A guide to selecting a manual hydraulic directional control valve

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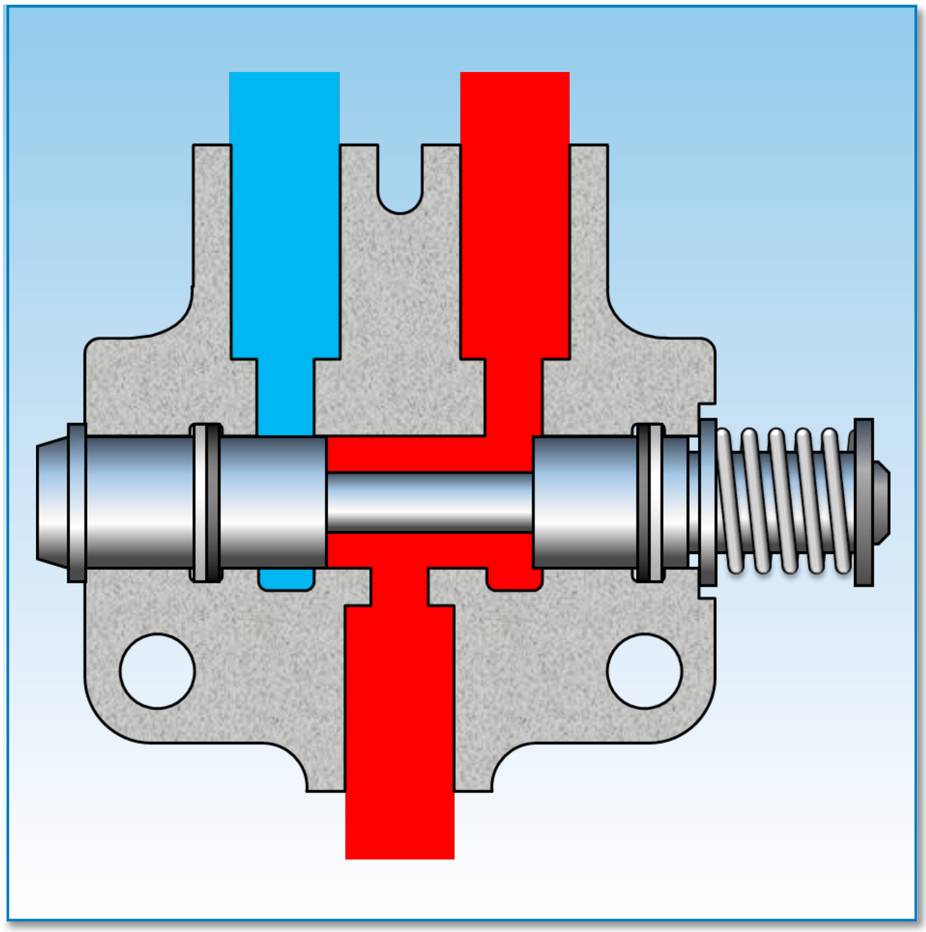
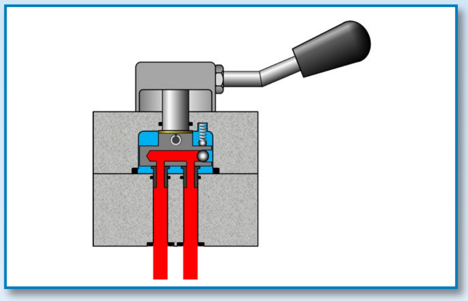
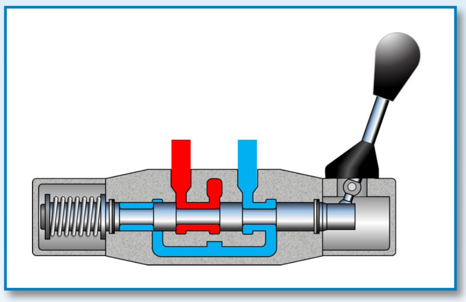
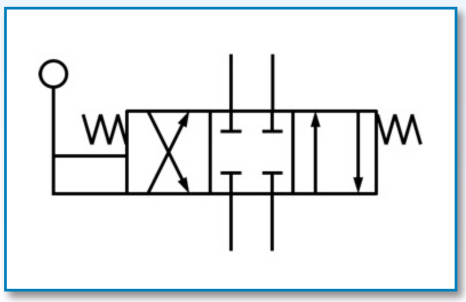
Characteristics and configurations of manual directional control valves used in hydraulic systems - selecting the right valve for the job.

Directional control valves are probably the most common of all hydraulic components and are used to control the starting, stopping and reversal of flow in a system. They are often associated with the control of a hydraulic actuator, such as a cylinder or motor, to select either 'forward, reverse or stop' but can also be used anywhere in a system where flow needs to be switched between alternative paths.









In some cases, the directional valve offers minimum restriction to the flow as it passes through the valve thus acting simply as a flow 'switch'. In other situations the valve can also act as a regulating valve to restrict the flow rate and thereby control the speed of operation of an actuator for example. In many applications the transition from one situation to another, eg. the starting, stopping or reversal of an actuator and load, will require careful consideration.

The selection of the correct directional valve for a particular application is therefore not always a straightforward process and careful consideration has to be given to the type and configuration of valve used. Although solenoid operated valves in industrial systems and sectional valves in mobile systems are the most commonly used directional control components, there are many situations where a simple manually operated directional valve is also of use. This may be either as the main directional valve in simpler systems or for a back-up/emergency operation in more complex ones.

This paper will therefore review the choices and characteristics of common manual directional valves available in order to help the applications engineer or system designer in selecting the correct valve for the job.

BACKGROUND

The first consideration when selecting a directional valve for use in a hydraulic system is to determine how many ports or flow paths are required. Generally speaking, valves are available with either two, three or four ports as shown in figure 1.

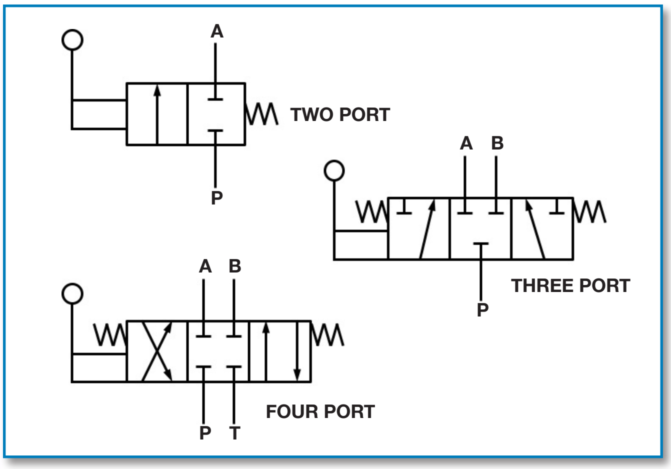


Fig. 1

It could be argued however that a two port valve is more accurately described as an on/off valve since it does not control the flow direction but simply switches it on or off. The three-port valve has an inlet (P) port which can be switched between two possible outlets (A or B) depending upon the state of actuation of the valve. The four-port valve adds a return to tank (T) port and can therefore control both the inlet and exhaust flow from a double acting cylinder or motor.

The second factor in the valve selection process is the number of spool positions required. Normally this will be a choice between a two-position or three-position valve and will depend upon the requirements of the system. Considering a four-port valve controlling a cylinder as shown in figure 2, a two-position valve will be able to direct the fluid flow to either fully extend or fully retract the piston depending upon the spool position. With the three-position valve however it is also possible to centre the valve and thus stop the piston at any point along its stroke.

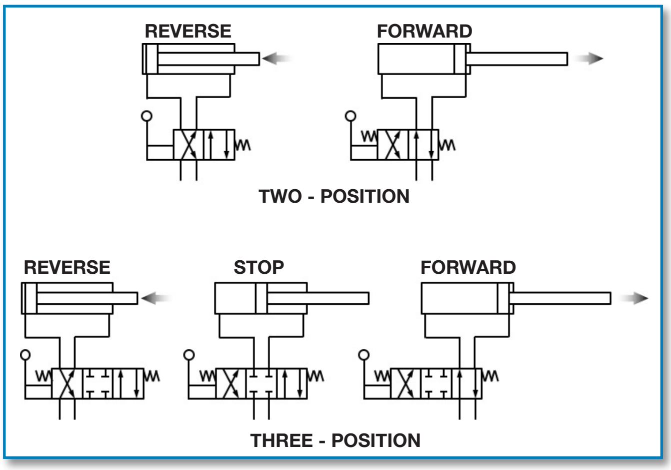


Fig. 2

The configuration of two-position valves can be either spring-offset or detented. A spring-offset valve, as its name suggests, will be biased by means of a spring to one position or another such that when the valve operating lever or plunger is released the valve will automatically return to its offset position. In some applications this could be used to return an actuator to its normal or 'parked' position when the operator releases the lever or to prevent a machine operation unless the valve is actuated. From a safety point of view however, consideration must be given to the consequences of a spring failure in the valve.

A detented valve has no spring return or offset feature and having moved the valve lever and spool it will simply stay in position when released. Normally there will be some form of detent or friction grip mechanism included to ensure that the valve cannot then move inadvertently (due to vibration for example).

A three position valve can also be detented to remain in any one of its three positions or it can be spring-centre which means that the valve will spring back to its centre position when the lever is released. Typical graphical symbols for the two types of valve are shown in figure 3.

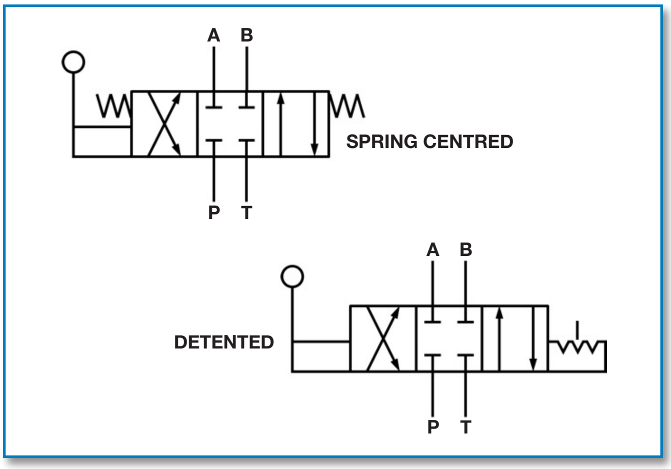


Fig. 3

The flow configuration of the valve in the centre position is something that will often require careful consideration. Just about any configuration is possible from all ports blocked to all ports connected together but figure 4 illustrates some of the more common arrangements.

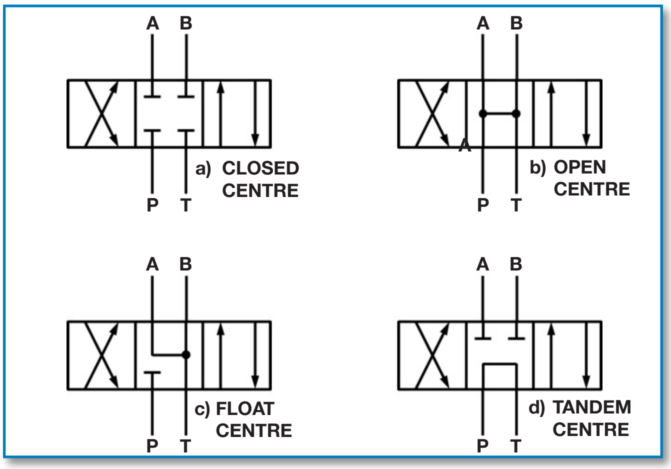


Fig. 4

An all ports blocked configuration (a) will block off the pump flow at the 'P' port (thus enabling the pump flow to be used in other parts of the system) and at the same time block flow into or out of an actuator thus locking it in position. It should be remembered however that, depending upon the type of valve used, it may still be possible to have leakage from any port to any other port when in this position which could allow the actuator to creep. Also of course with a hydraulic motor, there will inevitably be leakage internally in the motor across the ports and possibly into its external drain connection so even a leak-proof valve will not positively lock a motor in position. In some applications however, a leak-proof valve will be a distinct advantage, for example in clamping applications or where pressure on a cylinder is maintained by means of an accumulator.

An open centre valve (b) will unload the pump flow freely back to tank in the central position, while allowing the actuator to 'float' i.e. move virtually freely under the action of an external force. Unloading the pump may reduce the amount of waste heat generated in the system but it also means of course that the pump flow is not available to operate other functions while the valve is centred.

To enable a float condition of the A and B ports but retain use of the pump flow for other functions, the configuration shown in figure 4c could be used which has the 'P' port blocked but maintains the 'A' and 'B' ports open to tank.

Alternatively, if it is required to unload the pump but prevent movement of the actuator the 'tandem' centre condition can be used as shown in figure 4d. As before however, depending upon the type of valve used, leakage may still take place into or out of the 'A' and 'B' ports when the valve is centred.

As mentioned previously, many different configurations are possible in the valve centre position but the four illustrated in figure 4 are the most common. Which configuration is most suitable will depend therefore on the whether the pump flow needs to be unloaded or not and the characteristics and requirements of the actuator and its associated load.

Certain types of manual directional valve enable the flow paths to be opened and closed progressively thus providing a degree of flow control in combination with the basic directional valve function. This can provide the operator with a means of controlling the speed of an actuator and also control of its rate of stopping and starting (acceleration and deceleration).

Finally the pressure and flow ratings of the valve need to be determined. This is normally a straightforward process once the system design parameters have been calculated with respect to flow and pressure. When controlling differential area cylinders however, it must be remembered that the area and volume on either side of the piston will be different which means that the flow rates through the two flow paths of the directional valve will also be different. For example, if the cylinder has a full bore to annulus area ratio of 2 to 1, the exhaust flow from the annulus side will be half the inlet flow to the full bore side when extending. More significantly however, the exhaust flow from the full bore side when retracting will be twice the inlet flow to the annulus side. For this reason the flow rating of the directional valve chosen may have to be greater than the pump flow alone.

Similarly, when determining the pressure rating of a valve controlling a differential area cylinder, potential pressure intensification must be taken into account. Pressure intensification often occurs when restricting the exhaust flow from the annulus side of a cylinder, especially when the cylinder is subjected to a negative ('runaway') load, or decelerating a high inertia load. A valve may therefore have to be selected with a pressure rating higher than the normal system operating pressure at the pump outlet.

VALVE OPTIONS

Having determined the basic specification for the directional valve, the next step involves determining what type of valve will best meet the specification. The options for valve construction include:

- Sliding spool valves
- Rotary spool valves
- Ball valves
- Poppet valves
- Rotary shear valves

SLIDING SPOOL VALVES

As their name suggests, sliding spool valves operate by moving a spool linearly within a closely fitting body in order to connect or block ports machined within the body as shown in figure 5.

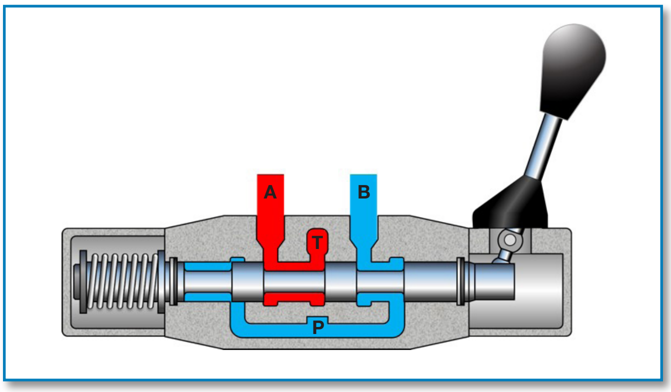


Fig. 5

This type of valve is available in many different configurations such as two or three position, spring-offset, spring-centred and detented. Also, numerous options are available for the spool centre condition. Such valves can be individually mounted, normally onto a standard ISO 4401 / CETOP / NFPA manifold interface, or mounted together as valve segments when two or more valves are required. Manifold mounted valves often use parts common to the equivalent solenoid valves which are produced in very large numbers by many different manufacturers and so benefit from the reduced manufacturing costs that large scale production provides. They are therefore one of the lowest cost alternatives of manual directional valves. Typically, valve sizes range from 30 L/min (8 gpm) up to 120 L/min (32 gpm) and higher. For valves designed to fit onto a standard interface the maximum pressure rating will be determined by the interface itself and will be in the range 250 to 350 bar (3600 to 5000 psi).

As with any sliding spool valve however, sealing between ports is achieved by the closeness of the spool fit within the body. The size of the clearance between spool and body is always a compromise between enabling the spool to slide freely without sticking (especially important for spring return spools) and reducing the leakage through the clearance to a minimum. In practice therefore, for a 75 l/min (20 gpm) rated flow valve, leakage rates (from P port to T port) of the order of 150 – 200 mL/min (10 – 12 in^3/min) would be typical when operating at maximum pressure.

The spool to body clearance of this type of valve also makes it susceptible to contamination particles being forced into the clearance by the pressure difference causing wear and possible malfunction (failure to spring return). Even particles smaller than the spool to body clearance can over time build up and jam the spool (a phenomenon known as 'silting').

Where a leak-proof valve is not required however (e.g. in motor drive applications) and for pressures up to approximately 350 bar (5000 psi) the sliding spool valve can offer a low-cost solution and is available in a relatively large range of sizes. Typical applications include the direction control of hatches, doors, ramps etc. where load holding is not required or where additional valves are included to provide load holding (figure 6).

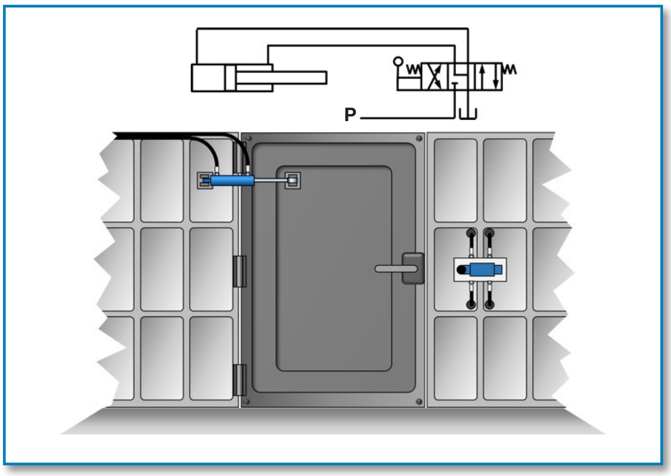


Fig. 6

ROTARY SPOOL VALVES

Rotary spool valves also use a spool fitted in a sleeve but in this case the spool is rotated to select the flow paths rather than sliding (figure 7).

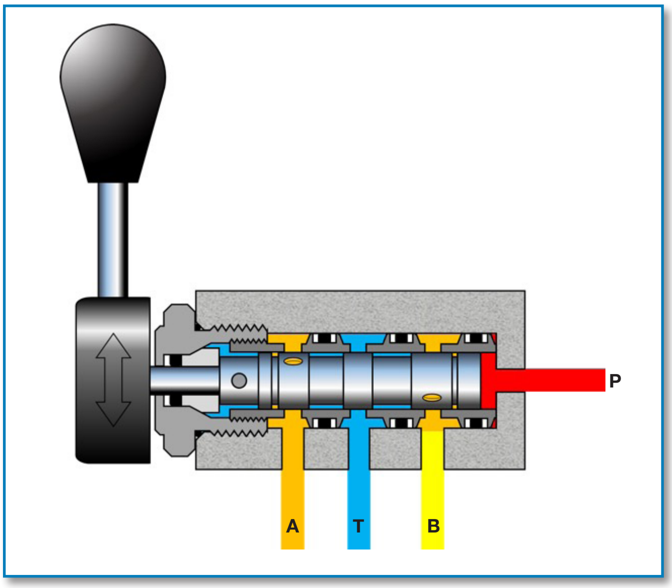


Fig. 7

Inlet flow is normally at the end of the spool and passes through a passageway along the centre of the spool. Holes and slots in the spool are then either opened up or blocked off from the ports in the body as the spool is rotated by the hand lever to create the required flow paths.

Rotary spool valves are frequently manufactured as 'screw-in cartridge' valves which enables them to be either incorporated into manifold blocks along with other control valves or mounted in their own individual body. In some applications a rotary lever is less susceptible to inadvertent operation and also when panel mounting the valve the pipe connections and valve body can be mounted behind the panel leaving just the operating lever on the panel front.

Leakage and contamination sensitivity will be similar to sliding spool directional valves so the valves are not suitable on their own for applications requiring a leak-proof function. Pressure ratings also will be similar to those of sliding spool valves but flow ratings tend to be in the range up to 50 L/min (13 gpm) although some may go to larger sizes. Figure 8 illustrates a typical application for a rotary spool valve used to control the direction of rotation of a hydraulic motor powering a concrete core drill. The valve would typically be a three-position valve (to provide forward, reverse and stop functions of the motor) and be detented to avoid the need for the operator to continuously hold it in position.

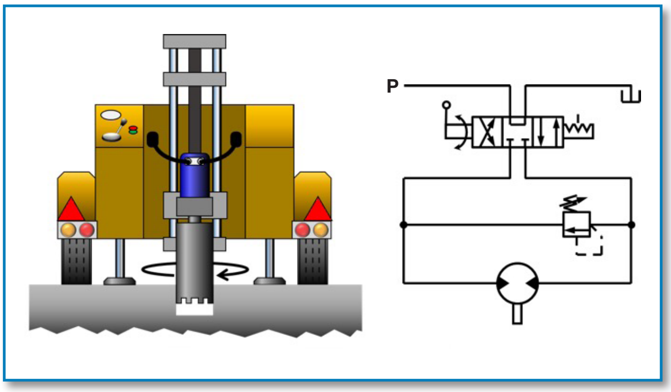


Fig. 8

BALL VALVES

A ball valve is also a rotary valve but in this case passageways are provided through a spherical ball which can be rotated inside a ball seat by means of a handle (figure 9).

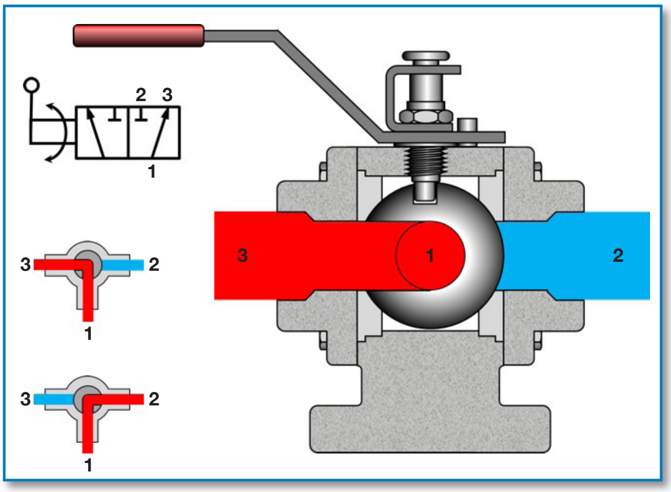


Fig. 9

Ball valves are normally two or three-port valves with flow taking place when the passageways through the ball line up with the ports in the valve body and seat. They are very simple components and are available in a very large range of sizes, configurations and pressure ratings (up to 1000 bar or 15000 psi). Although the valve can be partially opened to provide a basic flow throttling function, one of the main advantages of a ball valve is the fact that when fully open they offer very little flow restriction i.e. the flow path is virtually a straight-through connection. This makes them ideal for use in such areas as pump suction lines where they can isolate the pump for maintenance purposes but offer very little resistance to pump inlet flow when open and hence reduce the likelihood of pump cavitation (figure 10).

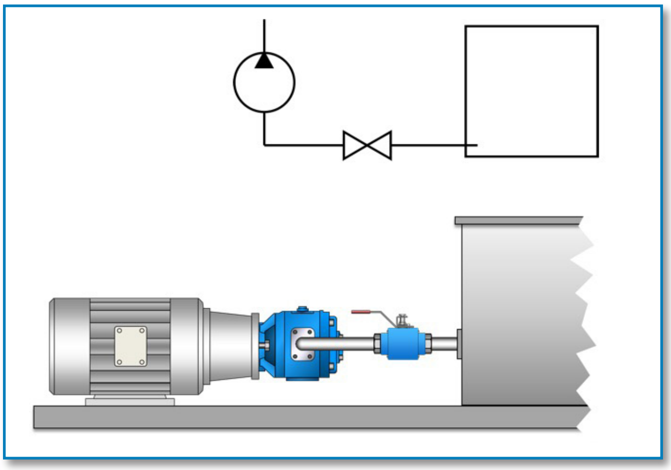


Fig. 10

POPPET VALVES

Flow through a poppet valve is controlled by means of a ball or conical poppet being pushed against, or lifted clear of a seat as shown in figure 11.

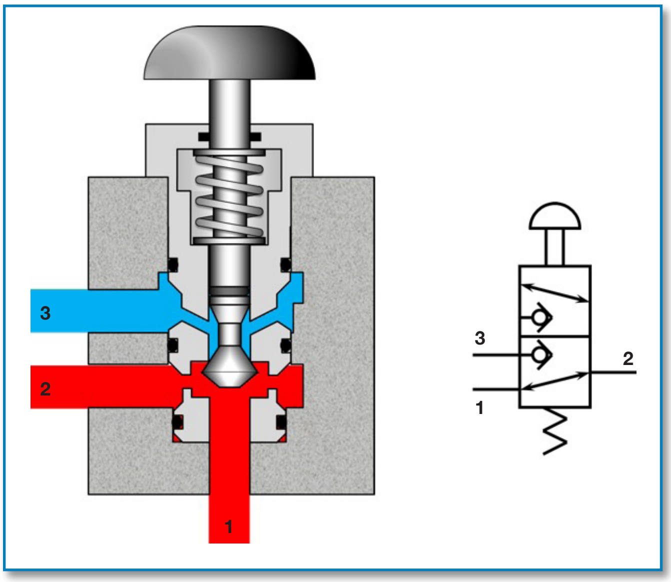


Fig. 11

Typically they are two or three-way valves although two valves can be incorporated in a common body to provide a full four-way function. The fact that the valve blocks flow by the action of a poppet sitting on a seat creating a metal-to-metal contact, means that poppet valves are close to being leak-proof and thus separate load holding valves (for example to prevent creep on a vertically loaded cylinder) are often not required. With no clearance between moving components, poppet valves are also less susceptible to fluid contamination issues although large contamination particles may still prevent the valve seating correctly or even damage the poppet or seat. The fact that the opening the valve often requires a relatively large amount of force on the valve stem, (to overcome the out of balance pressure force) means that rated flows for poppet valves are relatively low although pressure ratings up to 350 bar (5000 psi) and higher can be achieved.

Figure 12 shows a 2-way poppet valve used for emergency lowering of a scissor lift (for example for use in the event of an electrical power failure).

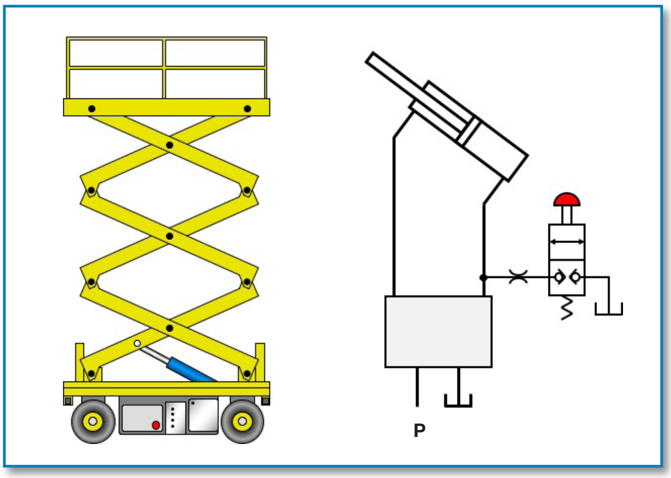


Fig. 12

In this application is it obviously important to use a valve with a virtually leak-proof characteristic to prevent leakage from the lift cylinder during normal operation. However, poppet valves tend to be either open or closed so little control over the amount of flow is possible to regulate the speed of lowering. If this is required therefore, an additional restrictor or needle valve may be required in the system.

ROTARY SHEAR VALVES

Rotary shear valves use connections through a flat plate to transmit flow from one port to another as shown in figure 13.

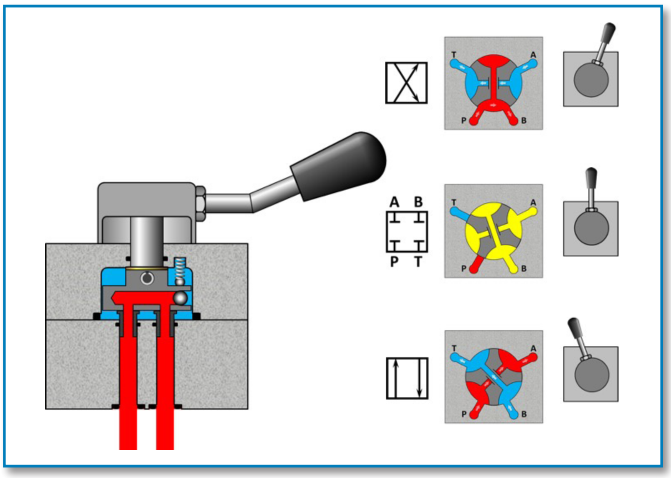


Fig. 13

A seat fitted to each port is hydraulically pressed against the flat plate and by careful manufacturing an optically flat connection between the two components can be obtained. Although it would be technically incorrect to describe any type of directional valve as 'leak-proof', the rotary shear valve is probably as close as it is possible to get to a leak-proof operation. Maximum leakage rates are quoted as one drop every ten minutes even for larger valves up to approximately 40 L/min (10 gpm) rated flow with smaller valves even less. Pressure ratings up to 700 bar (10,000 psi) are also possible depending upon the size of valve. Combined with a relatively low sensitivity to contamination damage, this type of valve is therefore a very popular choice where zero leakage combined with high pressure capability are key requirements. An example application is shown in figure 14 where the valve is used to control the operation of a blow-out preventer (BOP) on an oil drilling rig.

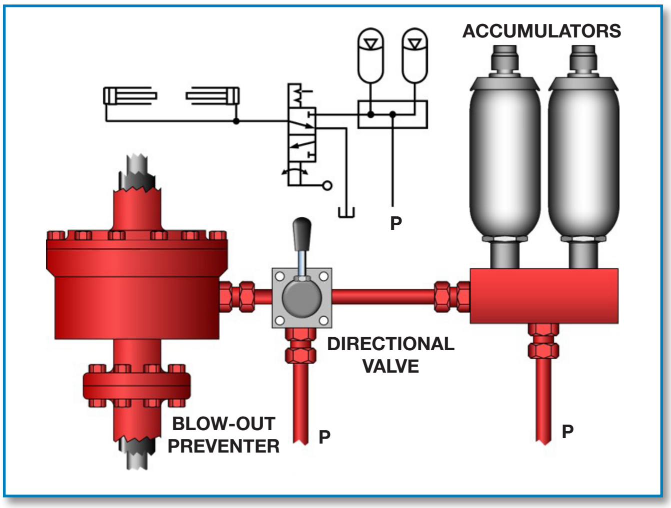


Fig. 14

Power for the BOP is provided by hydraulic accumulators so the leak-proof characteristic of the valve ensures accumulator charge does not leak away over relatively long periods of time. Manual operation of the valve also avoids the necessity for expensive ATEX approved solenoid valves.

Some rotary shear valves are able to throttle the flow by partial opening of the valve (often referred to as 'inter-flow') This provides a useful feature when used as an emergency lowering valve for example in that the speed of lowering under gravity can be regulated by the directional valve itself rather than requiring additional components.

CONCLUSION

As with all hydraulic components, no one type of manual directional valve will prove suitable for all applications. It is therefore necessary for system designers and applications engineers to determine the key characteristics required of a directional valve and then choose the most appropriate type for the job. As has been described, such characteristics may include:

- Flow configuration
- Pressure rating
- Flow rating
- Fluid compatibility
- Contamination sensitivity
- Internal leakage
- Mounting arrangements and options
- Flow throttling capability
- Environmental suitability

The final consideration of course is cost but this should really only be taken into account once the technical requirements have been met.

The table shown in figure 15 summarises the characteristics of the different valves discussed in this paper.

CHARACTERISTIC	TYPE OF VALVE				
	SLIDING SPOOL	ROTARY SPOOL	ROTARY BALL	POPPET	ROTARY SHEAR
Internal leakage	Poor	Poor	Good	Good	Good
Contamination sensitivity	Poor	Poor	Average	Good	Good
Flow throttling capability	Good	Good	Average	Poor	Average
Price	Good	Average	Average	Average	Average
Comment	Very common, wide range	Relatively low flow capability	Low pressure drop when fully open	Low flow capability, very low leakage	Highly configurable, zero leakage capability

Relative rating
Good
Average
Poor

Fig. 15

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Steve Skinner has a degree in Mechanical Engineering from the University of Bath and has been involved in hydraulic fluid power systems for over 40 years including working on circuit design, on-site commissioning, troubleshooting, sales and marketing.

He is also the author of a number of training booklets as well as a book entitled, 'Hydraulic Fluid Power, A Historical Timeline', which he describes as, "a light-hearted ramble through the history of hydraulic fluid power from its birth at the end of the 18th century up to the modern day". To find out more visit:

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