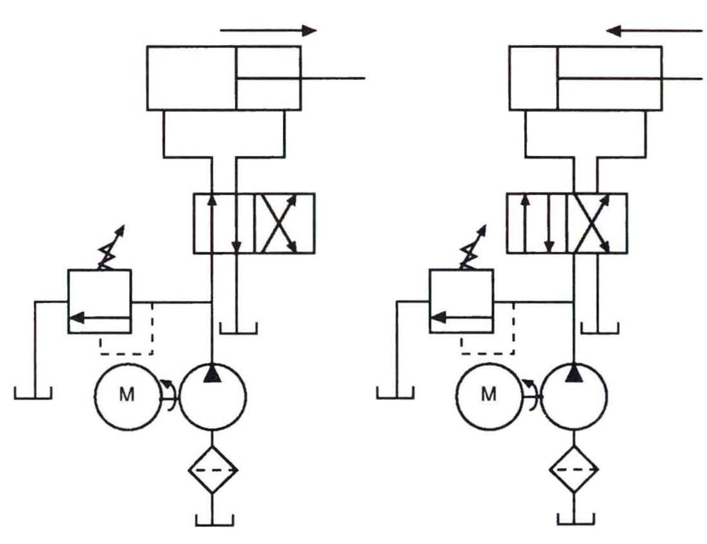
4-way directional valve



In the directional valve we have dealt with earlier, the valve consisted of a pump passage, tank passage, and two actuator passages. This valve is known as a 4-way valve because it has four distinct passages within its body.

The function of a 4-way directional valve is to cause the reverse motion of a cylinder or hydraulic motor. To perform this function, the spool directs flow from the pump passage to one actuator passage when it is in one extreme position. At the same time, the spool is positioned so that the other actuator passage is exhausted to tank.

4-way directional valves in a circuit

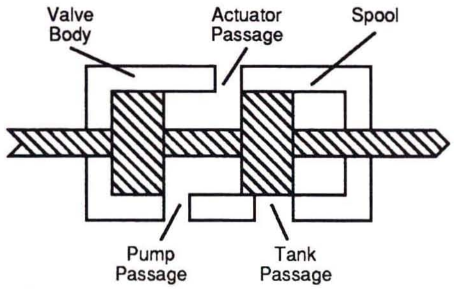


Since all valves consist of a body and an internal moving part, the moving part of all valves has at least two positions - both extremes. These two positions in a directional valve are depicted by two separate squares. Each square shows by means of arrows how the spool is connecting the passages within the body at that point in time. When the valve is shown symbolically, the two squares are connected together. But, when placed in a circuit, one square, and only one square, is connected in the circuit. With this arrangement, the condition within the valve is shown while an actuator is moving in one direction. To picture the actuator moving in the opposite direction, the other square of the symbol is mentally slid into the circuit.

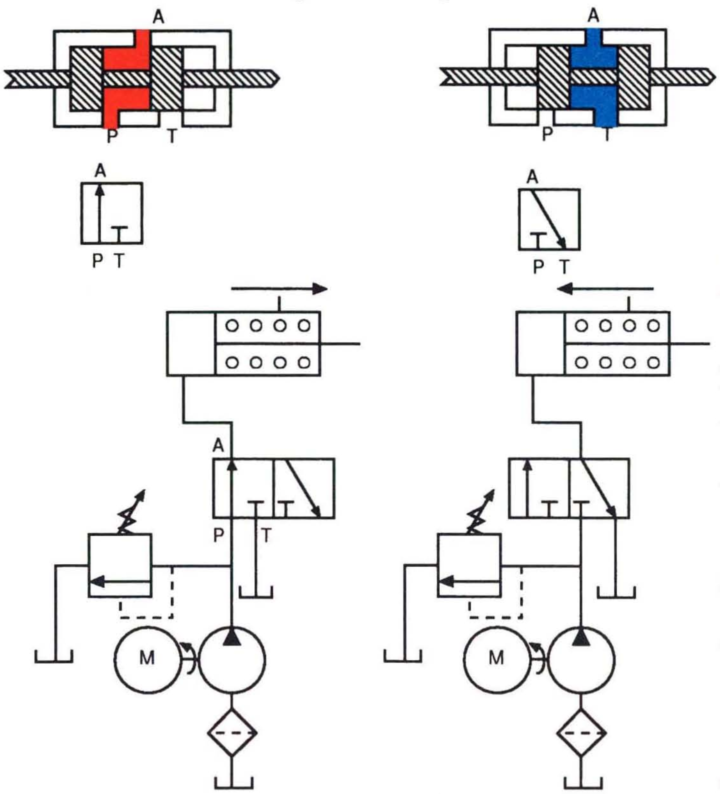
A directional valve symbol, which shows only two spool conditions within a body, is known as a two-position valve.

3-way directional valve

A 3-way valve consists of three passages within a valve body - pump passage, tank passage, and one actuator passage.



The function of this valve is to pressurize an actuator port when the spool is in one extreme position. When the spool is positioned in the other extreme, the valve exhausts the same actuator port. In other words, the valve alternately pressurizes and exhausts one actuator port.



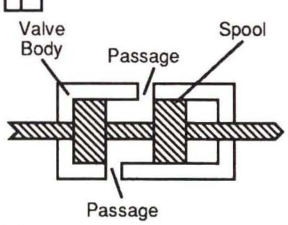
3-way directional valves in a circuit

A 3-way directional valve can be used to operate single acting actuators like rams and spring-return cylinders. In these applications, the 3-way valve directs fluid pressure and flow to the cap end side of the cylinder. When the spool is shifted to the other extreme position, flow to the actuator is blocked. At the same time, the actuator passage within the body is connected to tank.

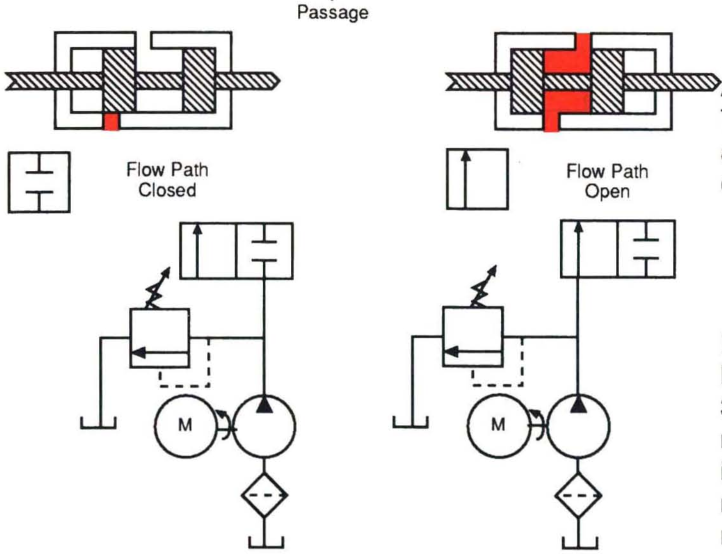
A vertical ram is returned by its own weight or the weight of its load when the actuator passage of a 3-way valve is drained to tank. In a spring return cylinder, the piston rod is returned by a spring within the cylinder body.

In industrial hydraulic applications, 3-way valves are not generally found. If a 3-way function is required, a 4-way valve is usually converted to a 3-way valve by plugging an actuator port.

2-way directional valve



A 2-way directional valve consists of two passages which are connected and disconnected. In one extreme spool position, the flow path through the valve is open. In the other extreme, there is no flow path through the valve.



2-way directional valve in a circuit

A 2-way directional valve gives an on-off function. This function is used in many systems to serve as a safety interlock and to isolate and connect various system parts.

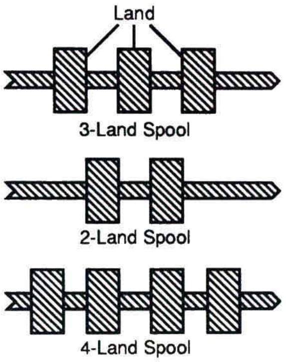
directional valve sizes and ratings

Directional control valves used in industrial hydraulic applications come in several basic sizes - 1/4", 3/8", 1/2", 3/4", and 1¼" (6.35 mm, 9.5 mm, 12.7 mm, 19.05 mm, and 31.75 mm). It is common industrial practice to rate the valves on their nominal or average flow rating. Examples of such ratings are respectively at 3-10 gpm (11.37 - 37.9 lpm), 10-20 gpm (37.9 - 45.48 lpm), 40 gpm (75.8

lpm), 80 gpm (303.2 lpm) and 160+ gpm (379 lpm). At this nominal gpm rating the pressure differential from P to A or B to T is approximately 40 psi (2.76 bar).

directional valve spools

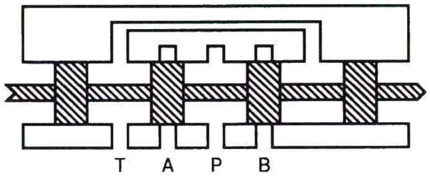
The spool in the 4-way directional valve which we have seen consists of a shaft with three large diameters spaced apart equally. These are known as lands. The spool is identified as a 3-land spool.



Most industrial hydraulic directional valves have either 2-land or 4-land spools. Directional valves with small flow ratings are generally equipped with 2-land spools, while the 4-land spools are most frequently found in valves with large flow ratings.

subplate-mounted 4-way valves

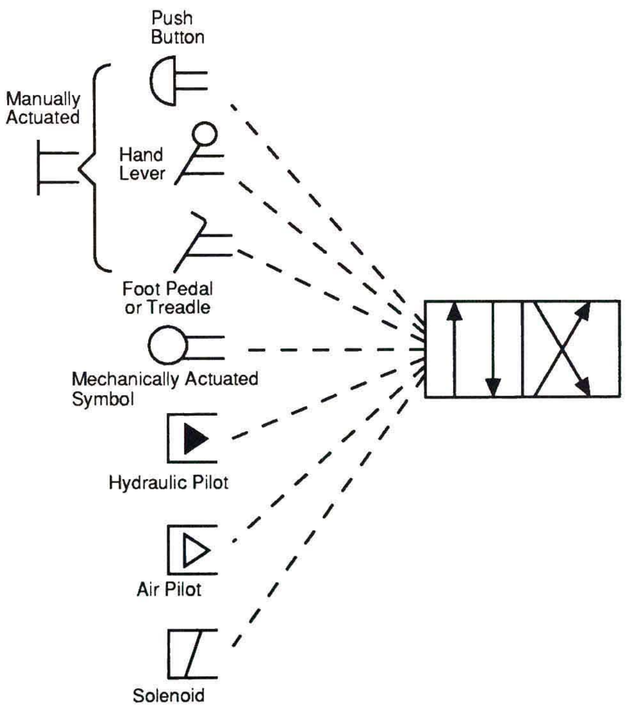
The bodies of the 4-way directional valves which have been illustrated had pump and tank passages situated on one side. The two actuator passages were positioned on the opposite side of the body. This arrangement closely followed the symbol for the valve. But, for ease in installation, most industrial hydraulic directional valves are subplate mounted; that is, they are bolted to a plate to which system piping is connected. The ports of subplate-mounted valves are located on the bottom surface of the valve body.



Subplate-Mounted 4-Way Body with 4-Land Spool

directional valve actuators

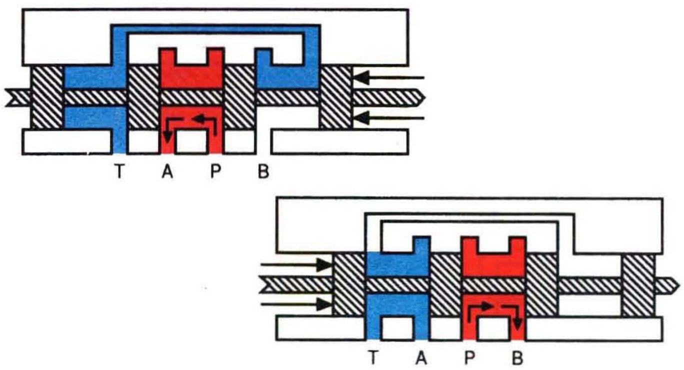
We have seen that a directional valve spool can be positioned in one extreme position or the other. The spool is moved to these positions by mechanical, electrical, hydraulic, pneumatic, or human energy.



Directional valves whose spools are moved by muscle power are known as manually operated or manually actuated valves. Various types of manual actuators include levers, pushbuttons, and pedals.

A very common type of mechanical actuator is a plunger. Equipped with a roller at its top, the plunger is depressed by a cam which is attached to an actuator. Manual actuators are used on directional valves whose operation must be sequenced and controlled at an operator's discretion. Mechanical actuation is used when the shifting of a directional valve must occur at the time an actuator reaches a specific position.

Pilot Operated 4-Way Valve



pilot operation

Directional valve spools can also be shifted with fluid pressure either air or hydraulic. In these valves, pilot pressure is applied to the two extreme spool lands if it is a 4-land spool, or to separate pilot pistons if it is a 2-land spool.

solenoid operation

One of the most common ways of operating a directional valve is with a solenoid.

solenoid

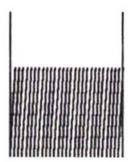
A solenoid is an electromechanical device which converts electric power into linear mechanical force and motion. Its counterpart in a hydraulic system is a cylinder.

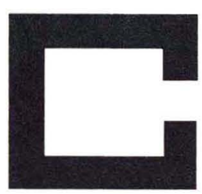
Solenoids typically found on industrial hydraulic valves can be divided into "air gap" and "wet armature" types.

air gap solenoid

Of the two types, air gap solenoids are the older design. They are basically an electromagnet made up of a T plunger, wire coil, and C frame. Because of the shape of the plunger and frame around the coil, this is sometimes called a "CT" solenoid.


"T" Plunger

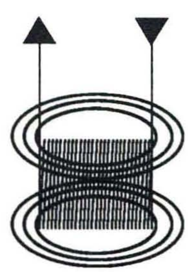

Wire Coil


"C" Frame

how an air gap solenoid works

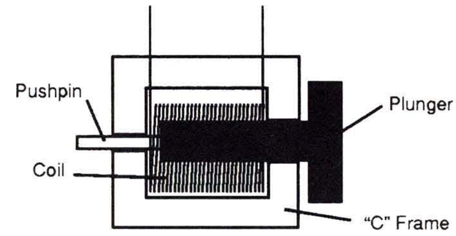
With an electric current passing through a wire, a magnetic field sets up around the wire. As illustrated earlier, this effect can be seen by sprinkling iron filings on a plastic sheet through which a current-carrying wire is located. The electric current will cause filings to take the shape of its magnetic field.

If the wire were coiled in many turns, the magnetic field would be several times stronger generating around the coil and through its center.



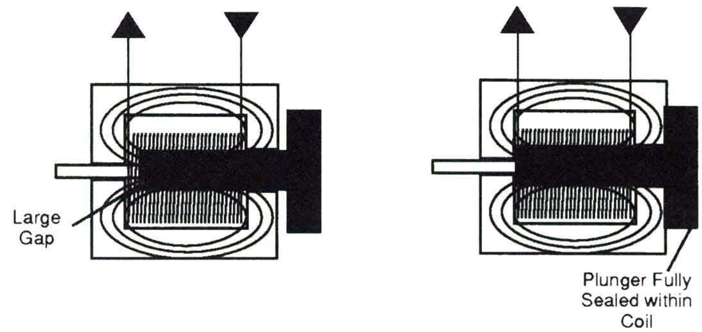
A solenoid depends on this magnetic field to shift a directional valve spool. The more intense the field, the more shifting force will be developed. To intensify a magnetic field, an air gap solenoid is equipped with an iron path, called a C frame, which surrounds the coil. Another iron path, the plunger, is positioned in the center of the coil to concentrate the magnetic field even more; this iron path is movable.

As an air gap solenoid coil receives electric current, the plunger is partially out of the coil. The resultant magnetic field generated from the current, attracts the plunger pulling it in. The directional valve shifts as the plunger hits a pushpin mechanically connected to the valve spool. With the spool shifted, the plunger fully seats within the coil resulting in the magnetic field traveling completely through an iron path.



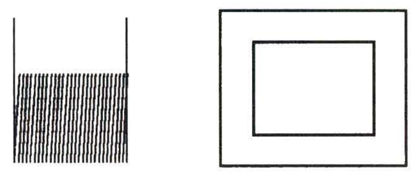
Air Gap Solenoid

Iron is an excellent magnetic conductor; air is a poor magnetic conductor. Air gap solenoid operation depends on the magnetic field pulling in the plunger reducing the high resistance air gap within the coil center. As the plunger moves in, the air gap gradually decreases causing solenoid force to become increasingly stronger. Solenoid force is greater with the plunger pulled in than out.



wet armature solenoid

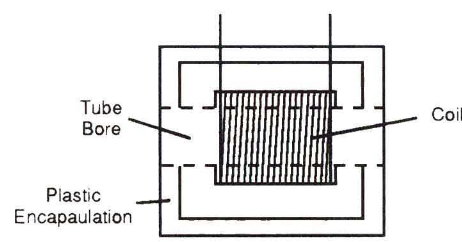
Wet armature solenoids are a relatively new arrival on the industrial hydraulic scene. Their acceptance over air gap designs has been due to their increased reliability resulting from better heat transfer characteristics and elimination of pushpin seals which in an air gap solenoid have a tendency to leak.

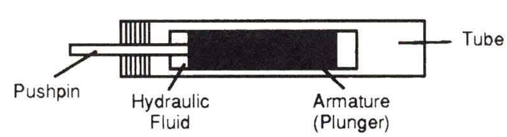


Wire Coil   Rectangular Frame

what a wet armature solenoid consists of

A wet armature solenoid consists of a coil, rectangular frame, pushpin, armature (plunger) and tube. The coil is surrounded by the rectangular frame and both are encapsulated in plastic. In the encapsulated unit, a hole runs through the coil center and two sides of the frame. The tube fits within this bore as it is screwed into a directional valve body. Housed within the tube is an armature which is bathed by system fluid through the tank passage within the directional valve. This accounts for the "wet armature" identification.

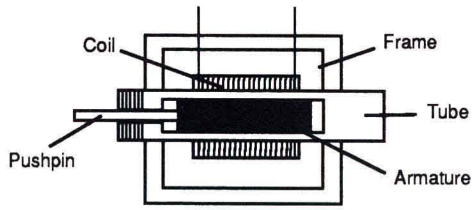




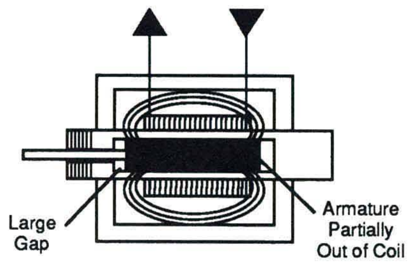
how a wet armature solenoid works

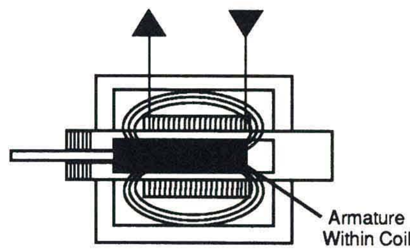
With an electrical current passing through its windings, a magnetic field sets up around the coil. This magnetic field is intensified by the rectangular iron path surrounding the coil and also by the armature in the coil center.

As a wet armature coil receives electric current, the movable armature is partially out of the coil. The magnetic field generated from the current attracts the armature pulling it in. Directional valve



Wet Armature Solenoid





shifts as the armature hits a pushpin in contact with the valve spool. With spool shifted, armature is fully centered within the coil resulting in the coil magnetic field traveling completely through an iron path.

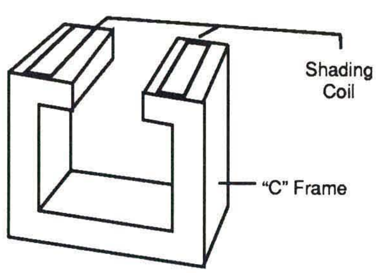
Iron is an excellent magnetic conductor; the oil surrounding armature and pushpin is a poor magnetic conductor. Wet armature solenoid operation depends on the magnetic field pulling in the armature reducing the high resistance gap in the coil center. As the armature moves in, the gap gradually decreases causing solenoid force to become increasingly stronger. Solenoid force is greater with the armature pulled in than out.

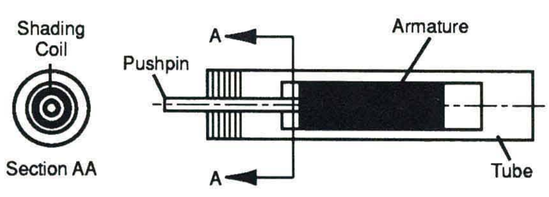
ac hum

Electrical power with an alternating current (AC) is the usual industrial source of control power in the United States. Alternating current in the United States moves from zero to positive, through zero to negative, and back to zero at the rate of 60 times per second or 60 Hz.

Magnetic field and solenoid force are greatest when current is at positive and negative peak values. As current goes through zero, magnetism and solenoid force decrease. This causes the solenoid load (usually a spring-biased spool) to push out the plunger or armature. When magnetism and force build again, the plunger or armature is pulled back in. This motion results in the solenoid humming, buzzing or chattering and is known as AC hum.

shading coils





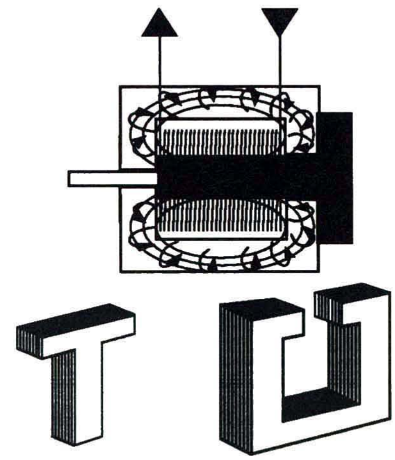
To minimize AC hum and increase solenoid force, shading coils are used. In an air gap solenoid, shading coils are copper loops which are attached to the C frame. In a wet armature solenoid, a shading coil is a copper wire ring at the pushpin end of the tube.

As the solenoid operates, current is generated in a shading coil which lags behind the applied current. Now, as the main magnetic field of the coil has its lowest value, the magnetic field of the shading coil is sufficient to hold the plunger or armature in. As a result, AC hum is greatly reduced.

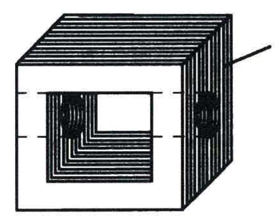
eddy currents

AC magnetic fluctuations also cause small stray currents to develop within the solenoid; these are known as eddy currents. Moving in tiny circles within iron magnetic paths, eddy currents consume power and generate heat reducing solenoid force.

To minimize eddy current effects, the C frame and plunger of air gap solenoids are made up of thin metal sheets which are insulated from one another with an oxide coating. Each metal sheet is known as a lamination. Magnetism can easily flow in its usual path around the coil, but eddy currents cannot flow between laminations because of insulating coatings. Because it is made of laminated sheets stacked together, a C frame is frequently called a "C stack."

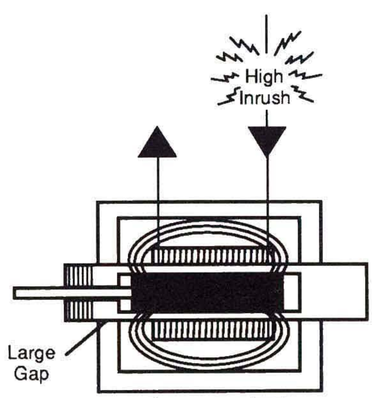


In a wet armature solenoid, eddy current effects are minimized by fabricating the rectangular frame surrounding the coil as laminations. However, this is not the case with the armature. Since a wet armature solenoid is more powerful than an air gap type, it is impractical from a durability standpoint to fabricate the armature as laminations. In a wet armature solenoid, the armature is one piece.

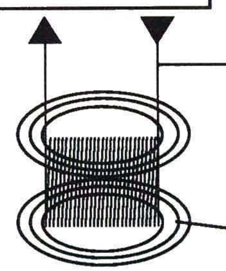


By containing eddy currents, heat is reduced and solenoid force is increased.

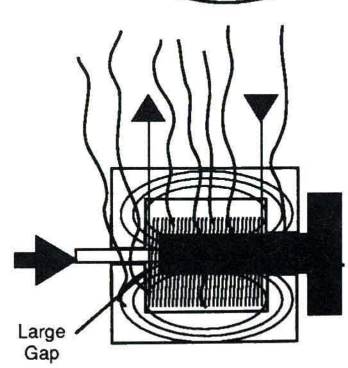
solenoid inrush current



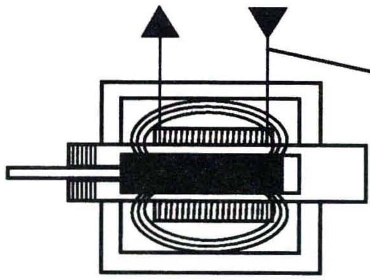
Alternating current in a solenoid coil results in solenoid force to shift a directional valve spool. It is also the cause of heat generation which can eventually burn out a solenoid coil. The more current flowing in solenoid windings, the more tendency there is for the solenoid coil to fail.

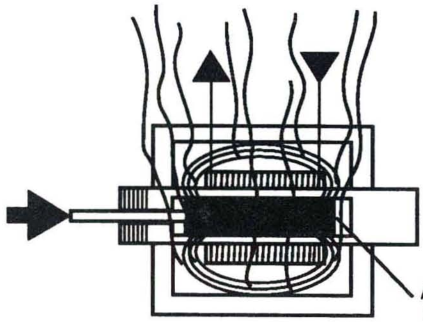


If the solenoid does not move to close the air gap the current remains high causing excessive heat. Unlike positive displacement, industrial hydraulic systems where fluid flow is relatively constant, current flow in the common electrical system is related to resistance. The greater the resistance to current flow, the less current will develop and the less heat will be generated. Since heat significantly affects solenoid life, the goal, then, is to achieve sufficient shifting and holding force with as little current as possible. This is accomplished by designing into the coil sufficient AC resistance which is known as impedance.



Impedance is made up of two elements. One element is the result of pure resistance to electron flow of the conductor material e.g., copper offers less electrical resistance than aluminum. The other element of impedance is the effect generated by the electromagnetic field surrounding the coil. This field tends to hold back or restrict current





flow into the coil. The stronger the magnetic field becomes, the less current flows in solenoid windings.

As solenoid is energized, its plunger or armature is partially out of the coil. Magnetic field is not at full strength because of the high resistance gap within coil center. At this point, resistance to current flow comes primarily from pure resistance to electron flow of the conductor material. Consequently, a high inrush current is experienced in coil windings. This decreases as plunger or armature moves in completing the magnetic path. With plunger or armature fully seated, impedance is maximum; alternating current within the solenoid is minimum.

Peak inrush current as a solenoid is energized, is several times greater than holding current with plunger or armature fully within the coil. If anything obstructs plunger or armature from fully seating, large amounts of current will rush into the coil generating high temperatures. In a non- encapsulated air gap solenoid, this can cause plastic material on coils ends to melt. With encapsulated air gap or wet armature designs, plastic encapsulation bubbles. And in both solenoid types, wire insulation deteriorates rapidly shorting out the coil in a minute or two. This is the case as a solenoid attempts to shift a spool which is blocked or stuck.

continuous duty solenoid

A continuous duty solenoid is one that can be held energized indefinitely without overheating. Heat dissipating ability of the solenoid is great enough to dissipate most heat generated by the coil's lower holding current.

Solenoids of most industrial hydraulic directional valves are continuous duty solenoids.

solenoid limitations

Solenoid operated directional valves have a few limitations. Where a hydraulic system is used in a wet or explosive environment, ordinary solenoids may not be used. Where the cycle life of a directional valve must be extremely long, an electrically controlled solenoid valve is not generally used.

Probably the greatest disadvantage of solenoids is that the force which can be developed by them to shift a directional valve spool is limited. As a matter of fact, the force required to shift a directional valve spool is substantial in the larger sizes. In the larger valves, many times a 1/4" (6.35 mm) or 3/8" (9.5

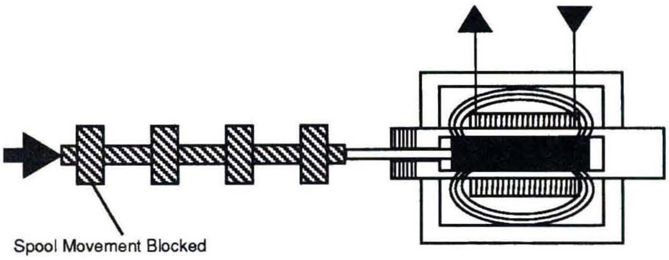
mm) solenoid operated directional valve is positioned on top of the larger valve. Flow from the small valve is directed to either side of the large valve spool when shifting is required. These valves are designated solenoid controlled, pilot operated directional valves.

solenoid failure

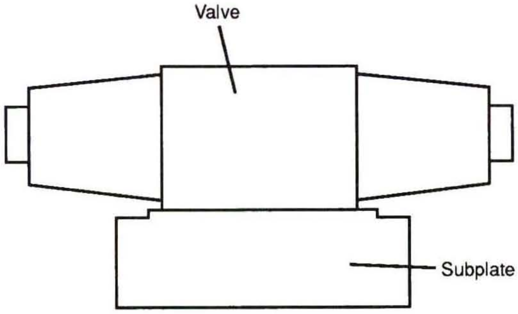
Solenoids of direct acting directional valves fail because of heat. This is generally the result of solenoid blockage, high ambient temperatures, or low voltage (insufficient force to seat the plunger).

solenoid blockage

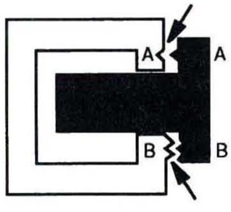
A valve spool which has become stuck will block a solenoid plunger or armature from completely closing; this results in a solenoid coil receiving a high inrush current continuously. The solenoid will be incapable of dissipating the developed heat; and the coil will burn out.



Although excessive flow through a valve will block a solenoid, mechanical interference of spool movement is the more frequent cause of blockage. Valve spools can become stuck because of contamination like silt, metal chips, coring sand, and Teflon tape or because of burrs which build up between spool and valve body. Oxidized oil particles or varnish can also coat a spool eliminating the clearance between spool and body. Varnish can be removed usually by washing with lacquer thinner.

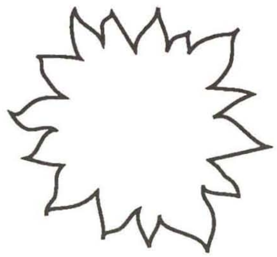


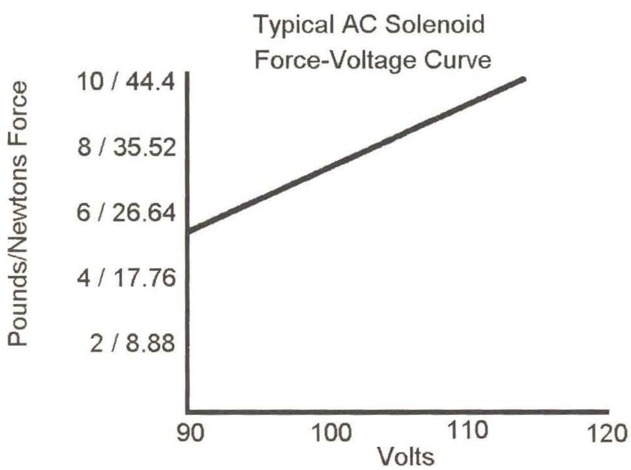
A solenoid can also become blocked due to a valve base which is not flat. In this condition, when mounting bolts are tightened, the valve base may warp slightly, restricting spool movement resulting in coil burnout. Generally, the flatness of a valve base is required to be within 0.0003-0.0005 in (.00762 - .0127 mm).

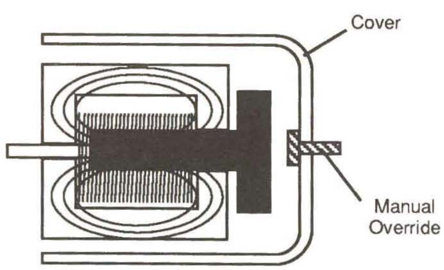


In an air gap solenoid, as a solenoid plunger is drawn into its coil, a wear pattern develops between plunger and C frame. When a solenoid of this type is disassembled, it is recommended that the plunger be replaced in its original position. If not, then different wear patterns on either end of the plunger will not match. The plunger will not fully seat. The solenoid will buzz indicating failure is near.

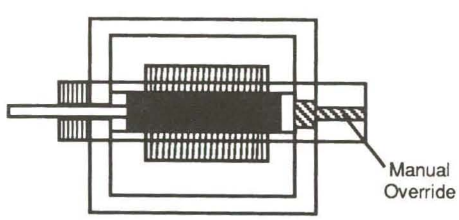
In some cases, a double solenoid valve may have its solenoids energized at the same time. This usually means one plunger or armature fully seats and the other becomes blocked; one solenoid coil burns out as a result. Simultaneous energizing of







Air Gap Solenoid



Wet Armature Solenoid

two solenoids is frequently caused by a failed or faulty component in the electrical control or an incorrect electrical hookup.

high ambient temperature

As electrical current pulls in a solenoid plunger or armature, heat must be dissipated from the coil. If the surrounding air temperature is exceedingly high, heat dissipation will be difficult and the coil may burn out. This can be the case if ventilation is poor or the machine is operating near a source of heat.

low voltage

When line voltage drops to approximately 100 volts for 115 volt, 60 Hz solenoids, insufficient force is developed to seat plunger or armature within the designed time frame. With inrush current generated for a longer time period, a solenoid operates at a higher temperature eventually failing. In some cases, early stages of coil burnout are indicated by a buzzing or chattering noise. Low voltage problems frequently occur during periods when many utility customers require power. If low voltage is suspected, the power company can install a 24-hour recorder to verify the condition.

manual override

Air gap solenoids of industrial hydraulic valves made to industry standards are protected by covers. On cover ends, a small metal pin is located. The pin is positioned directly in line with the solenoid plunger. As the pin is mechanically pushed into the cover, it contacts the plunger hitting the valve pushpin shifting the spool. Solenoid function is overridden. The pin is known as a manual override. The manual override in a wet armature solenoid is located on the end of the tube which houses armature and pushpin.

Manual overrides are used to check movement of a directional valve spool. If a solenoid failed because a spool jammed, spool movement can be checked by pushing in the manual override.

With an air gap solenoid, spool movement frequently cannot be checked with a burnt-out coil in a solenoid cover. When an air gap solenoid fails due to a plunger not fully seating, high temperature causes plastic material on the coil end to melt. Melted plastic obstructs plunger movement within the coil. Under this circumstance, the manual override cannot be pushed into the cover.

Manual overrides are also used to cycle an actuator without energizing the complete electrical control system. If cylinder operation needs checking or flow controls require adjustment, manual overrides can be used to cycle the actuator.

solenoid controlled pilot operated, spring offset

Solenoid operated, pilot operated, two position directional valves are not frequently equipped with two solenoids. This is an unnecessary expense and an additional solenoid to worry about in the system.

More commonly, a two position directional valve uses a solenoid to shift the pilot valve spool to an extreme position. The spool is generally returned to its original position by means of a spring. Two position valves of this nature are known as solenoid controlled pilot operated spring offset directional valves.

normally passing and normally non-passing valves

Spring offset 2-way and 3-way valves can be either normally passing or normally non-passing.

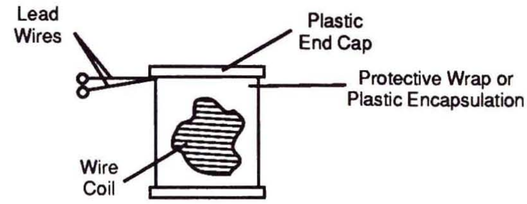
When spring offset directional valves are shown symbolically in a circuit, the symbol indicates its normal condition.

In the illustration, two solenoid operated spring offset 2-way valves are positioned in a line. The block of the symbol on which the spring acts determines the valve's unactuated position. In valve A, the spring acts on its non-passing position. As the solenoid is energized, the open block is pushed into the line. Valve A is a normally non-passing 2-way. Valve B is a normally passing 2-way.

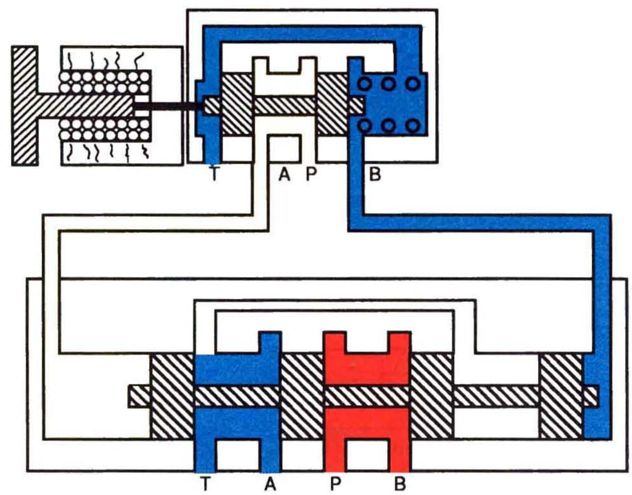
With a two-position 3-way valve, there is always an open path through the valve. In one extreme position, P is connected to tank. With a 3-way valve, normally non-passing indicates that the P port is blocked in the normal, unactuated position. In the illustration, valve C is a normally non-passing 3-way; valve D is normally passing 3-way.

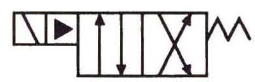
normally passing and normally non-passing valves in a circuit

Spring offset 2-way and 3-way valves can be used as system interlocks.



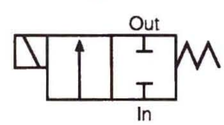
Air Gap Solenoid Coil





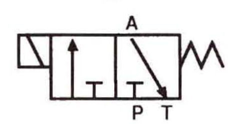
Spring Offset, Solenoid Controlled, Pilot Operated, 4-Way Directional Control Valve

A



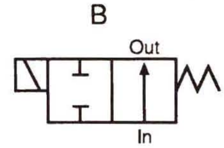
Spring Offset
Solenoid Operated 2-Way
Valve Normally non-passing

C



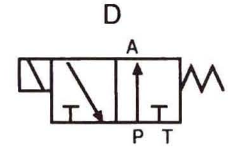
Spring Offset
Solenoid Operated 3-Way
Valve Normally non-passing

B

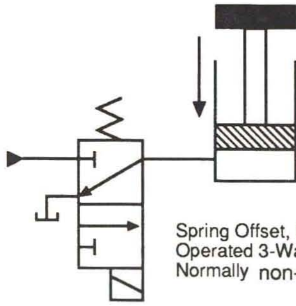


Spring Offset
Solenoid Operated 2-Way
Valve Normally passing

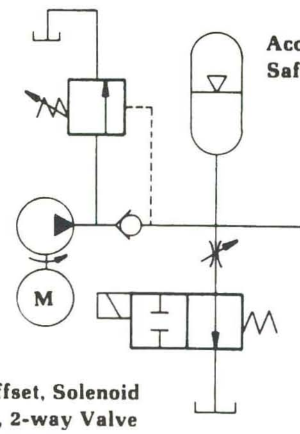
D



Spring Offset
Solenoid Operated 3-Way
Valve Normally passing

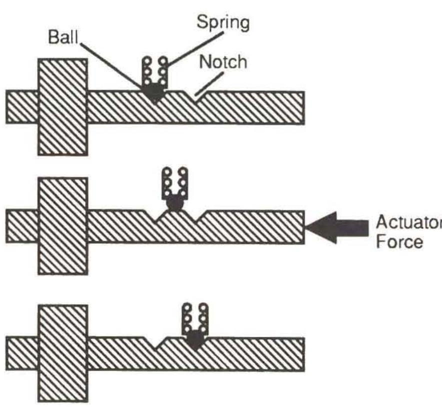


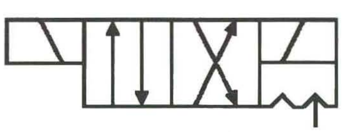
Spring Offset, Solenoid Operated 3-Way Valve Normally non-passing



Accumulator Safety Bleed

Spring Offset, Solenoid Operated, 2-way Valve Normally Passing





2-position, solenoid operated detented, 4-way directional valve

In the illustration, a spring offset, solenoid operated, normally non-passing 3-way valve ensures that the load attached to the single-acting cylinder will not rise until an electric signal is transmitted to the solenoid. The signal may indicate that a part is in position, a door is closed, or that the machine is in some manner ready for cycling.

In any accumulator circuit, a means should be available of automatically unloading the accumulator(s) once the system is shut down. This can be accomplished with a spring offset, solenoid operated, normally passing 2-way valve. In the example illustrated, the solenoid of a 2-way valve can be energized when the system electric motor is started. This blocks flow through the valve allowing the accumulator to charge. When the system is shutdown, the solenoid is de-energized and a spring pushes the valve spool to its normally passing position. Accumulator bleeds down safely through the needle valve. Therefore, anytime the electric motor is shutdown, the accumulator automatically bleeds off.

detents

If two actuators are used to shift the spool of a two position valve, detents are sometimes used. A detent is a locking device which keeps a spool in the desired shifted position.

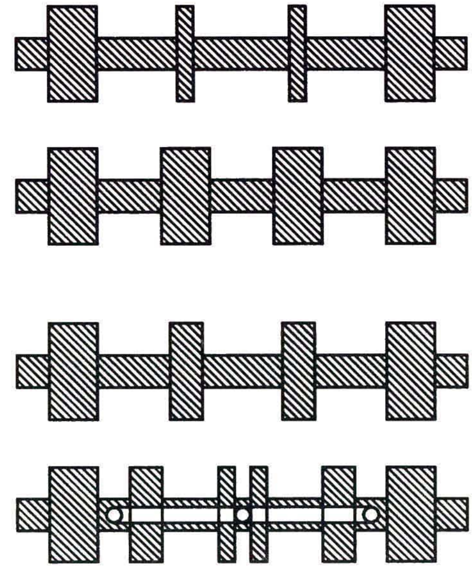
The spool of a detented valve is equipped with notches or grooves. Each notch is a receptacle for a spring-loaded movable part. In the detent illustrated, the movable part is a ball. With the ball in the notch, the spool is held in position. When the spool is shifted, the ball is forced out of one notch and into another notch.

Directional valves which are equipped with detents are not required to keep their actuators energized to achieve a shifted position.

In the following section, we review the center positions of hydraulic 4-way directional valves and then look at their characteristics and application in a system.

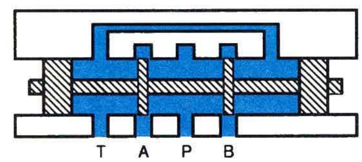
center conditions

In referring to the possible flow paths through a two position, 4-way directional valve, flow paths as the spool was in either extreme were considered only. But, there are intermediate spool positions. Industrial hydraulic 4-way directional valves are frequently three position valves consisting of two extreme positions and a center position. The two extreme positions of a 4-way directional valve are directly related to actuator motion. They are the power positions of the valve. They control movement of an actuator in one direction and then in the other. The center position of a directional valve is designed to perform logic or to satisfy a need or condition of the system. For this reason, a directional valve center position is commonly referred to as a center condition. There are a variety of center conditions available with 4-way directional valves. Some of the more popular center conditions are the open, closed, tandem, and float centers. These conditions can be achieved within the same valve body simply by using the appropriate spool.

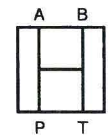


open center condition

A directional valve with an open center spool has P, T, A, and B passages all connected to each other in the center position.

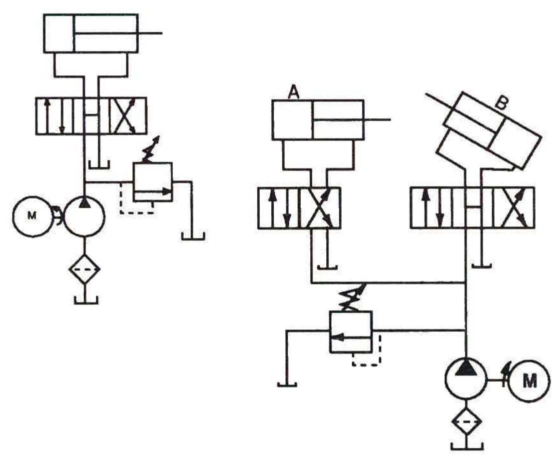


Open Center Spool



open center valve in a circuit

Open center 4-way valves are many times used in single actuator circuits. In these systems after an actuator has completed its cycle, the directional valve spool is centered and pump flow returns to tank at a low pressure. At the same time, the actuator is free to move. Disadvantages of an open center valve are that no other actuator may be operated while the valve is centered and a cylinder load cannot be held in a mid-stroke position.

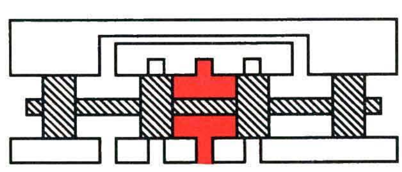


In the circuit illustrated, cylinder B extends and retracts as the directional valve is shifted from one extreme position to another. When the valve is centered with cylinder in mid-stroke, cylinder load can continue to move. And, with valve B centered, cylinder A cannot be operated since all pump flow continually dumps to tank.

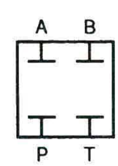
closed center condition

A directional valve with a closed center spool has P, T, A, and B passages blocked in the center position.

closed center valves in a circuit

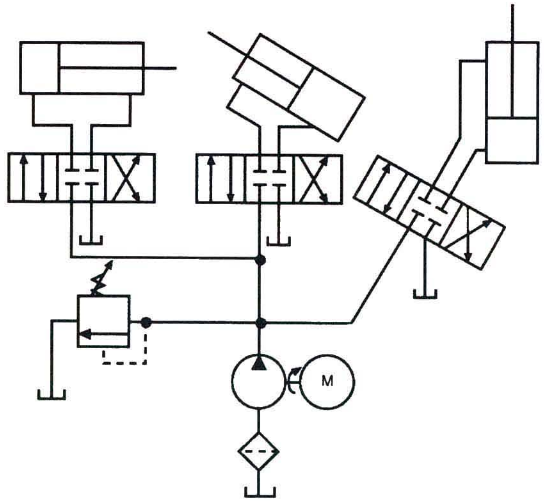


Closed Center Spool



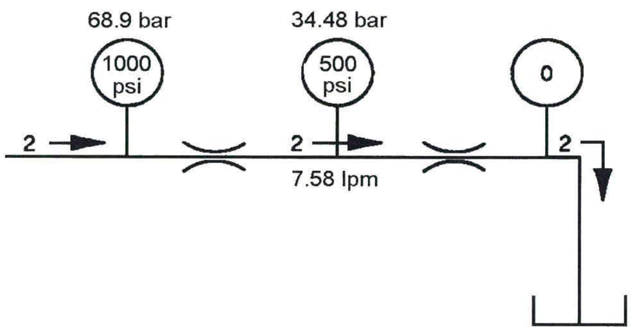
A closed center condition stops the motion of an actuator as well as allowing each actuator in a system to operate independently from one power supply.

Closed center directional valves have some disadvantages. One disadvantage is that pump flow cannot unload to tank through the directional valve during actuator idle time. However, this can be accomplished by venting a pilot operated relief valve.



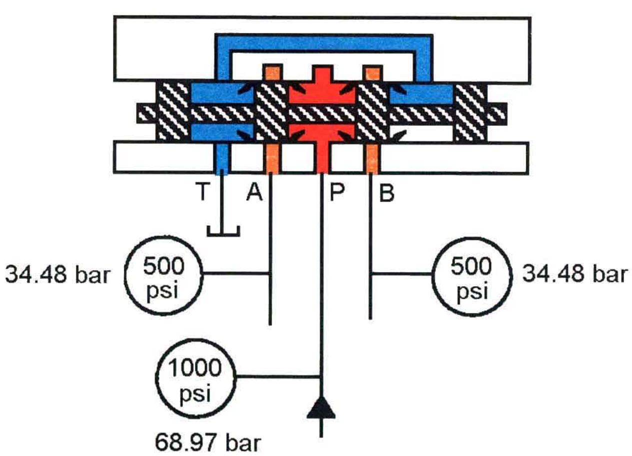
Another disadvantage of a closed center valve is that the spool leaks just as in any spool valve. This means if the spool is subjected to system pressure for anything longer than a few minutes, pressure will build in the A and B actuator lines. This occurrence can be explained by an example.

In the illustration, two fixed restrictions are placed in a line passing flow to tank. Both restrictions are exactly the same. Tank pressure is assumed to be zero.



Total pressure differential across both restrictions is 1000 psi (68.97 bar). Since restrictions are equal, equal amounts of pressure energy are transformed into heat as 2 gpm (7.58 lpm) passes to tank. Restriction 1 transforms 500 psi (34.48 bar) of the 1000 psi (68.97 bar) into heat. Restriction 2 transforms the remaining 500 psi (34.48 bar) into heat. Pressure differential across each restriction is 500 psi (34.48 bar). Pressure between both restrictions is 500 psi (34.48 bar).

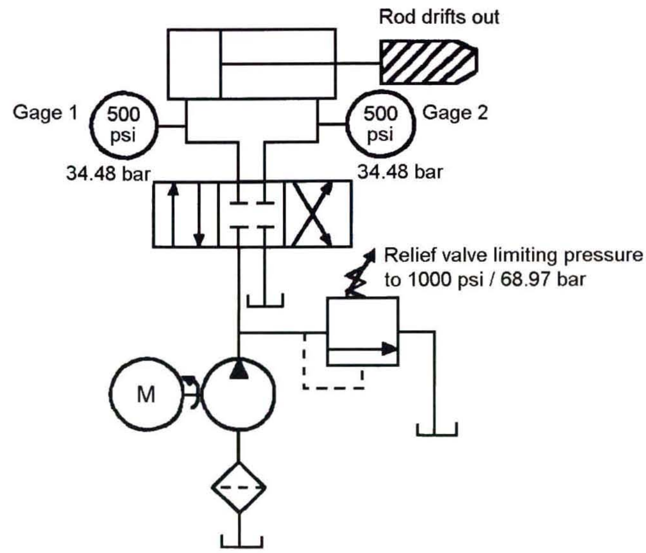
As a closed center directional valve is centered, fluid leaks through the valve. Leakage passes from the P port across a spool land edge into the A port. Since fluid has no place to flow out of the A line, the leakage path continues across the other spool land edge into the tank port.



With the valve spool centered, assume pressure at the P port is 1000 psi (68.96 bar) and tank pressure is zero. Each spool land edge blocking the A port from pressure and tank ports, can be considered a fixed restriction as illustrated in the example. As fluid leaks from the P port into the A port, 500 psi (34.48 bar) is used. As fluid continues to leak into the tank port, it loses another 500 psi (34.48 bar). Pressure in the A port and, therefore, in the A actuator line is 500 psi (34.48 bar).

This action occurs in a similar manner on the other side of spool, building pressure to 500 psi (34.48 bar) in the B port and B actuator line.

In the example circuit, a closed center directional valve is subjected to 1000 psi (68.96 bar) in its P port while in the center position. After a few minutes a pressure of approximately 500 psi (34.48 bar) will be seen in the actuator lines. With 500 psi (34.48 bar) acting on both ends of a single rod cylinder, a force imbalance is generated which tends to extend the rod. If the cylinder does not have a sufficiently large load, it will tend to creep out.

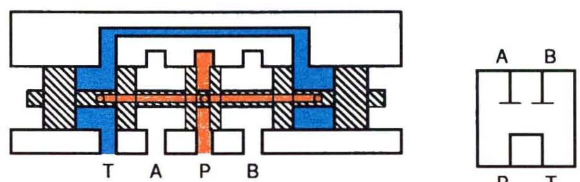


NOTE: In actual practice, pressure at the cylinder rod side would be approximately 500 psi (34.48 bar). Pressure at the cap side would stabilize at something less than 400 psi (27.59 bar). Basically, forces (P x A) across the piston would be practically in balance.

Correcting a rod drift problem of a closed center valve is not accomplished by incorporating a pilot operated check valve at cylinder rod side. Closed center directional valves are not generally used with pilot operated check valves. A PO check can become ineffective as soon as sufficient pressure is built up in its pilot line. PO checks do little to control rod drift of this nature.

tandem center condition

A directional valve with a tandem center spool has P and T passages connected and A and B passages blocked in the center position.

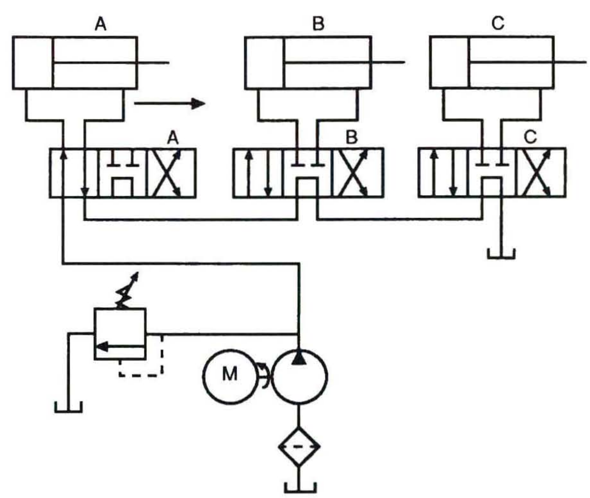


Tandem Center Spool

tandem center valves in a circuit

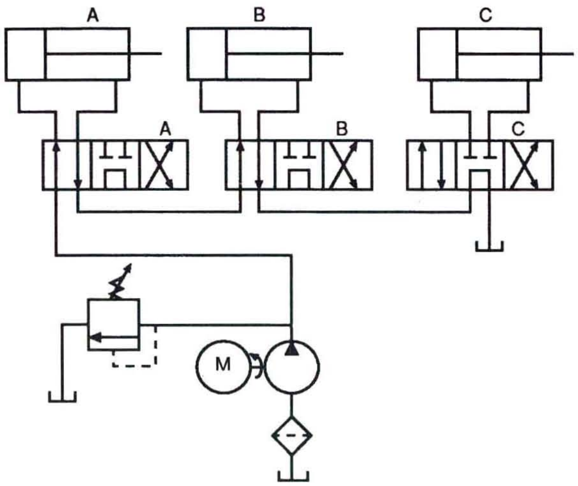
A tandem center condition stops actuator motion, but allows pump flow to return to tank while a system is idling.

Many times tandem center directional valves are connected in series with one valve's T port connected to another valve's P port. With this arrangement, actuators can be operated individually or together. Also, during idle time, pump flow can be unloaded to tank through the directional valve.



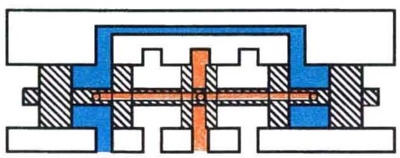
In the illustrated circuit, three cylinders have their motion controlled by individual tandem center directional valves. When directional valve A is shifted, parallel arrows are pushed into the circuit; cylinder A extends. Discharge flow passes through valves B and C back to tank. When cylinder A operation is completed, valve A is centered. At this point, either cylinder B or C can be operated. Each cylinder can operate independently; pressure required at each cylinder is determined by load and piston area as is the usual case.

With tandem center directional valves in series, cylinders can be operated simultaneously. If valves A and B are actuated at the same time, cylinder A receives full pump flow; it has priority since valve A is closer to pump. Rod speed of cylinder B is determined by the discharge flow from cylinder A. If valve C is actuated, then, its rod speed would be



determined by the discharge from cylinder B. With this arrangement, cylinders can operate at the same time; pressure required at each cylinder will depend on its load and the load of any downstream cylinder. After work has been completed, all three valves are centered allowing pump flow to dump to tank.

It was pointed out previously that various center conditions can be achieved from a 4-way directional valve by inserting the appropriate spool into a valve body. When a tandem center spool is used in a valve body, its flow rating is reduced. And, the center, unloading condition of the spool is not as good as might be expected when looking at a tandem center symbol.

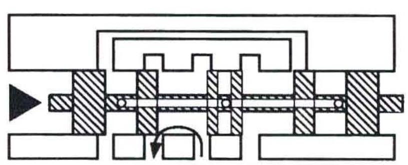


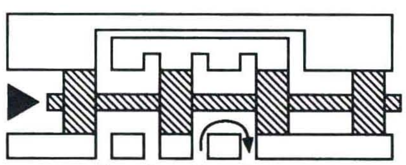
Tandem Center Spool

The P and T passages of an industrial hydraulic 4-way valve are not located next to each other. With the P passage in the center and the T passage at both extremes, passages are connected in the center position by means of a passage through the spool shaft. This is a narrow flow path which can result in a 150 psi (10.35 bar) drop from P to T. If pump flow must pass through several valves, pump/electric motor may be required to develop substantial power during idle.

In order to allow flow path from P to T in the center position, the spool shaft between the lands is much thicker than in any other spool type. This results in a restricted flow path when the spool is shifted to either extreme.

A tandem center directional valve operates a little differently than directional valves with other spool designs. Because of its construction, when a tandem center spool is shifted toward the right side, flow passes from P to A. With any other spool, such as a closed center spool, flow passes from P to B when shifted to the right.





Consequently, if a tandem valve replaces a valve with a different spool configuration, the actuator controlled by the directional valve will operate backwards if all other things remain the same.

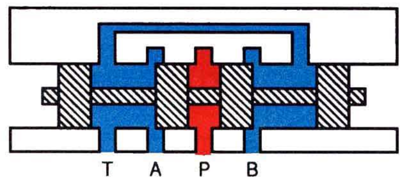
float center

A directional valve with a float center spool has the P passage blocked, and A, B, and T passages connected in the center position.

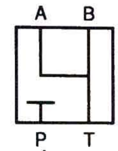
float center valves in a circuit

A float center condition allows independent operation of actuators tied to the same power source as well as allows free movement of each actuator.

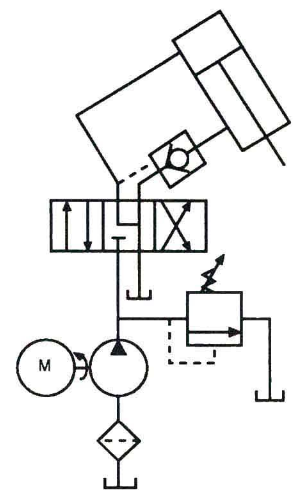
An advantage of a float center is that actuator lines do not have a buildup of pressure when the P passage is blocked as in a closed center valve. This controls piston rod drift.



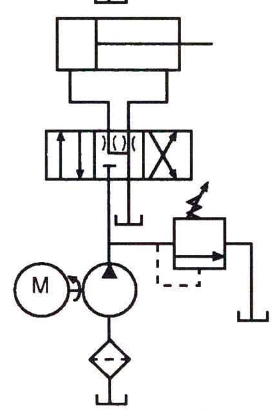
Float Center Spool



A disadvantage of this spool is that a load cannot be stopped or held in place. If this is a system requirement, a pilot operated check can be used in conjunction with the valve. Float center spools are sometimes referred to as "PO check" spools for this reason.

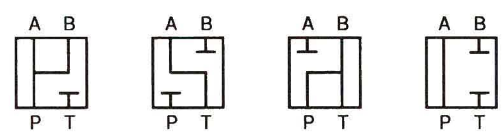


If a load controlled by a float center spool must be slowed in its motion when the valve is centered, a float center spool with metering orifices on the A and B lands is used. The orifices restrict the flow to tank through A and B when the spool is centered. This generates a back pressure in an actuator which tends to slow and may even stop motion. Float center spools of this nature are sometimes referred to as "motor spools."



other center conditions

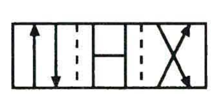
Other center conditions besides open, closed, tandem, and float, are available from directional valve manufacturers. These center conditions do not have specific names, but they give even greater flexibility in satisfying system demands.

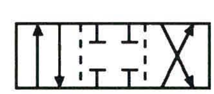


crossover conditions

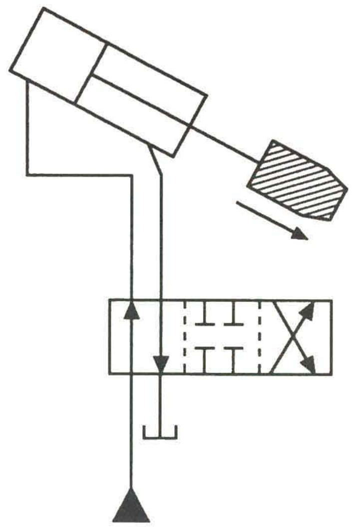
Two position directional control valves have two extreme positions which usually control actuator direction while doing work. Two position directional valves come equipped with a center position as well. The center position is known as a transition or crossover. This is what an actuator sees for a fraction of a second as a spool shifts from one extreme position to another. Open and closed center conditions are the most frequently used crossovers.

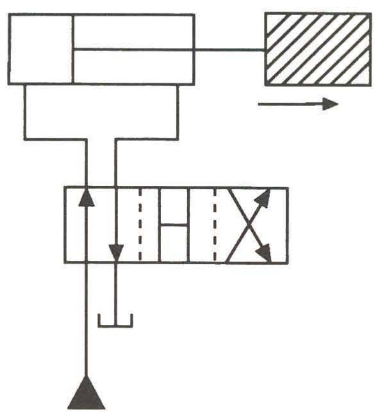
A closed center crossover does not allow pump/electric motor pressure to drop during a spool shift.

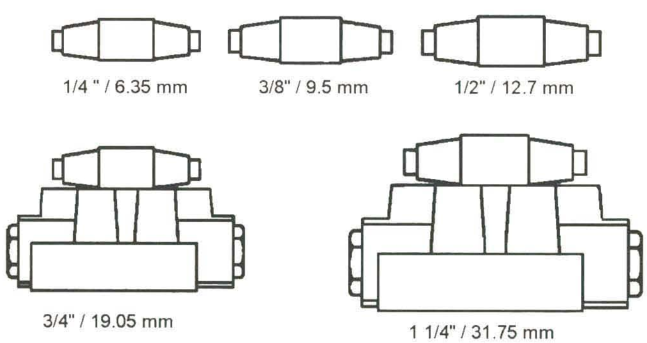

Open Center Crossover


Closed Center Crossover

In the illustrated circuit, a drill cylinder is controlled by a two position, 4-way valve with a closed center crossover. (The crossover condition is illustrated by enclosing the center position with dash lines.)







With directional valve shifted so that parallel arrows are in the circuit, the drill cylinder extends. When the piston rod reaches a certain position, directional valve shifts to the crossed arrows. While moving across center, pump pressure is not allowed to fall. This does not permit the piston rod to lunge downward during the shift.

An open center crossover allows actuator lines to bleed slightly before reversal takes place. This is an important consideration in reversing a high inertia load.

In the illustrated circuit, a cylinder is moving a heavy load. When the load reaches a certain position, directional valve is shifted to reverse load direction. As the spool moves to the opposite extreme, an open center crossover bleeds all ports to tank. For a fraction of a second, pressure drops and then builds once again as the spool fully shifts. Bleeding of the ports helps eliminate shock as the load changes direction. If a closed center crossover were used with this type load, load inertia would develop a shock pressure in an actuator line as all ports were blocked while moving to an opposite extreme.

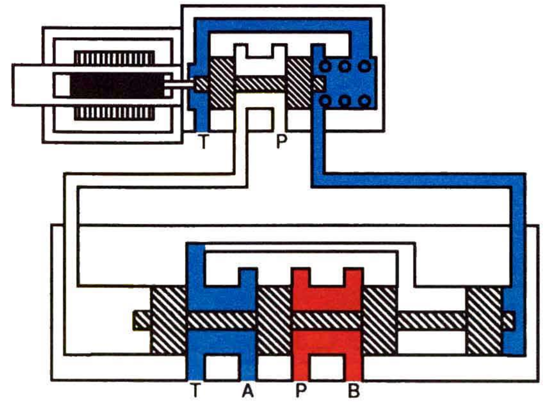
Up to this point, we have concentrated on direct solenoid operated directional valves. The remaining text material will deal with solenoid controlled, pilot operated directional valves. We will review their operation and see what accessories are available with these type valves.

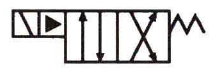
solenoid controlled pilot operated directional valve

Industrial hydraulic directional valves come in various sizes. Ranging in port sizes of 1/4" (6.35 mm), 3/8" (9.5 mm), 1/2" (12.7 mm), 3/4" (19.05 mm), 1" (25.4 mm) and 1-1/4" (31.75 mm). As indicated earlier, a very common means of shifting a directional valve spool is with a solenoid. However, this is only practical in 1/4" (6.35 mm), 3/8" (9.5 mm) and some 1/2" (12.7 mm) port sizes. In the larger 3/4" (25.4 mm) and 1¼" (31.75 mm) valves which are designed to handle flow rates of 40 gpm (132.7 lpm) and greater, direct solenoid shifting of a spool is impractical.

In large valves, force required to shift a spool is substantial. A solenoid which could generate the force, would necessarily be quite large. In valves of this type, customarily a 1/4" (6.35 mm) or 3/8" (9.5 mm) solenoid operated directional valve is positioned on top of the main valve body in a piggyback arrangement. Pressurized flow from the small valve is directed to either side of the large valve spool when shifting is required. Instead of controlling the motion of a cylinder or motor, the pilot valve controls the motion of the main valve spool.

A directional valve of this type is known as a solenoid controlled, pilot operated directional valve. Pilot pressure moves the main valve spool, but the solenoid controls the pilot.





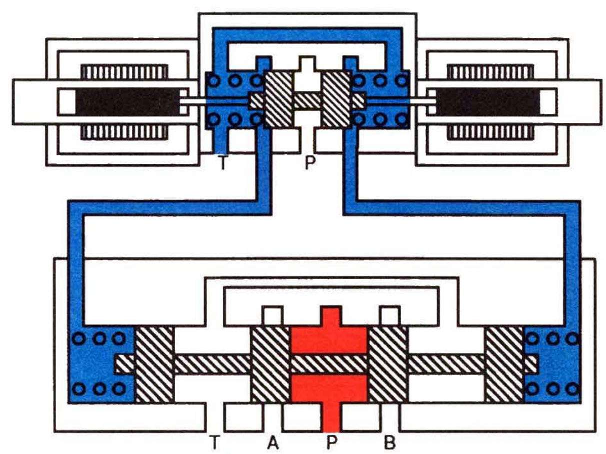
Spring Offset, Solenoid Controlled, Pilot Operated, 4-Way Directional Control Valve

spool centering in a pilot operated valve

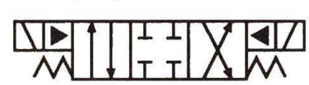
A directional valve with three positions must have an ability to hold its spool in the center position. This can be done with springs or fluid pressure.

Spring centering is the most common means of centering a directional valve spool. A spring centered valve has a spring located at each end of the spool. When the valve is actuated, the spool moves from the center condition to one extreme compressing a spring. When the float center pilot valve is centered, pilot chambers at both spool ends are drained. The spring then returns the main spool to center.

Spring centering can be a problem with valves which are handling flows beyond their intended capacity. Under this condition, the spool may shift to an extreme position. Once shifting force is removed, the spring is intended to push the spool back to center. If pressurized flow is excessive, the fluid will exert enough force to hold the spool shifted.



Spring Centered Valve



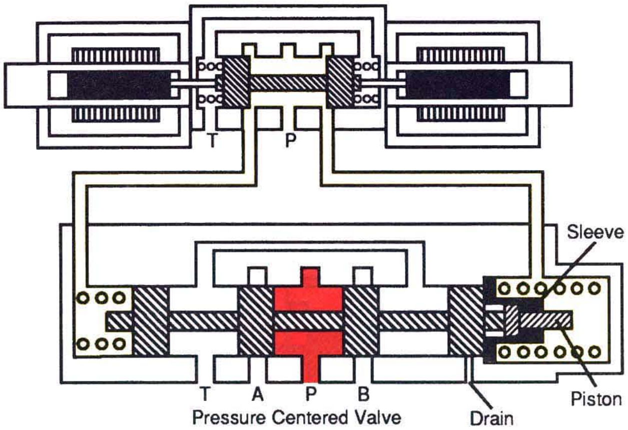
Simplified Symbol

Solenoid Controlled, Pilot Operated Directional Valve

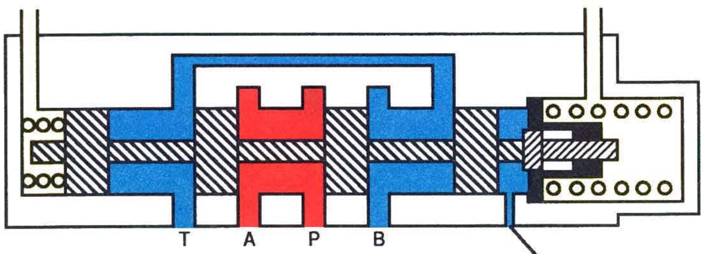
Centering the spool of the pilot operated directional valve is sometimes accomplished with hydraulic pressure. Pressure centering a valve ensures that the spool will center even if the flow rate through the valve is excessive.

In a pressure centered, pilot operated, 4-way valve, the pilot valve center position has P connected to A and B, T is blocked. In centering the valve, fluid pressure is simply directed to both sides of a spool simultaneously. Since the areas of the spool lands at either end are identical, equal forces are generated when they are exposed to the same pressure. This does not guarantee the spool will center.

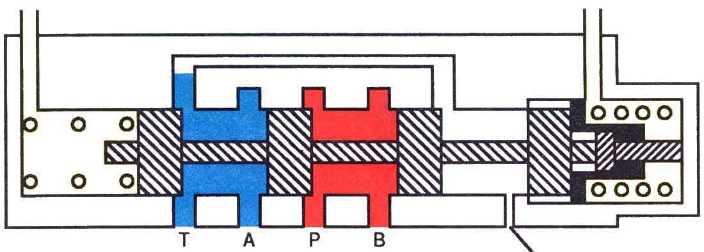
In a pressure centered valve, the space between an end spool land and the pilot chamber is sealed by a sleeve which is held against a shoulder in the pilot chamber. This space is also drained of any fluid leakage by means of an external drain passage. When the spool is required to be centered,



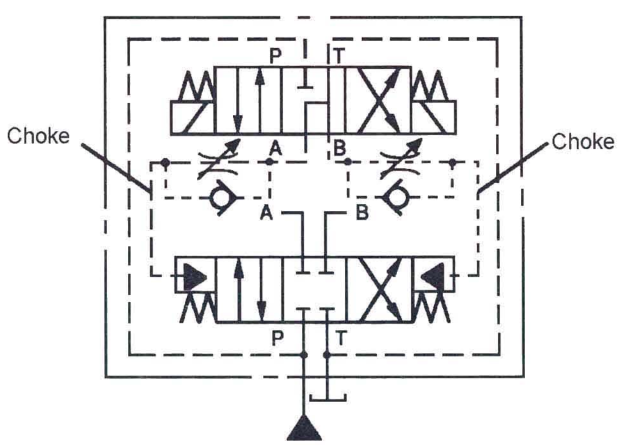
Pressure Centered Valve



Spool in Extreme Left Position



Spool in Extreme Right Position



fluid pressure is directed to the chambers at both spool ends by the pilot valve. Regardless of which extreme position the spool is in, there will be a difference in areas exposed to pressure at the time of centering.

When the spool is centered from the extreme left position, fluid pressure acts on the left end of the spool. Since the right spool end is drained, the spool moves toward the right until it butts up against the sleeve. At this point the spool is centered.

When the spool is centered from the extreme right position, fluid pressure acts on the left spool end and the sleeve at the right end. Since the sleeve has more area than the spool land at the left, a larger force is generated to move the spool toward the left. The spool moves left until the sleeve contacts the shoulder in the chamber. At this point, the spool is centered.

When the valve is to be shifted from the sleeve side of the spool, fluid pressure acts on the piston in the sleeve center. The piston then forces the spool to its extreme left position.

choke control

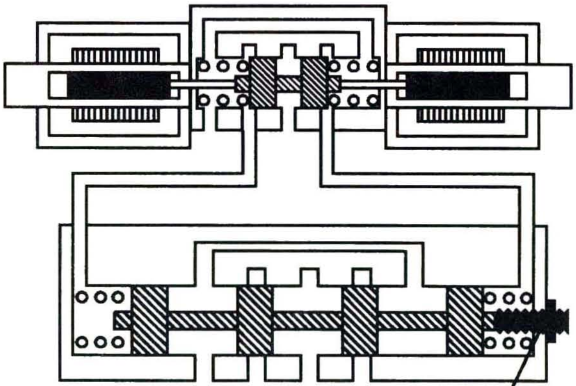
As the main spool of the pilot operated directional valve is shifted, shock can be developed as large fluid flows are forced to change direction quickly. A choke control slows the spool shift of the main valve so that shock is reduced.

A choke control is a "sandwich" valve which fits in between a main valve body and pilot valve of a solenoid controlled, pilot operated directional valve. It consists of two needle valves and two bypass check valves. The valve sandwich is arranged so that as the spool shifts in one direction a needle valve meters flow out of the pilot-spring chamber; the other needle valve is bypassed. As the spool shifts in the opposite direction, the other needle valve meters flow out of the other pilot-spring chamber. The more the needle valves are adjusted in, the more flow is restricted or choked. Consequently, the slower is the spool shift.

A choke control does not eliminate shock due to spool shift; it reduces shock. If a crash is experienced each time a large directional valve is shifted, a choke control will reduce the crash to a bang. If the shock is a bang, chokes reduce it to a thump.

stroke adjustment

One thing which can be done with the main spool of a pilot operated valve is to limit its travel. This, of course, is not advised with a direct, AC solenoid valve.



Pilot Operated Directional Valve
With Stroke Adjustment

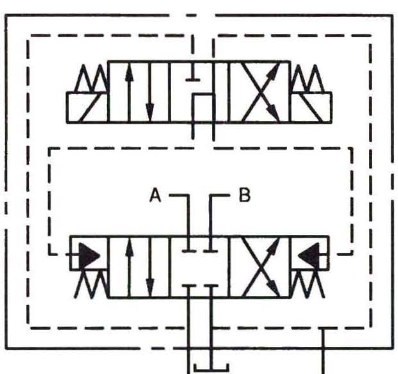
A stroke adjustment is a screw adjustment which limits spool travel in the main valve of a solenoid controlled, pilot operated directional valve. Partially limiting spool travel in one direction means that a port is not completely uncovered. This causes a restriction through the valve when the spool is shifted in one direction giving the effect of a coarse needle valve.

If the stroke adjustment is screwed in completely, one extreme position of the valve is blocked out. This in effect transforms a three position valve into a two position valve. The two valve positions are made up of one extreme position and the valve center condition.

directional valve drain

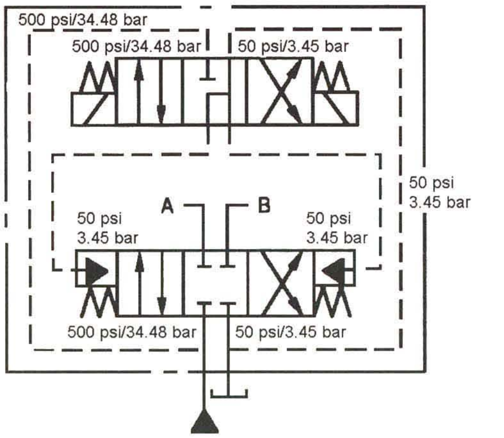
The pilot valve tank passage of a solenoid controlled, pilot operated directional valve is called a drain.

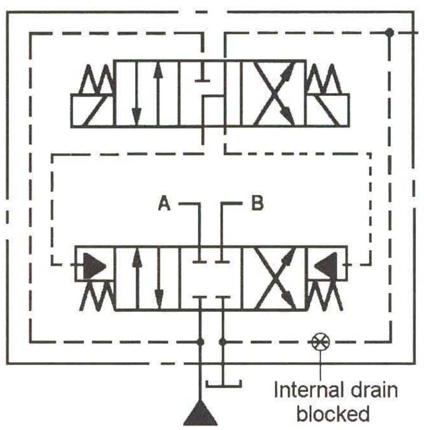
The detailed symbol of a solenoid controlled, pilot operated directional valve shows that the tank port of the pilot valve is connected by means of an internal passage to the tank passage of the main valve. This internal passage connection is known as an internal drain. With an internal drain, pressure in the tank passage must be contended with in shifting the main valve spool.

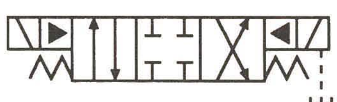


From the illustrated symbol, the P port of a closed center directional valve is subjected to 500 psi (34.48 bar) system pressure. This pressure is also supplied to the solenoid pilot valve by means of an internal passage. Back pressure in the tank line is 50 psi (3.45 bar).

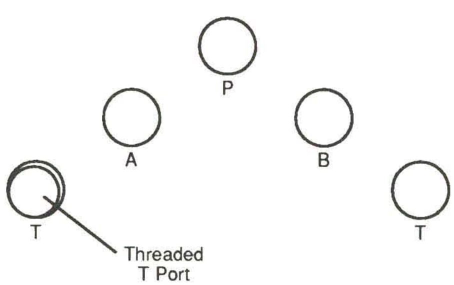
With the float center pilot valve centered, each end of the main valve spool is exposed to the back pressure. When the pilot valve is shifted, 500 psi (34.48 bar) is directed to the left spool end. In order to shift the main spool to the right, pilot pressure must overcome 50 psi (3.45 bar) backpressure and the spring which has a value of another 50 psi (3.45 bar). Of course, 500 psi (34.48 bar) can accomplish this quite easily. The main spool shifts.







Simplified Symbol



In some situations, the pilot valve is externally drained. This is the case when shock pressures are experienced in the tank line.

Assume that an internally drained directional valve has its spool held shifted to an extreme position with a pilot pressure of 500 psi (34.48 bar). This is the case in the last example. Keeping in mind that any pressure in the tank line acts on the main spool end drained to tank, assume now that a single acting cylinder discharges in another part of the circuit. Pressure climbs in the tank line to 1000 psi (68.97 bar) for a fraction of a second. Since the tank line is usually common for all valves, this pressure arrives at the main spool end drained to tank. With 500 psi (34.48 bar) on one side and 1000 psi (68.97 bar) on the other, the spool shifts in an undesired direction for a fraction of a second. This results in erratic motion at an actuator.

To remedy the situation, the valve should be externally drained. This is accomplished by removing the pilot valve from the main valve. This exposes the pilot valve porting on top of the main valve. The port pattern will consists of a P port, A and B ports, and two T ports. One of the T ports will be threaded. A pipe plug is inserted into this port blocking the internal drain. The pilot valve is replaced and a separate drain line is connected to the external drain port (Y port) of the main valve subplate. (NFPA. DO2 foot pattern shown.)

With a pilot operated directional valve externally drained, back pressure on a spool land is very low during shifting.

Externally draining a pilot operated directional valve is also required with tank line back pressure check valves. This will be illustrated below.

directional valve pilot pressure

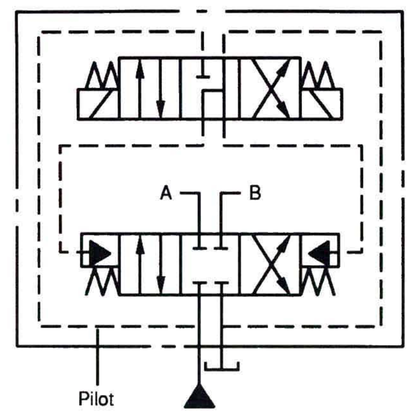
Pressure supplied to the pilot valve of a solenoid controlled, pilot operated directional valve is known as pilot pressure. This is used to shift the main valve spool.

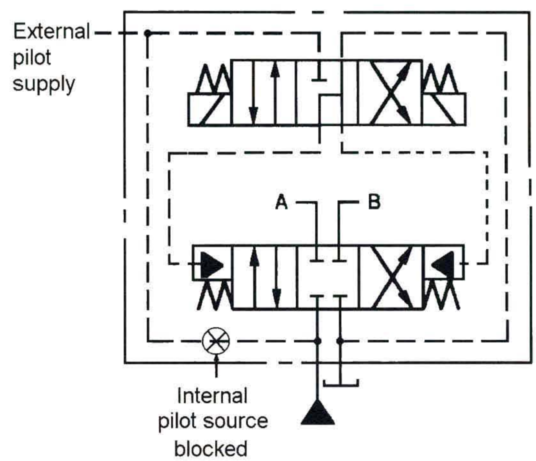
The composite symbol of a solenoid controlled, pilot operated directional valve shows that the P port of the pilot valve is connected by means of an internal passage to the P passage of the main valve. This is an internal pilot connection.

With an internal pilot, pilot pressure to shift the main valve spool has the same value as system pressure. From a previous example, a system pressure of 500 psi (34.48 bar) was supplied to the main valve spool. This was used in overcoming spring and back pressure at a spool end during shifting. As long as the pilot pressure is sufficient to overcome spring and back pressure, the spool will shift.

In some situations, the valve is required to be externally piloted. This is the case when internal pilot pressure is either too low or too high.

Assume that the system in which an internally piloted directional valve is operating, has erratic system pressure. In one instant system pressure might be 500 psi (34.48 bar); the next instant it's 50 psi (3.45 bar). This situation cannot be depended on to shift the valve. To solve the problem, the valve can be externally piloted with an external, dependable source of pilot pressure.

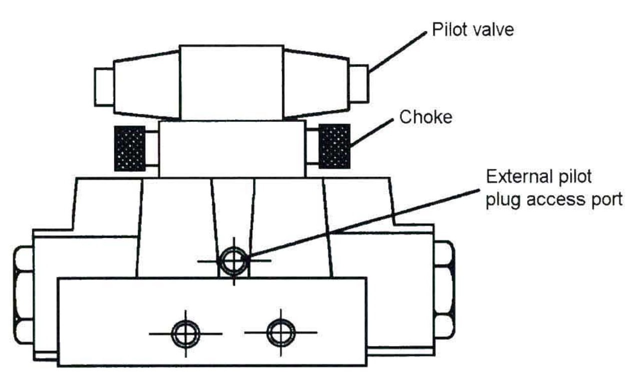




Externally piloting a directional valve is also desirable if system pressure is quite high. Assume that a system pressure of 2500 psi (172.4 bar) is supplied internally to a pilot valve. When the main valve spool is required to be shifted from one extreme position to another, the pilot valve is shifted. 2500 psi (172.4 bar) acts on a spool end, accelerating the spool quickly to an extreme. This can generate considerable shock.

Besides using choke controls, the pilot valve can be externally supplied with a pilot source of lower pressure.

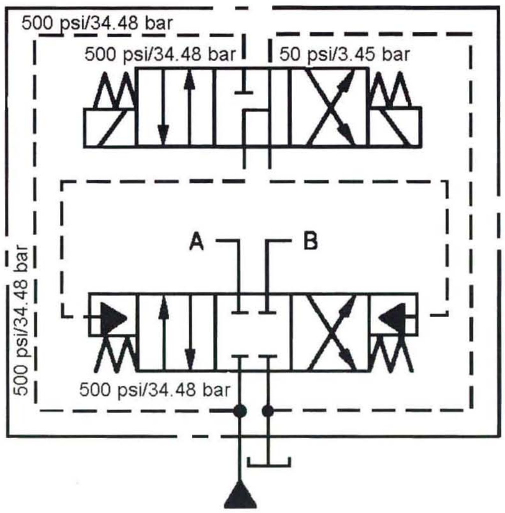
To change from internal pilot to external pilot, an internal pipe plug must be added. On the side of the main valve body, a pipe plug or SAE plug covers a port which communicates with the internal pilot passage. This plug is removed. Inside the port, the pilot passage and another threaded port can be seen. The internal port is plugged with a very small pipe plug (1/16 in./1.6 mm). This blocks the internal pilot. The outer pipe plug, or SAE plug, is then replaced and the external pilot port (X port) on the main valve subplate is connected to the source of pilot pressure.



NOTE: Before such changes are attempted, the components manufacturer should be consulted.

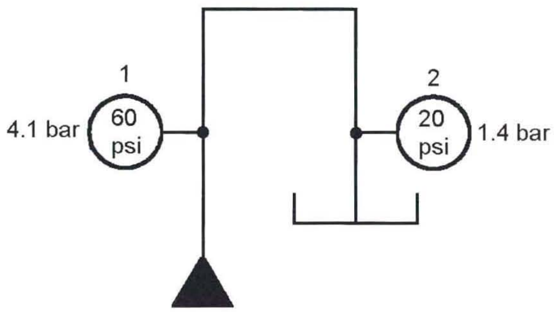
Externally piloting a pilot operated directional valve is sometimes required when a back pressure check valve is positioned in the pressure line ahead of the valve.

backpressure check valve



Pilot pressure to shift the main spool of a solenoid controlled, pilot operated directional valve frequently comes through the main valve body from the main system pressure.

In the illustrated symbol, a pilot operated directional valve with a closed center is shown. With 500 (34.48 bar) psi present at the valve P port, 500 psi (34.48 bar) is supplied to the pilot valve through an internal passage. To shift the main spool, the solenoid pilot valve is shifted. 500 psi (34.48 bar) is directed to one end of the main spool and the spool shifts.

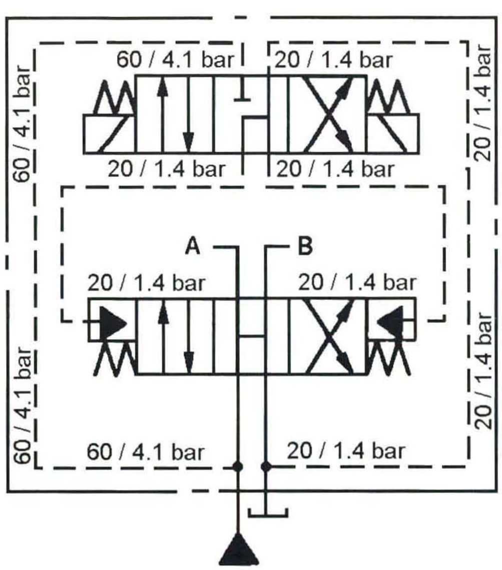


Solenoid controlled, pilot operated directional valves which have P connected to tank in the center position, do not have a readily available supply of pressure for the pilot valve. This is the case with open and tandem center directional valves.

In the illustration, pump flow returns directly to tank through system piping. Gages in the line indicate that system pressure at gage 1 is 60 psi (4.1 bar); and at gage 2 pressure is 20 psi (1.4 bar).

This exact situation exists with a tandem and open center directional valve while centered. Gage 1 would indicate the point within a valve where the internal pilot pressure is picked up. Gage 2 would indicate the point where the pilot drain is connected internally.

With this situation, 60 psi (4.1 bar) is supplied to the pilot valve to shift the main valve spool. This pressure must overcome 20 psi (1.4 bar) backpressure and a 50 psi (3.45 bar) spring. Of course, this cannot be done.



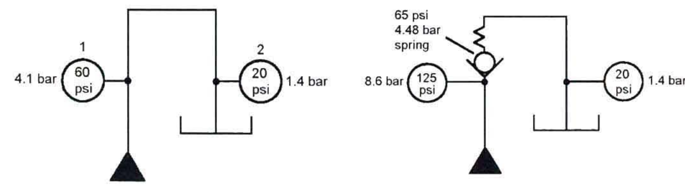
To remedy the situation, the valve can be externally supplied with pilot pressure from a remote source. The pilot valve could also be externally drained, but in this instance eliminating 20 psi (1.4 bar) backpressure may not ensure that the spool will shift.

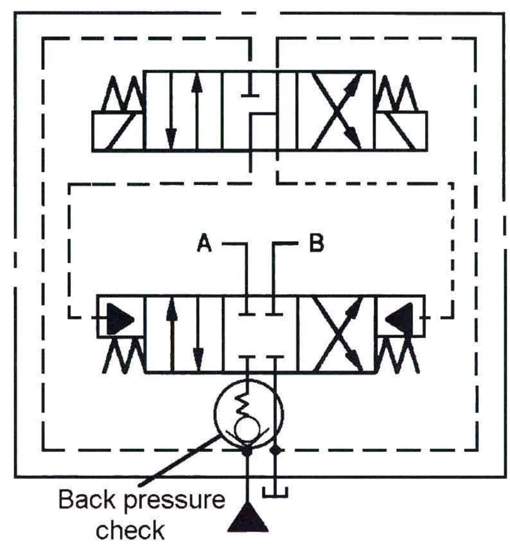
Frequently, with tandem and open center pilot operated valves, back pressure check valves are used. A back pressure check has a stiffer spring than a normal check valve. This spring requires that more pressure be present at the valve inlet to push the poppet off its seat. The additional pressure is then supplied to the pilot valve.

Backpressure check valves can be positioned in either pressure or tank lines. They can be located within the valve or external to the valve.

Some manufacturers offer a 65 psi (4.48 bar) backpressure check valve within the P port of the main valve. Its effect can be illustrated by considering a previous example.

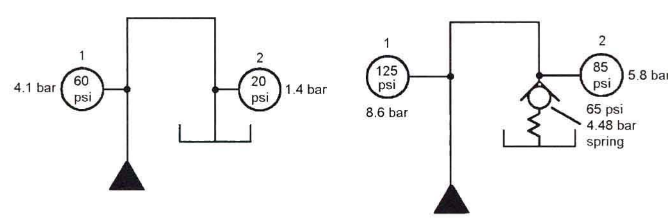
In the illustration, pump flow dumps directly to tank through system piping. Gage 1 indicates 60 psi (4.1 bar); gage 2 indicates 20 psi (1.4 bar). Putting a 65 psi (4.48 bar) check valve after the gage 1 point, requires pressure, in order to flow back to tank, be an additional 65 psi (4.48 bar) for a 125 psi (8.6 bar) total. If gage 1 indicated the point where internal pilot pressure is picked up, then 125 psi (8.6 bar) pilot pressure would be supplied to the pilot valve. When shifting is required, 125 psi (8.6 bar) is directed to either spool end overcoming 20 psi (1.4 bar) back pressure and a 50 psi (3.45 bar) spring.





Some valve manufacturers offer a 65 psi (4.48 bar) backpressure check valve in the tank port of the main valve. Its effect can be illustrated by the following example:

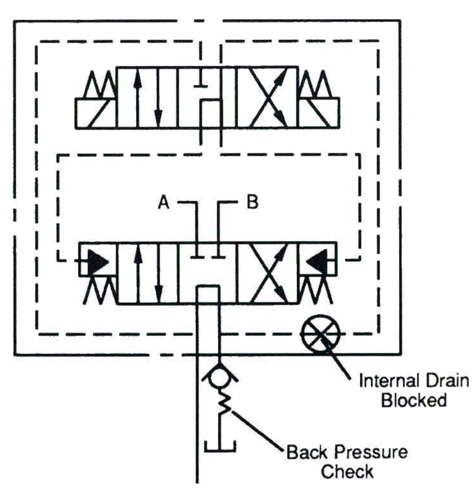
Once again, pump flow dumps directly to tank through system piping. Gage 1 indicates 60 psi (4.1 bar); gage 2 indicates 20 psi (1.4 bar). With a 65 psi (4.48 bar) back pressure check placed after gage 2, fluid pressure must be an additional 65 psi (4.48 bar) for an 85 psi total (5.8 bar) in order to get to tank. This also means gage 1 indicates an additional 65 psi (4.48 bar) or 125 psi (8.6 bar).

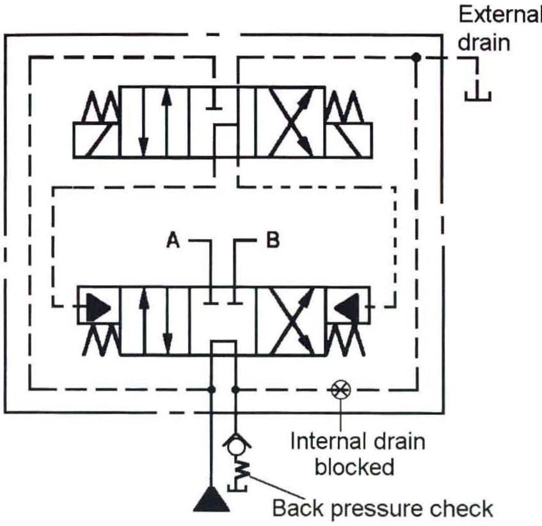


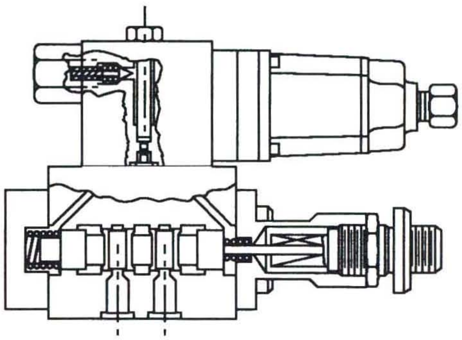
Assume that gage point 1 is where pilot pressure is picked up and gage 2 is the place where the internal drain is connected. With this situation, the pilot valve is supplied with 125 psi (8.6 bar) pilot pressure. In order to shift the valve, this pressure must overcome a back pressure of 85 psi (5.8 bar) and 50 psi (3.45 bar) spring. The spool will not shift. To remedy the situation, the pilot valve is externally drained eliminating the 85 psi (5.86 bar) back pressure.

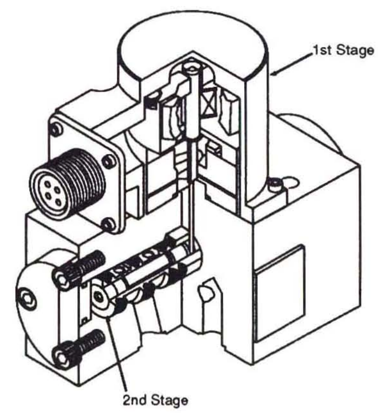
A back pressure check valve may also be located externally in the tank line.

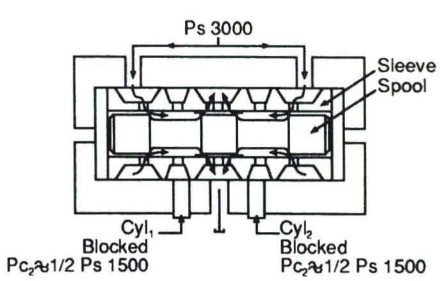
Anytime a tank line back pressure check is used with tandem and open center valves, the valve is externally drained.











electrohydraulic directional flow control valves

Over the years an increasing need for higher response, stiffer systems, better flow characteristics and an efficient means of interfacing electronic control systems with hydraulic control systems has arisen within the industrial hydraulic industry. The use of electrohydraulic directional flow control valves has met this need.

In general, we will discuss two types of electrohydraulic valves; namely, proportional and servo valves. Which type is used in a particular hydraulic system depends upon the sophistication of performance required by the system.

proportional vs. servo

There are several areas that distinguish the electrohydraulic proportional valve from a typical electrohydraulic servo valve. These areas are in the overall response of the valve, the spool center condition, the hysteresis, repeatability, and threshold of the valve, and the filtration requirements of the valves.

response

Response is generally defined for proportional valves as the time required for the valve to achieve maximum rated flow due to an electrical step input command signal.

However, the response of a servo valve is generally expressed in terms of its "frequency response." The frequency response is expressed in hertz and is the frequency of a small sine wave command signal that causes the flow amplitude to be -3db when compared with the flow amplitude at a low frequency reference level (.1Hz). The -3db point occurs when the output flow amplitude is 70.7% of the flow amplitude at the low frequency.

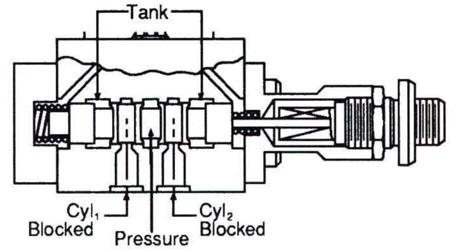
The response for the proportional valve vs. servo valve is 2-10 Hz vs. 10-300 Hz respectively.

spool center condition

The spool center condition or crossover characteristics of the main spool between the proportional valve and servo valve is quite noticeable when related to cost of valve and valve stability.

Servo valves are critically lapped by carefully matching both the width and the position of the spool lands to the metering recesses within the valve body. In other words, the spool and valve body or sleeve are matched to produce a line-line contact by hand fitting (this adds greatly to their cost).

Proportional valves are designed so that the spools and valve bodies are interchangeable. This typically results in a crossover overlap on the order of 10-30% of the total spool stroke. The overlap creates a flow condition known as deadband. Though not a problem in circuits dealing with velocity control, deadband can cause instability and loss of resolution in a closed loop feedback positioning system.



hysteresis, repeatability, threshold

Hysteresis is an accepted measurement of the difference in electrical command signal as percentage of rated electrical command for a given flow output level, when the flow output setting is alternately approached from above and below the desired flow output.

Repeatability is an indication of the ability of the valve to repeat a given flow when a given electrical command signal is repeatedly applied to the valve.

Threshold is the smallest discreet change in electrical command signal that will produce a corresponding change in the output flow.

"Open loop" proportional valves may exhibit levels as high as 10%. Typical levels for "closed loop" proportional and servo valves are 3% and less.

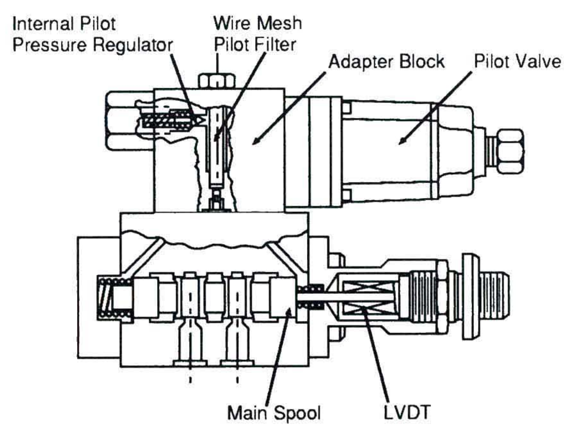
filtration requirements

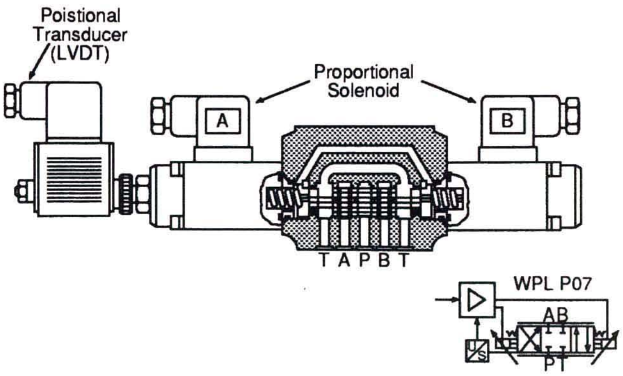
Particulate contamination is the enemy of all hydraulic systems and especially servo valves. Because of their close tolerances, filtration requirements of 3 micrometres are specified. Proportional valves are a little more tolerant of contamination and require filtration of 10 micrometres.

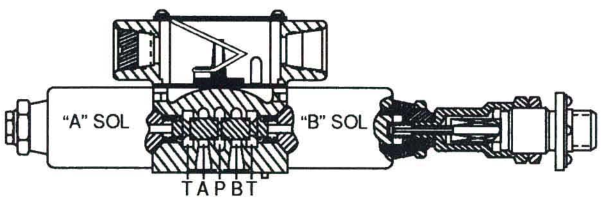
NOTE: Some proportional valves use small servo valves as the pilot head, thus, requiring additional filtration for the flow of fluid being supplied to the pilot head.

proportional valve construction

A typical proportional valve consists of the torque motor pilot valve, adapter block, wire mesh pilot filter, internal pilot pressure regulator, main spool and body, and LVDT (Linear Variable Differential Transducer).







Another style of proportional valve uses proportional solenoids to operate the main valve spool direct with a positional transducer attached to the end of the valve spool to provide a feedback signal. Still another type of proportional solenoid control pilot operated valve design is used.

how a direct operated proportional solenoid directional valve works

The main spool is held in the center condition by springs. Ports P, T, A and B are all blocked by the lands of the spool.

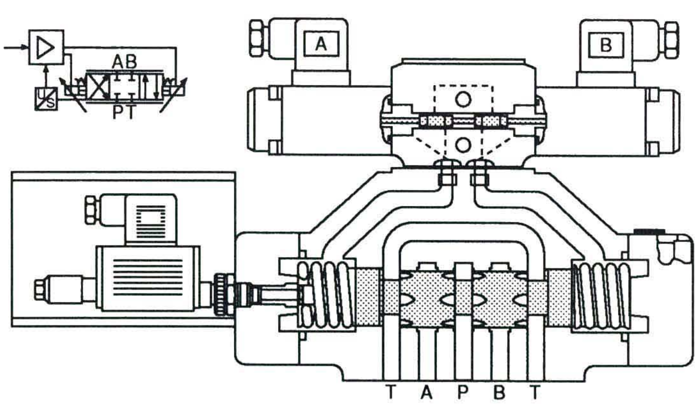
When solenoid "A" is energized with a positive voltage, the main spool is moved to the right, proportional to the input voltage directing flow from port P to B.

The positional transducer or LVDT is attached directly to the main spool which measures the precise movement (position) of the spool and feeds this back to the electronics as a voltage signal.

Briefly in the electronics, the feedback signal and the solenoid input signal are compared generating what is called an "error." The electronics will then supply either a + voltage or - voltage input signal to the proportional solenoid "A" or "B" that is energized, moving the spool either right or left respectively until the "error" equals zero.

At the same time, flow from the valve is increased or decreased.

how a pilot operated proportional solenoid controlled directional valve works



The main spool is held in the center condition by springs. Ports P, A, B and T are blocked by the land areas of the spool. With neither proportional solenoid energized, the pilot spool blocks flow from the pilot supply port.

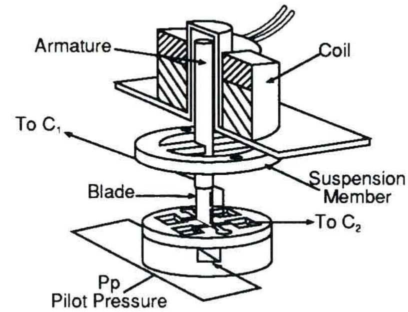
Energizing proportional solenoid "A" forces the pilot spool to the right which converts the electrical signal into a pressure signal. Pilot oil is directed to the right spring cavity of the main spool. The metering slots on the main spool open progressively based upon the amount of pressure supplied by the pilot valve.

Attached to the main spool is a positional transducer or LVDT. It functions in the same way as previously discussed for direct operated valves.

a pressure differential proportional directional valve (torque motor pilot)

A pressure differential type proportional directional valve is a two stage unit. The pilot valve sometimes called the 1st stage and the main spool or 2nd stage valve.

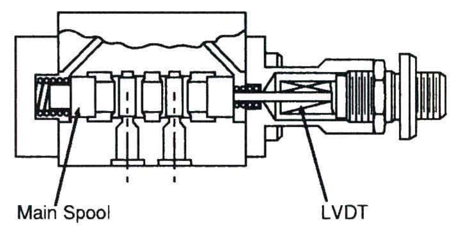
1st stage pilot valve consists of



The pilot valve basically consists of coil, armature, suspension member, diverter plate, and blade. Some pilot valves incorporate a built-in relief valve and filter to limit pilot pressure and prevent contamination of the orifice(s) in the blade.

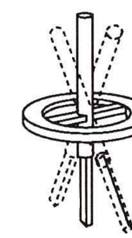
The combination of magnet, coil and armature assembly is commonly called a torque motor.

2nd stage main slave consists of



The 2nd stage or main valve consists of a spool, return springs, and an LVDT (Linear Variable Differential Transducer). This stage is quite similar to a standard directional valve.

how the pilot valve works


(Armature Motion)

Current from the electronics passing through the coil will create a north or south pole on top of the armature. The polarity of the current will determine the direction of movement of the armature between the poles of the magnet. As the armature is attracted to one of the magnet poles, it pivots on the suspension member and thus moves the diverter blade.

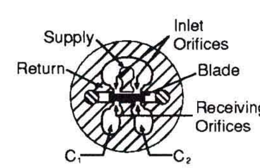


Figure 2 ($C_1 = C_2$)

This movement will be proportional to the magnitude of the command. The blade in the center position partially interrupts each jet in a manner to provide equal pressure in both receivers (C1 & C2).

When the blade moves from center, it will increase the interruption of the other jet stream. This will decrease the pressure in one receiver and increase the pressure in the other receiver. The resulting differential pressure between C1 and C2 will cause the second stage spool to shift proportionally.

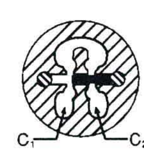


Figure 3 (C_1 Pressure Greater Than C_2)

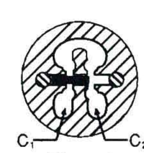
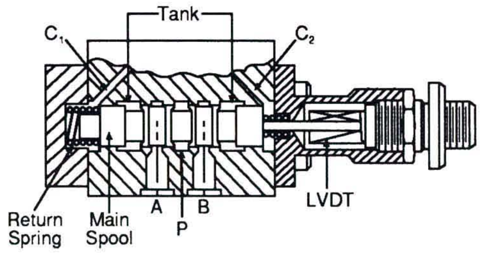
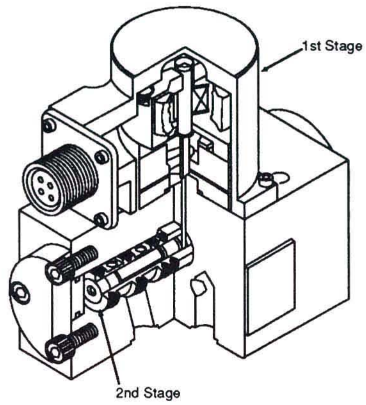
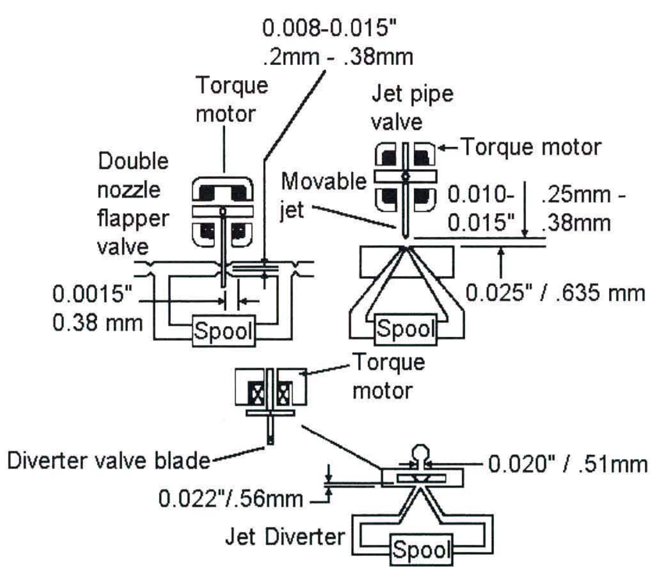


Figure 4 (C_2 Pressure Greater Than C_1)







how the main valve works

As was explained, the valve spool is moved back and forth by the differential pressure generated between C1 and C2. However, these are not the only forces acting on the spool. Additional forces due to flow forces, dirt, friction and pressure loading can cause this type of proportional valve main spool to change position. To counteract these problems, an LVDT is attached to the spool which generates an accurate electrical signal which is feedback to the electronics to indicate the spool position, known as feedback.

The LVDT feedback is compared to the input command signal within the electronics. If the two are not equal, the electronics increases or decreases the electrical power to the pilot coil, thereby adjusting the delta p across P1 to P2. This repositions the spool where the command inputs indicate it should be.

what a servo valve consists of

A typical servo valve consists of a first stage (pilot valve) mounted onto the second stage (spool valve) with a mechanical feedback of spool position to the torque motor assembly.

types of first stages

There are three most common first stage designs, flapper nozzle, jet pipe and jet diverter. The minimum orifice for a flapper nozzle valve is the 0.0015 (0.38mm) clearance between the flapper and the 0.010/0.015 (0.25mm/0.38mm) diameter nozzle.

A jet pipe valve has a typical nozzle diameter of 0.008/0.010 (0.2mm/0.25mm) for the minimum orifice.

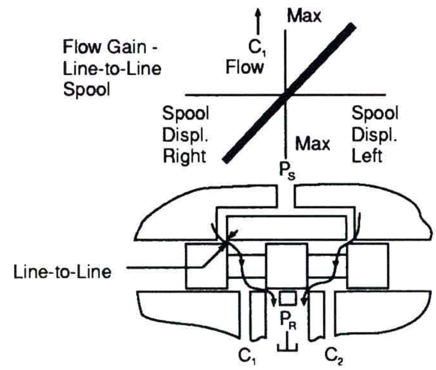
A jet diverter valve has a minimum orifice of 0.020 (0.51mm).

It is not within the context of this textbook to suggest which first stage is best suited for an application, but it should be noted that the larger the orifice, the more contamination tolerant is the valve.

types of 2nd stage spool designs

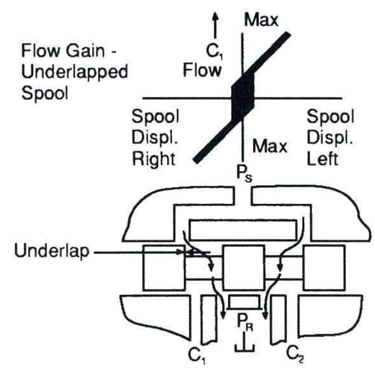
The condition or matching of the second stage spool lands at the center position can and does vary depending upon the requirements of the system and/or tolerances during manufacturing.

The most common requirement dictates an edge condition of the spool lands to valve body ports to be as close to "line to line" as possible. Optional spool land matching includes "underlapped" and "overlapped" conditions. Each one of these creates unique flow characteristics within the valve.



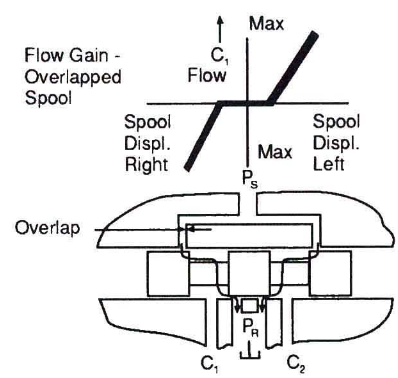
line to line condition

This line to line condition results in an ideal flow gain plot where the output flow to the cylinder ports is zero with the spool in the center position and increases immediately with spool travel.



underlapped condition

An underlapped condition has more clearance between the spool land edges and metering notches or ports in the spool sleeve or valve body. This results in a higher leakage flow in the center spool position. Note that with this condition, the spool must travel through the underlap before proportional flow begins to the cylinder port.



overlapped condition

An overlapped condition will reduce leakage flow to a minimum and no cylinder port flow will occur until the spool has traveled through the overlap. It should be noted that this configuration creates what is known as "deadband" in the valve operation.

Deadband is a zone of valve movement in either direction from center where no actuator (cylinder or motor) response to input signal occurs.

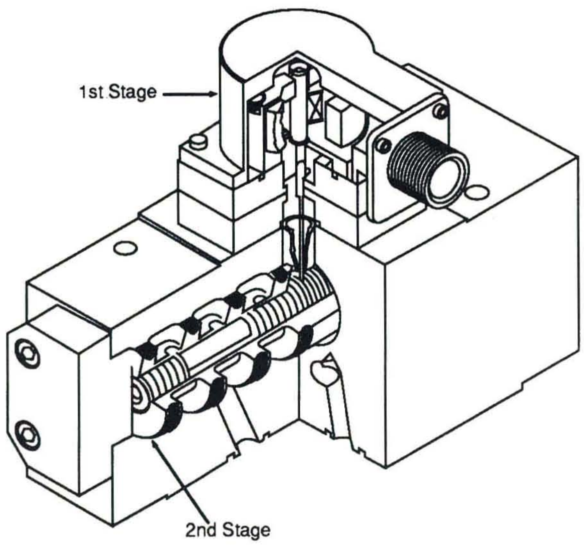
NOTE: This condition also occurs in proportional valves previously discussed.

how a servo valve works

A typical first stage section operation was explained in the proportional valve operating discussion and it is the same for servo valves.

The differential pressure created by the first stage is applied across the ends of the second stage spool and will cause it to move. In order to locate the spool into a position that is proportional to the electrical input command a feedback spring connects the first stage armature and second stage spool together.

This spring can be considered as a cantilever beam that is sized to provide a linear resisting force that is equal to the torque motor force for every spool



position. When there is no electrical command, the diverter blade/armature assembly, the feedback spring, and the center position of the spool have a center line relationship.

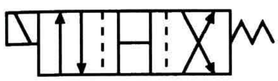
Applying an input command signal to the torque motor causes the diverter blade/ armature assembly to move generating a differential pressure between PC1 and PC2. Again the spool is moved and at the same time deflecting the feedback spring developing a torque in opposition to the motor torque. When the spool has moved to the point where these two torques are equal, the diverter blade/armature assembly, the feedback spring and the spool are essentially recentered and spool movement stops at this new position related to input command signal.

As the input command signal is reduced to zero, the torques go to zero and the spool returns to its center position.

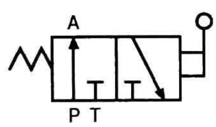
exercise
directional control valves
50 points

1. Describe in detail the following symbols:

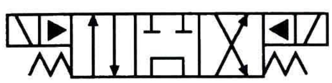
A.



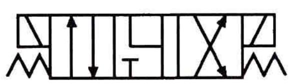
B.



C.



D.



directional control valves (cont.)

2. SITUATION: A cylinder receives a flow rate of 100 gpm (37.9 lpm). The cylinder is required to slow down in mid-stroke and go into a feed rate. The return stroke is at the full 100 gpm (379 lpm) pump flow.

   PROBLEM: Design the system with the components listed below using the appropriate ANSI or ISO standard symbol.

   1 - pump
   1 - electric motor
   1 - filter
   1 - reservoir
   1 - relief valve
   1 - directional valve
   1 - cylinder
   1 - deceleration valve
   1 - check valve
   1 - pressure compensated flow control

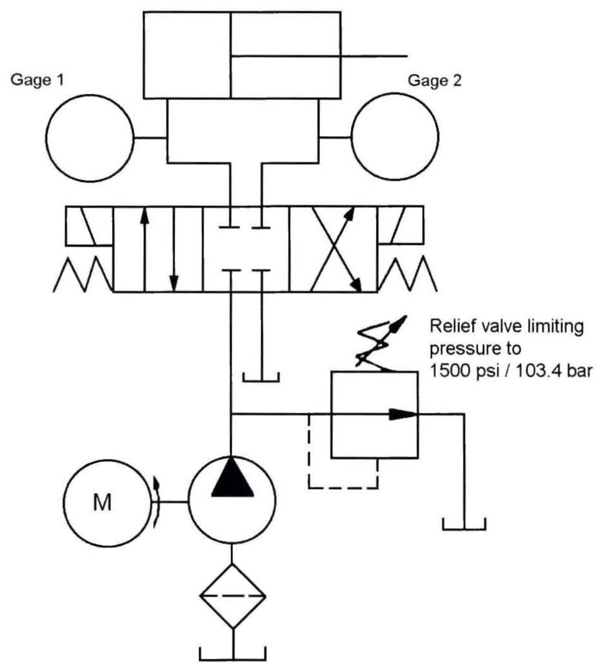
directional control valves (cont.)

3. In the circuit illustrated, assume that the directional valve has been centered for several minutes.

   What do the gages in the cylinder lines read?

   Gage 1 ______ Gage 2 ______

   How is the cylinder affected?



directional control valves (cont.)

4. It was shown earlier that cylinder rod speed could be increased by regeneration. However, the maximum force developed by the cylinder was diminished because of it.

   In the circuit illustrated, select a directional valve so that in one position regeneration is achieved; in a second position maximum force is received; in a third position, the cylinder is retracted.