Chapter 11

Directional Valves

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1 General

1.1 Operation and function

All valves which are used to control the start, stop and change in direction of flow of a fluid are called "directional valves".

1.2 Special characteristics

The designation of a directional valve refers to the number of service ports (not including control ports) and the number of spool positions.

A valve with 2 service ports and 2 spool positions is thus designated as a 2/2 way directional valve (*Fig. 1*).

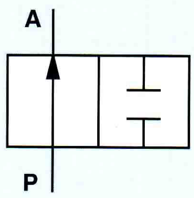
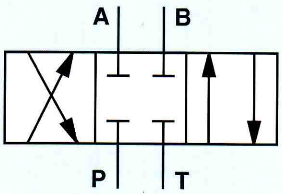


Fig. 1: *2/2 way directional valve*

A directional valve with 4 service ports and 3 spool positions is then a 4/3 way directional valve (*Fig. 2*).



P = Pressure port (pump port)

T = Tank port (drain port)

A, B = Working ports

Fig. 2: *4/3 way directional valve with designation of ports*

Spool positions as well as their corresponding operating elements are labelled with little letters "a" and "b". In fig. 3 a valve with 2 spool positions is shown and also a valve with 3 spool positions. In directional valves with 3 spool positions, the central position is the "neutral position (or rest position)".

The rest position is the position which moving parts have assumed when they are not active, but affected by a force (e.g. spring).

This position is designated as "0" in valves with 3 or more spool positions. In valves with 2 spool positions, the rest position is designated either as "a" or "b".

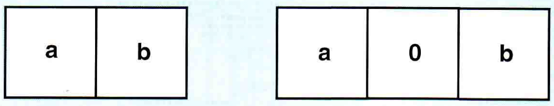


Fig. 3: *Basic symbol for directional valves, left: 2-way valve, right: 3-way valve*

When a valve is shown horizontally (fig. 4), the order of the spool positions a,b,... follows the alphabet from left to right.

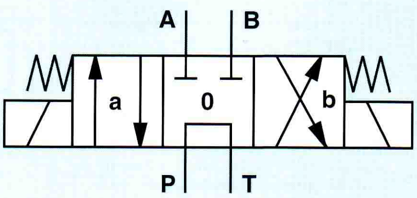


Fig. 4: *4/3 way directional valve with designation of ports, spool positions and operating elements*

Directional valves

- **Directional spool valves**
  - **direct operated**
    - Manually operated
      Sizes 6 to 32
      p_{max} = 350 bar
      Q_{max} = 1100 L/min
    - Mechanically operated
      Sizes 6 and 10
      p_{max} = 315 bar
      Q_{max} = 120 L/min
    - Hydraulically operated
      Sizes 6 to 102
      p_{max} = 350 bar
      Q_{max} = 7000 L/min
    - Pneumatically operated
      Sizes 6 and 10
      p_{max} = 315 bar
      Q_{max} = 120 L/min
    - Electrically operated
      Sizes 4, 5, 6 and10
      p_{max} = 350 bar
      Q_{max} = 120 L/min
  - **pilot operated**
    - Electro-hydraulically operated
      Sizes 10 to 102
      p_{max} = 350 bar
      Q_{max} = 7000 L/min
- **Directional poppet valves**
  - **direct operated**
    - Manually operated
      Size 6
      p_{max} = 630 bar
      Q_{max} = 25 L/min
    - Mechanically operated
      Sizes 6 and 10
      p_{max} = 630 bar
      Q_{max} = 36 L/min
    - Hydraulically operated
      NG 6 to 10
      p_{max} = 630 bar
      Q_{max} = 36 L/min
    - Pneumatically operated
      Sizes 6 and 10
      p_{max} = 630 bar
      Q_{max} = 36 L/min
    - Electrically operated
      Sizes 4 and10
      p_{max} = 630 bar
      Q_{max} = 36 L/min
  - **pilot operated**
    - Electro-hydraulically operated
      Sizes 10 to 82
      p_{max} = 500 bar
      Q_{max} = 4000 L/min

Table 1

In *table 2*, the most common symbols for directional valves are shown, which may be combined with each other to produce a large number of functions. In practice, about 250 spool variations exist.

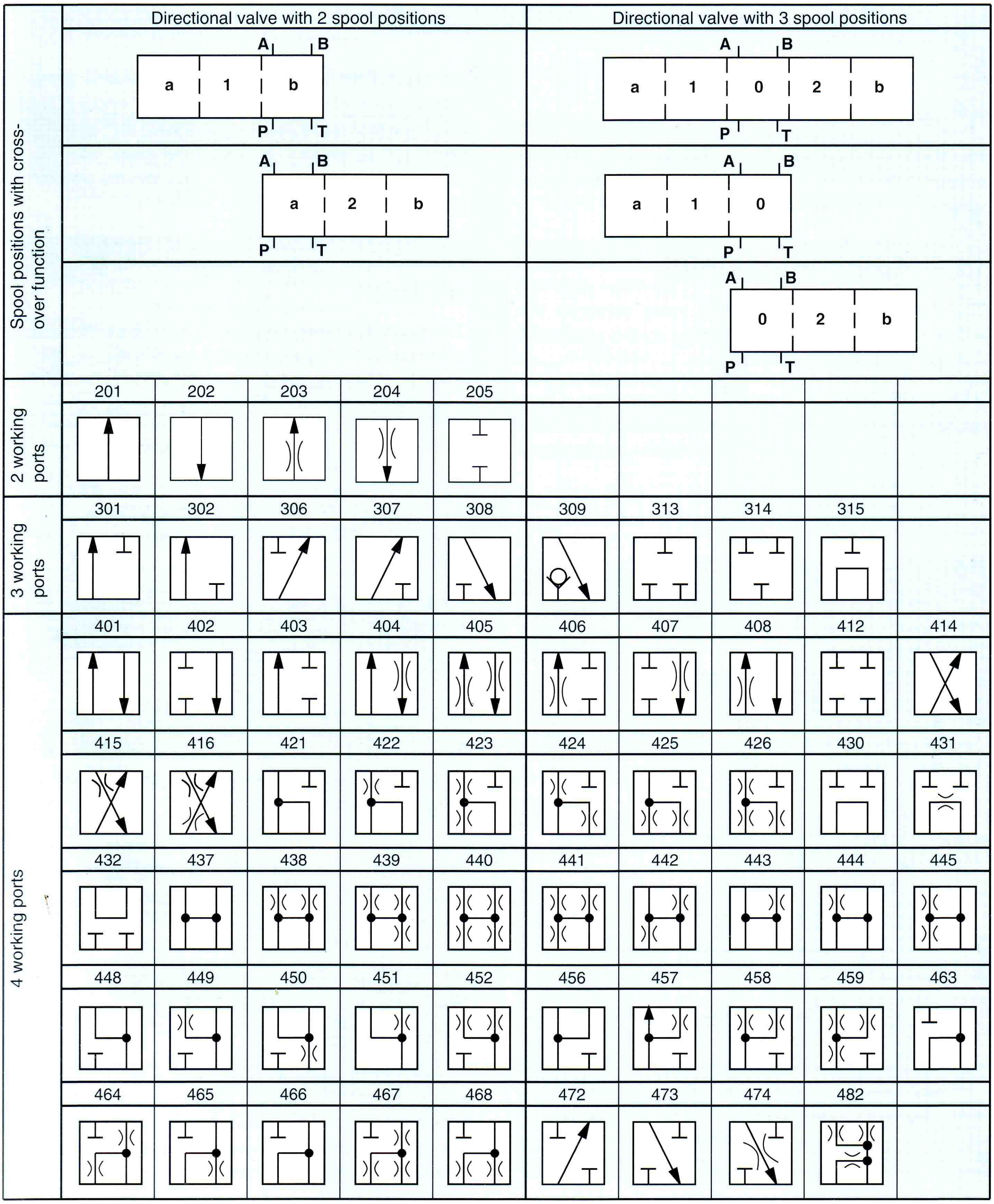


Table 2: *Summary of spool types*

1.3 Directional valve power

The performance and quality of a directional valve is determined on the basis of the following criteria:

- dynamic power limit
- static power limit
- resistance to flow
- leakage (in directional spool valves)
- operation time

1.3.1 Dynamic performance limit

The product of flow and operating pressure is the dynamic power limit of a directional valve (*diagram 1*). Power limits may be a function of the control spring, the solenoid or control pressure. Depending on the type of spool, one of these 3 parameters determines the power limit of the valve. The operating force must be able to overcome the spring force and the axial force existing in the valve. The spring force on its own must be capable of returning the spool against the axial force to its initial position.

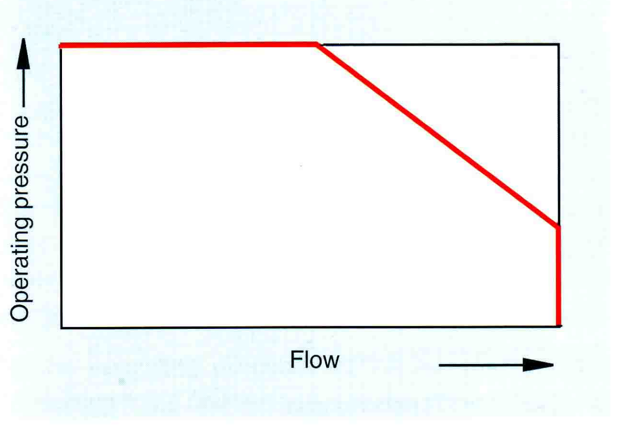


Diagram 1: *Power limit for directional valve*

The axial forces present in a directional valve are not the same in either size or direction for all spool types in one size of valve.

The performance limit which is a measure of the permissible flow at a particular pressure is determined by the axial force, which is produced in a directional valve when the control spool is operated.

It comprises the following parts

- mass force F_m
- stability force F_z
- flow force F_{St}
- resistance force F_w

1.3.2 Static performance limit

The static performance limit of a directional valve is very dependent on the effective time of the operating pressure. Under the influence of pressure, time and other factors, such as dirt, a retaining force is produced between the spool and the housing, which acts in opposition to the movement of the control spool.

If the directional valve is operated frequently, this retaining force is hardly noticeable. It is only after long idle times and at high pressure that this force leads to the spool sticking. This effect is particularly noticeable in direct operated valves, as only low operating forces are available for these valves.

In contrast to dynamic forces, the retaining force is very dependent on the time which the valve spends under pressure in one position.

There are several factors responsible for the creation of this force:

- Level of operating pressure
- Diameter of control spool
- Oil viscosity and temperature
- Quality of the surface finish of the housing bore and the control spool
- Spool clearance
- Filtration
- Overlap length and interruption of this overlap length through unloading grooves.

1.3.3 Pressure difference

The difference between the valve input pressure and the valve output pressure is the pressure difference Δp, i.e. the internal resistance of the directional valve. This pressure difference is produced in the region of laminar flow, mainly through friction with the wall and in the region of turbulent flow, mainly through the loss of kinetic energy due to the flow detaching itself from control lands.

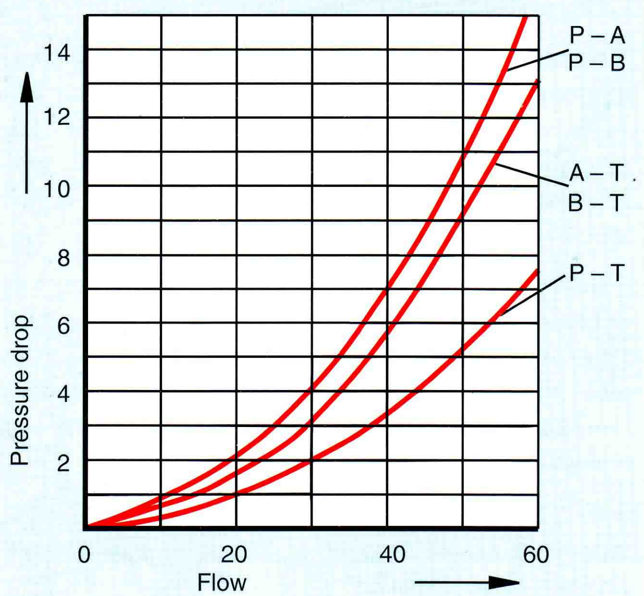


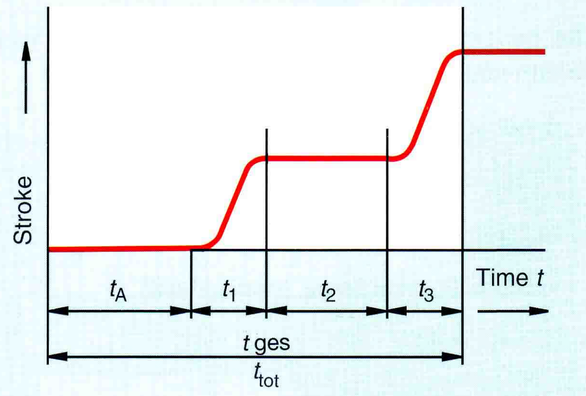
Diagram 2: *Δp-Q operating curve for a 4/3 way directional valve*

As, in practice, the pressure difference cannot be sufficiently accurately calculated, the manufacturers determine the values for individual valve sizes empirically and then show the results in the form of Δp-*Q* operating curves (*diagram 2*). It has to be made clear in these diagrams which connections (arising from an operation) the curves are referring to (e.g. P to A and B to T or P to B and A to T, etc.).

In order to compare measurements with these values it is necessary to carry out experiments to DIN ISO 4411, whereby the viscosity of the fluid must be kept constant.

1.3.4 Operation times

The operation time of a directional valve is the time required from when the operating force is initially introduced to when the control element completes its stroke. Its determination is in accordance with ISO 6403. Experiments on electrically operated directional valves have shown that the operating time comprises 4 phases (*diagram 3*).



t_A: Response delay time, is the time it takes for the solenoid armature to move after the energizing voltage has been switched on. During this time the solenoid force required to overcome the spring pre-tension and the holding forces (stick-slip) is built up.

t_1: Time for flow force to become effective at the main control land (start-up range).

t_2: Time for solenoid force to build up, which is required to overcome maximum flow force. It is dependent on the amount of flow force and effects the operating time t_{tot} (flow force range).

t_3: Time for control spool to cross-over and up to end of valve stroke (cross-over range).

Diagram 3: *Stroke-time diagram (spool operation phases)*

1.4 Types of directional valve

There are three types of directional valve, which vary in how they are constructed:

- Directional spool valves
- Directional poppet valves
- Rotary directional valves

The directional spool valve is the most common one used due to its many advantages, such as

- Simple construction
- Good pressure compensation, hence low operating forces
- High operating power
- Low losses
- Variety of control functions

2 Directional spool valves

Directional spool valves in which a moving spool is situated in the valve housing.

Depending on the number of flow paths to be controlled, two or more annular channels are formed or cast into a housing made of hydraulic cast iron, spherical graphite cast iron, steel or other suitable materials. These channels run either concentrically or eccentrically around a bore. Hence control lands are formed in the housing, which act together with the control spool lands.

When the control spool is moved, it connects or separates the annular channels in the housing.

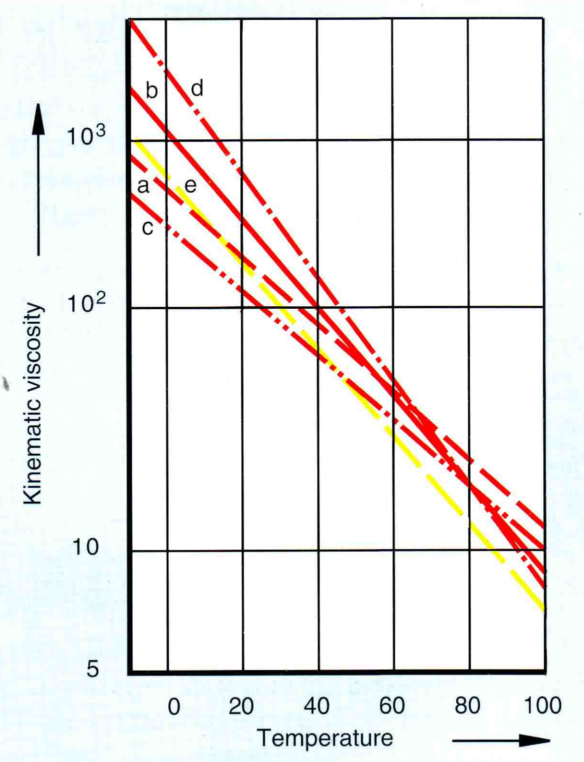
Directional spool valves are sealed along the clearance between the moving spool and the housing. The degree of sealing depends on the clearance, the viscosity of the fluid and especially on the level of pressure. Especially at high pressures (up to 350 bar) leakages occur to such an extent that they have to be taken into account when determining system efficiency. From reference material, it is known that the amount of leakage is primarily dependent on the clearance between spool and housing. Hence in theory, the clearance must be reduced or the length of overlap increased as the operating pressure increases.

However, this is not done for several reasons:

- As the pressure increases, the spool bends by a large amount in the axial direction and this leads to the clearance decreasing in the direction of the high pressure side. This must be taken into account when selecting a clearance, in order to prevent the spool from sticking.
- As the operating pressure increases, the required tensioning force needed to press the directional valve on the sub-plate also increases. The higher screw tensioning force which results causes the housing bore to deform by a large amount. This is a particular effect, which acts in opposition to the requirement for a smaller clearance, as the deformation of the bore must be compensated for by a larger clearance.
- Smaller clearances are more difficult to manufacture. In order to find a technical and economic solution, compromises need to be made between the various requirements.

Care must be taken in choosing the materials for the valve housing and control spool, so that materials have more or less the same expansion coefficient.

Temperature affects the fluid. As the temperature rises, viscosity falls and the density of the fluid (*diagrams 4 and 5*) and the leakage increase.



a Water-oil emulsion
b Chlorinated phosphate ester
c Glycol-in-water solution
d Chlorine hydrocarbon
e Mineral oil (for comparison)

Diagram 4: *Viscosity of fluids dependent on temperature*

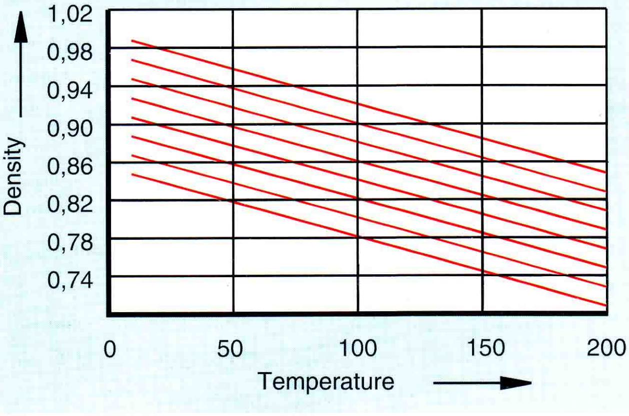


Diagram 5: *Density of fluids dependent on temperature*

The leakage losses from spool valves affect the volumetric efficiency of hydraulic systems and hence must be taken into account when designing a system.

Effects of leakage losses on hydraulic control are:

- Actuators, e.g. cylinders which are under a load pressure, may move in the effective direction of the load pressure due to the leakage losses.
- Actuators with a varying area ratio (single rod cylinders) may wander in the effective direction of the larger piston area, when using control valves with a closed central position.
- If accumulators are used in hydraulic circuits, the leakage of the spool must be taken into account when calculating the size of accumulator required.

In order to avoid losses due to leakages, a special type of directional spool valve (see "Leakage free directional spool valves", *section 2.3*) may be used.

Directional spool valves may be either direct or pilot operated. Whether a valve is direct or pilot operated, primarily depends on the required operating force and hence the size of the valve.

2.1 Direct operated directional spool valves

"Direct operated directional spool valves" imply that they are directional spool valves the control spools of which may be operated directly by solenoid, pneumatic/hydraulic forces or by a mechanically acting device without any intermediate amplification.

Due to the static and dynamic forces, which occur in directional spool valves due to the effect of pressure and flow, direct operated directional spool valves are usually only available up to a size 10. This limit corresponds to a power of about 120 L/min at an operating pressure of 350 bar and is mainly valid for solenoid operated directional spool valves.

Of course direct operated valves with solenoid operation could be produced for sizes larger than size 10. However considering the required operating forces, e.g for the size of solenoid required, for reasons of safety, idle times and due to the pressure shocks (which are difficult to control), it is not normally sensible to have direct operated valves of sizes above size 10.

The various types of operation are described below.

2.1.1 Electrical operation
Various types of solenoid operation

This type of operation is the most common, due to the automatic processes required in industry.

Usually one of four basic types of stroke solenoid is used:

- DC air gap solenoids.
- DC wet pin solenoids.
  These are also known as "pressure tight" solenoids. The solenoid armature runs in oil and the armature chamber is connected to the T port.
- AC air gap solenoid.
- AC wet pin solenoid.

The DC solenoid has a high degree of reliability and provides smooth operation. It does not burn out, if it stops during a stroke, for example, due to a sticking spool. It is suitable for a high frequency of operations.

A characteristic of the AC solenoid is its short operation times. If the solenoid armature cannot switch through to its end position, the AC solenoid will burn out after a certain time (approx. 1 to 1.5 hours for wet pin solenoids).

Mannesmann Rexroth mainly use wet pin solenoids in directional spool valves. This type is particularly advantageous for equipment in the open air or in a humid conditions (no corrosion of the internal parts). As the armature runs in oil, there is less wear, cushioned armature stroke and good heat transfer.

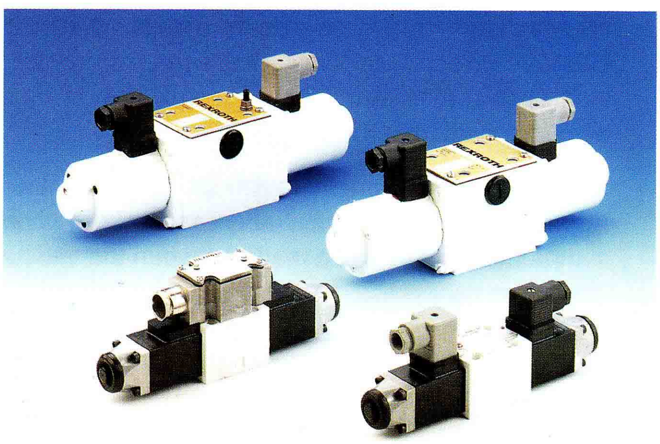


Fig. 5: *Electrically operated directional spool valve*

In fig. 6 is a directional spool valve with three spool positions. On the left hand side is an wet pin DC solenoid (4) and on the right hand side is an wet pin AC solenoid (5). (This model with " mixed" solenoids is only shown here for demonstration purposes.) The armature chamber of each solenoid is connected to the tank chamber of the valve housing. Hence these valves are known as three chamber valves.

The springs (6) are supported on the solenoid housings and centre the spool in neutral position by means of spring pad (8).

The solenoids shown are fitted with hand emergency operators (7). The control spool may thus be operated manually from outside. It is thus easy to check the operation of a solenoid.

Channels P, A and B are separated by lands in the housing. The T channel is not blocked, but connected to both tank chambers via a bypass channel within the valve. These chambers are sealed from the outside by the operating element or by a cover.

In a 5-chamber valve the T channel forms a chamber on both sides by means of lands (1) within the housing, in the same way as P, A and B have formed chambers (*fig. 7*).

The two end chambers (2) are connected together via a bore. If the control spool is moved, fluid is displaced from one end chamber into the other. By fitting a orifice or adjustable throttle (3) into this connection bore the operating time may be altered dependent on the diameter of the jet or the throttle setting.

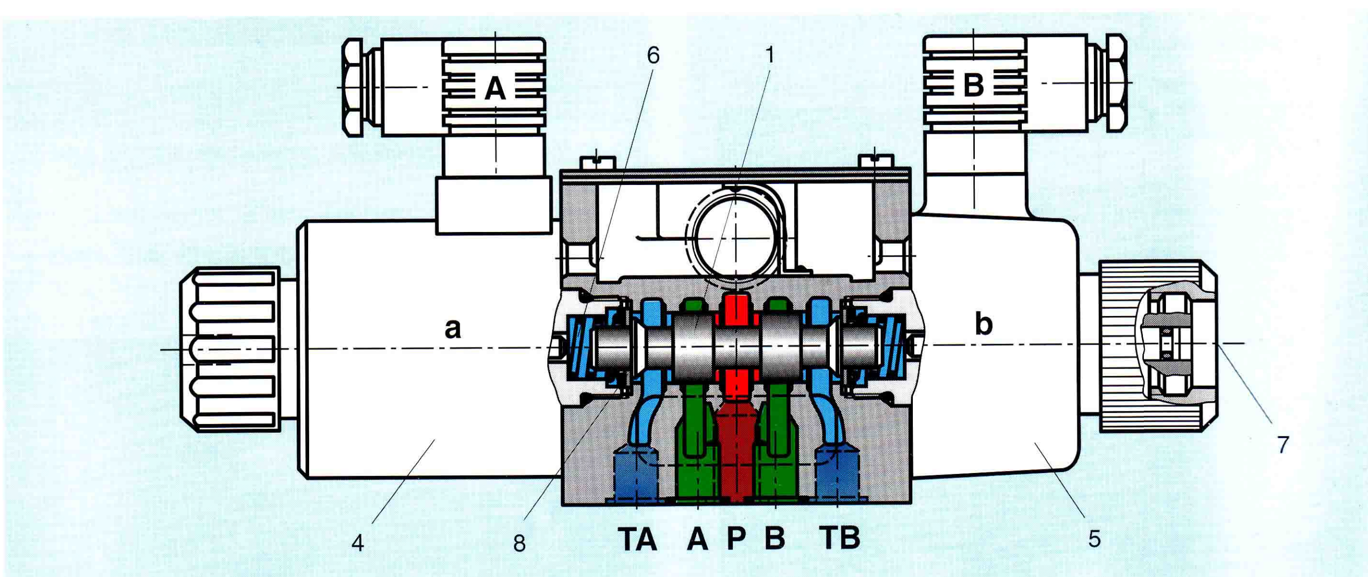


Fig. 6: *Directional spool valve with 3 chambers*

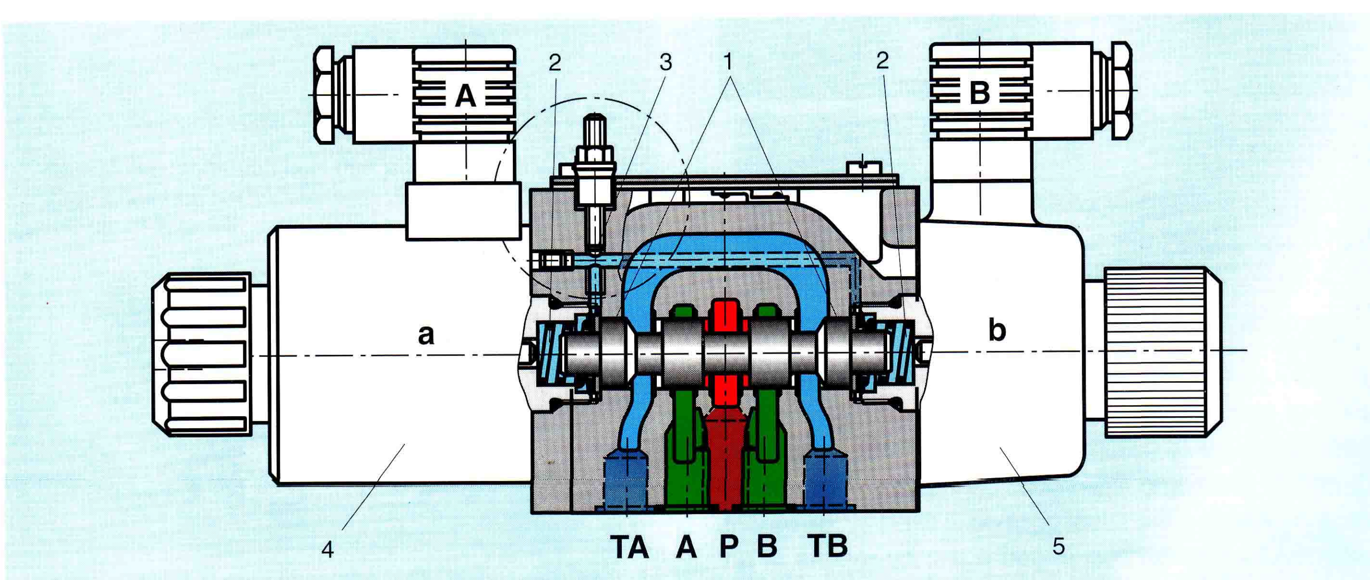


Fig. 7: *Directional spool valve with 5 chambers*

2.1.2 Mechanical manual operation

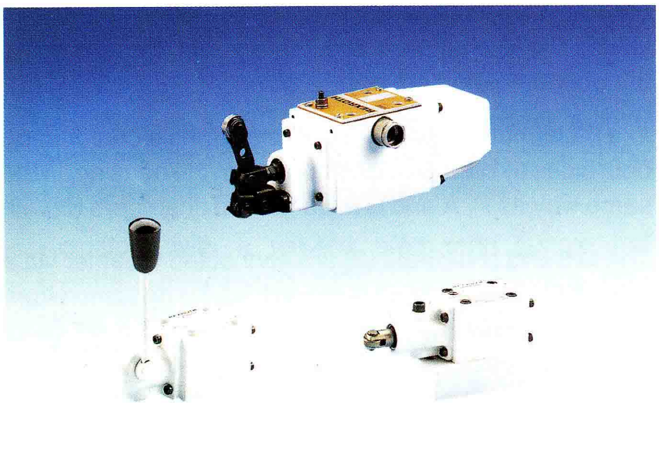


Fig. 8: *Directional valve with mechanical/manual operation*
Left: Roller shaft operation, type WMR
Centre: Roller shaft operation, type WMH
Right: Hand lever operation, type WMM

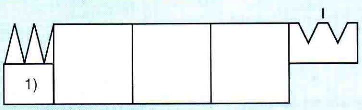
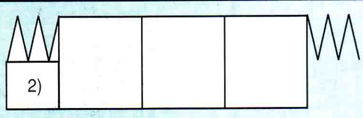
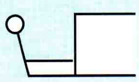
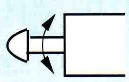
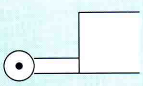
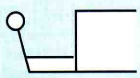
			with detente
			with spring return
	WMR	**WMM**	**WMD**
1)			
2)			

Table 3: *Manual and mechanical operating elements*

Fig. 9 shows a control spool being operated by means of a hand lever (1).

The spool is fixed rigidly to the operating mechanism (2) and follows its movement.

The spool is returned by springs (3), which push the spool back to its initial position once the operating force has been removed (e.g. letting go of the hand lever). If a detent is fitted and the spool cannot be returned by centring springs, the spool position is fixed by the detent and can then only be changed again by means of an operation (not possible in roller operation).

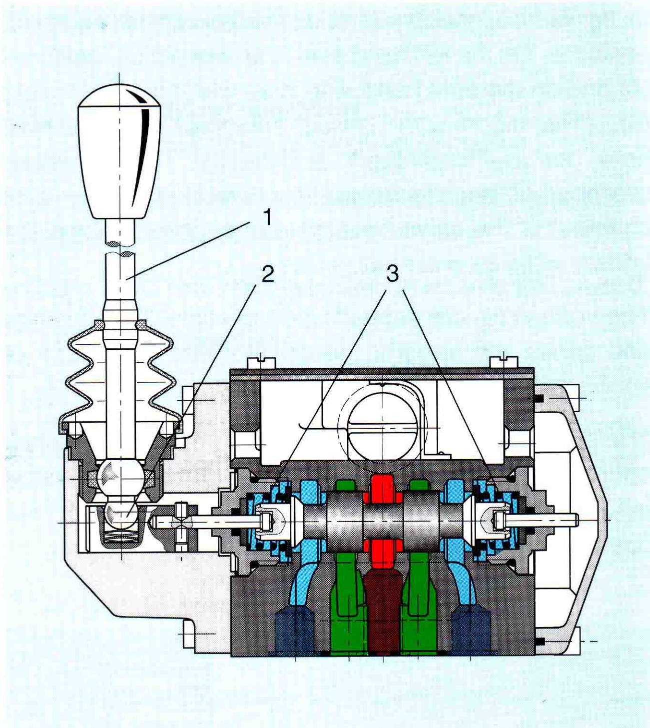


Fig. 9: *Manually operated directional valve, size 10, type WMM*

2.1.3 Fluid operation (hydraulic or pneumatic)

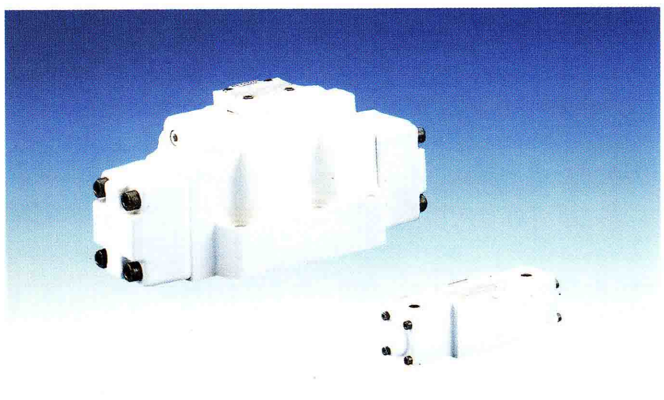


Fig. 10: *Directional valve with fluid operation; left: hydraulic operation, type WHD; right: pneumatic operation, type WP*

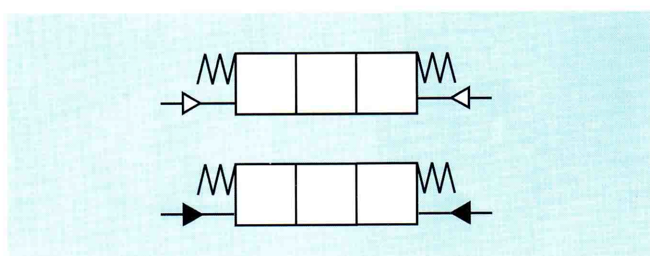


Fig. 11: *Directional valve with spring centering; pneumatic operation (top), hydraulic (bottom)*

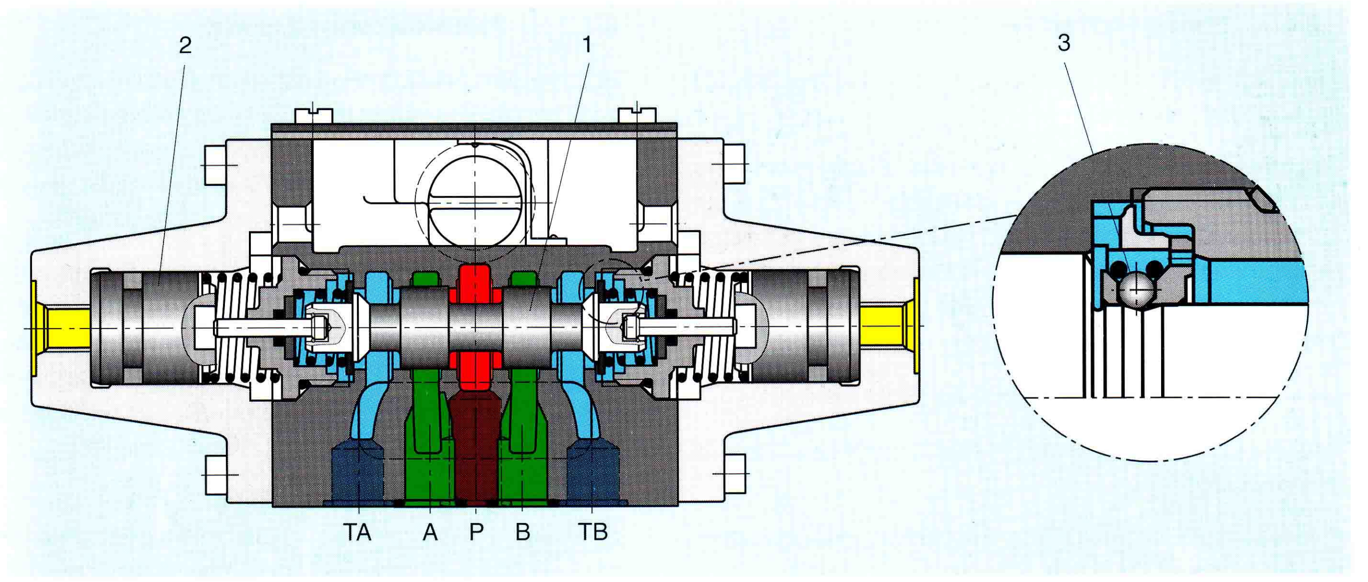


Fig. REF!: *Pneumatically operated directional valve with 2 spool positions and detent*

Spool (1) is in the right hand spool position. This was achieved by pressurising the opposite operating cylinder (2). The spool position is fixed by means of the detent (3).

The control spool is not connected to the operating cylinder. Two operating cylinders are always required if using 2 spool positions with detent or without spring return; or if using 3 spool positions.

An operating cylinder is added, if spool return is by means of a spring in a two spool position valve.

2.2 Pilot operated directional spool valves

For the control of large hydraulic powers, pilot operated directional spool valves are used.

The reason for this is the large operating force required to move the control spool.

For this reason, directional spool valves up to size 10 are usually direct operated and over size 10 pilot operated. Exceptions to this are directional spool valves with hand levers up to size 32.

A pilot operated directional spool valve comprises the main valve (1) and the pilot valve (2) (*fig. 15*).

The pilot valve is generally direct operated electrically (solenoids). When the pilot valve is operated, the control signal from it is amplified hydraulically and used to move the main control spool.

On size 102 (up to 7000 L/min) the pilot valve is itself a pilot operated directional spool valve (*fig. 14*).

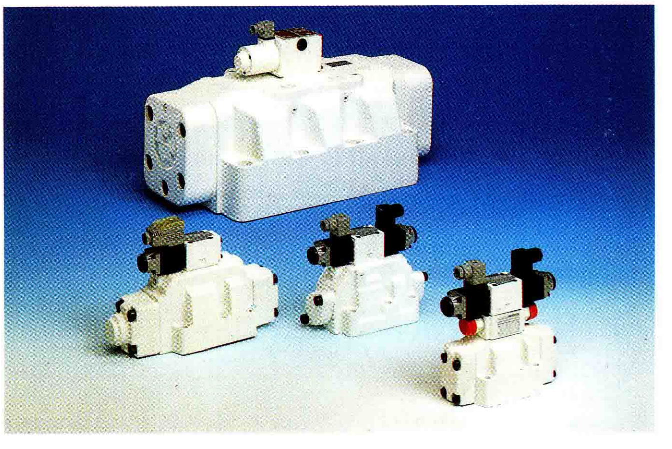


Fig. 13: *Electro-hydraulically operated directional spool valves for sandwich plate mounting*

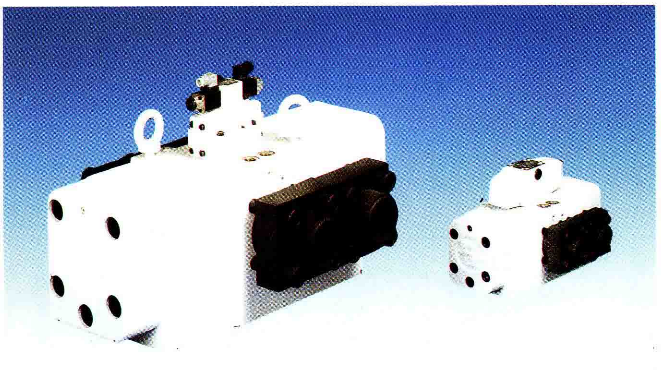


Fig. 14: *Electro-hydraulically operated directional spool valves for flanged connections*

2.2.1 Spring centred model

The pilot valve is an electrically direct operated 4/3 directional control valve (*fig. 15*).

On the spring centred model, the main control spool (3) is held in centre position by the springs (4.1 and 4.2). Both spring chambers (yellow) are thus connected in neutral position via the pilot valve with the tank (light blue) at zero pressure. Thus the centre position for the pilot valve is fixed (symbol J).

Oil is supplied to the pilot valve via control line (5).

Pilot supply is either internal or external (for exact details see *page 200a*).

If, for example, solenoid "a" at the pilot valve is operated, this moves the pilot valve spool to the left.

The left- hand spring chamber (6) is thus subjected to pilot pressure, the right-hand spring chamber (7) remains unloaded to tank.

Pilot pressure acts on the left end of the main spool and pushes it to the right against spring (4.2) until it reaches the cover. Hence port P is connected to port B and A to T in the main valve. When the solenoid is de-energised, the pilot valve returns to the centre position and spring chamber (6) is unloaded to tank again. Spring (4.2) can now push the main spool to the left, until it touches the spring plate of spring (4.1). The spool is once again in the centre position (neutral position).

The control oil from spring chamber (6) is pushed into channel Y via the pilot valve.

The operating process for solenoid "b" is similar.

A certain minimum pilot pressure is necessary to operate the main control spool, which depends on the symbol and valve type.

2.2.2 Pressure centred model

In the centre position of pressure centred valves (fig. 16), both control chambers (6) and (7) are connected with the control pressure. The main control spool is held in the centre position by the effect of the pressurised surfaces of spool (3), centring bush (8) and centring pin (9).

If solenoid "a" at the pilot valve is operated, this moves the pilot spool to the left. Control chamber (6) therefore remains connected with the control pressure, while control chamber (7) is unloaded to tank. Centring bush (8) touches the housing. Centring pin (9) pushes the main control spool to the right unit it reaches the stop.

The springs in chambers (6) and (7) are used, for example, to hold the spool in the centre position without pilot pressure, even with a vertical valve arrangement.

When solenoid "a" is de-energised, the pilot spool returns to the centre position and control chamber (7) is connected with the control pressure once again.

The end surface of spool (3) is larger than the end surface of centring pin (9). The main spool moves to the left until the spool end touches the centring bush. The surfaces of the centring bush and pin are larger than that of spool (3). The spool remains in the centre position.

If solenoid "b" is operated, then the pilot spool moves to the right. Control chamber (7) remains connected with the control pressure, while control chamber (6) is unloaded to tank. The surface of spool (3) is under pressure, causing the main control spool to move to the left, until centring pin (9) touches the cover. Centring bush (8) is also moved.

The desired spool position in the main valve is reached. When solenoid "b" is de-energised, the pilot spool returns to the centre position and control chamber (6) is connected with the control pressure once again.

The surfaces of centring bush (8) and pin (9) under pressure are larger than that of spool (3). The main spool moves to the right until the centring bush touches the housing. The surface of spool (3) acting on the right side is now greater than the surface of centring pin (9) acting on the left side, and the spool remains in the centre position.

A case drain port (violet) is necessary to unload pressure in the chamber between the main spool and the centring bush.

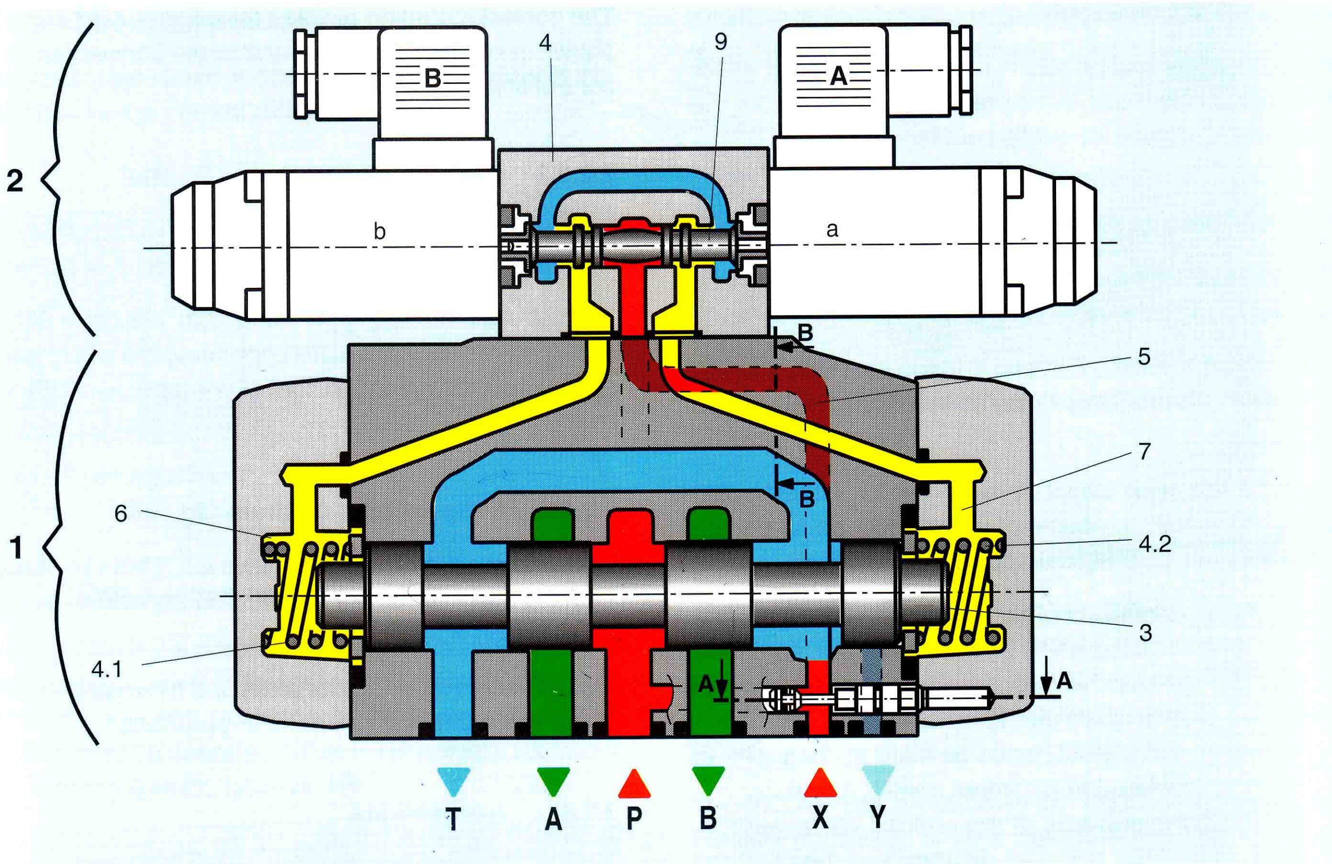


Fig. 15: *Electro-hydraulically operated directional spool valve, spring centred, for sandwich plate*

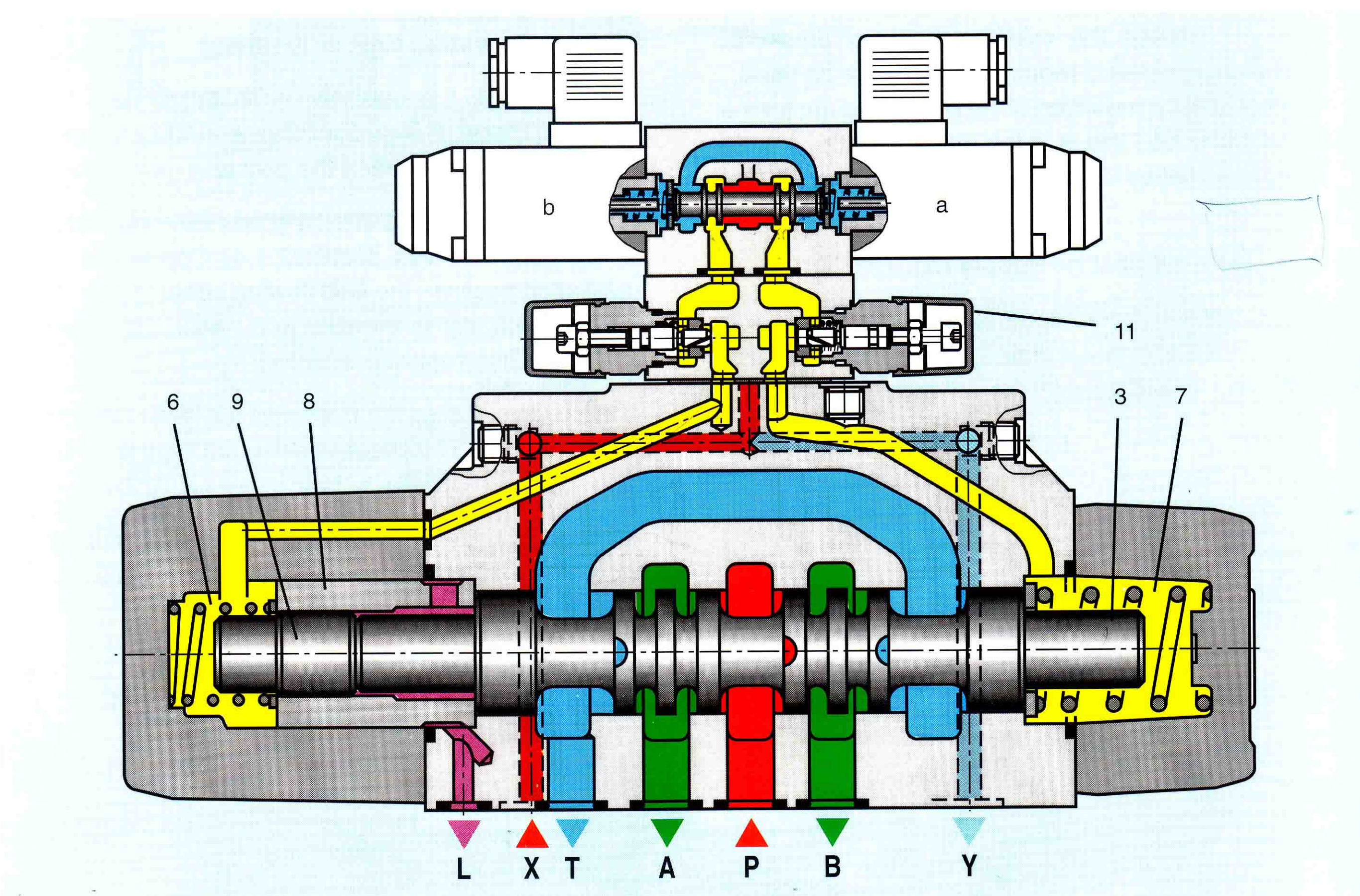


Fig. 16: *Electro-hydraulically operated directional spool valve, pressure centered, for sandwich plate*

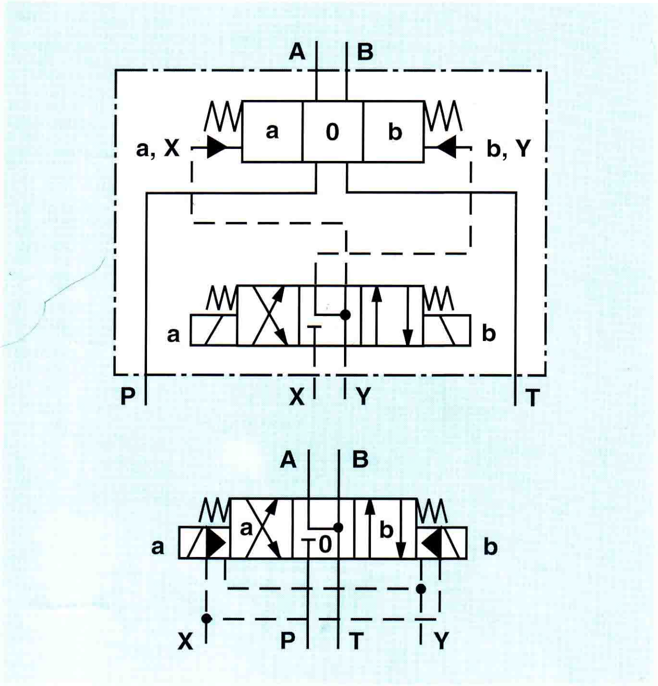


Fig. 17: *Symbol for electro-hydraulically operated directional valve - spring centred; top detailed, bottom simplified*

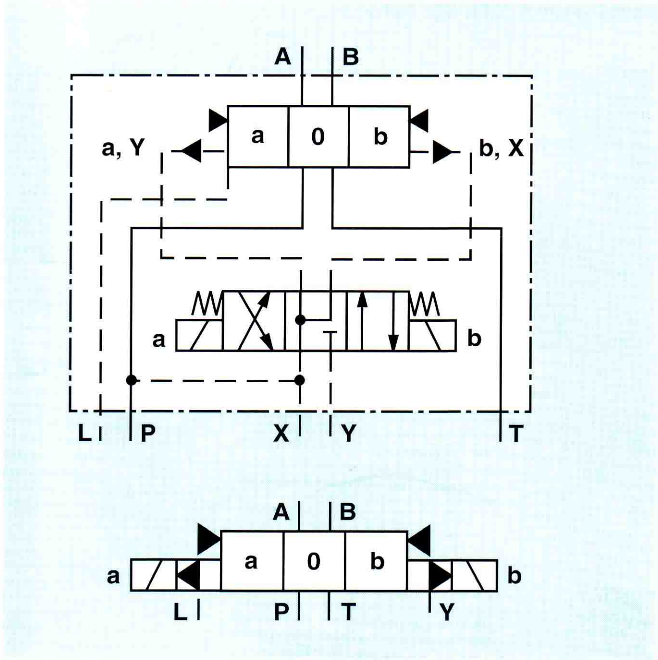


Fig. 18: *Symbol for electro-hydraulically operated directional valve - pressure centred; top detailed, bottom simplified*

2.2.3 Pilot oil supply

Pilot oil supply and/or return may be carried out either externally or internally. In the pressure centred model, the pilot oil return must be carried out externally.

2.2.3.1 Internal pilot oil supply (*Fig. 19a*)

The control fluid in the main valve is taken from channel P and fed to the pilot valve via the control line (red).

Control port X must be closed and the pin (10) mounted as shown. Alternatively it may be in the form of threaded plugs.

No separate pilot circuit is required for internal pilot supply. However, a couple of points must be taken into consideration for practical applications:

- If the main control spool has negative overlap (all ports are connected together) or bypass flow in the centre position, the required pilot pressure does not build up or else breaks down during an operation.
  A preload valve must hence be fitted in channel P in order to produce the minimum control pressure.
  The cracking pressure of the preload valve (approx. 4.5 bar) and the pressure difference of the pilot and main valves may be used as the control pressure.
- Care must also be taken that the operating pressure does not exceed the maximum control pressure, otherwise a pressure reducing valve must be fitted.
  It brings about a reduction of the pilot pressure; for the valves described this is in the ration 1 : 0.66.
  The same applies for the required minimum pressure.

2.2.3.2 External pilot oil supply (*fig. 19b*)

The pilot oil is taken from a separate control circuit, which in any case can be better adapted to the requirements of pressure and flow, than with internal supply.

On the valve shown (*fig. 15*), it is easy to change "internal" to "external" or vice versa, by changing the mounting position of pin (10) or threaded plug. To modify the model shown, it is necessary only to dismantle the cover and turn pin (10).

The correct mounting position for external pilot supply is shown in *fig. 19*. The pin separates the connection of the control line from channel P.

2.2.3.3 Internal pilot oil drain (*fig. 20a*)

Oil flowing back from the pilot valve is fed direct into channel T of the main valve. Control port Y is closed.

It must also be borne in mind that pressure surges occurring in channel T when operating the main control spool affect the unloaded control chamber as well as the pilot valve.

2.2.3.4 External pilot oil drain (*fig. 20b*)

Oil flowing back from the pilot valve is not fed into channel T of the main valve, but instead fed separately back to tank via port Y.

Fig. 20 shows internal pilot drain and external pilot drain at the same time for comparison purposes.

2.2.4 Accessories

By using accessories, the valves described may be made to match the requirements of particular applications.

2.2.4.1 Operation time adjustment

Fig. 16 shows the operation time adjustment device (damping block). It is designed as a sandwich plate and may be mounted between the pilot and main valves.

This device is a double throttle check valve (see chapter on flow control valves, section 2.1.4). Depending on the installation position, the fluid flowing either to or from the control chambers is throttled and hence the operating time of the main spool is affected.

In the installation position shown, the return control oil flow is throttled. The check valve is open to the control oil supply.

For simple applications, the operating time may be altered by means of orifices in the control channel.

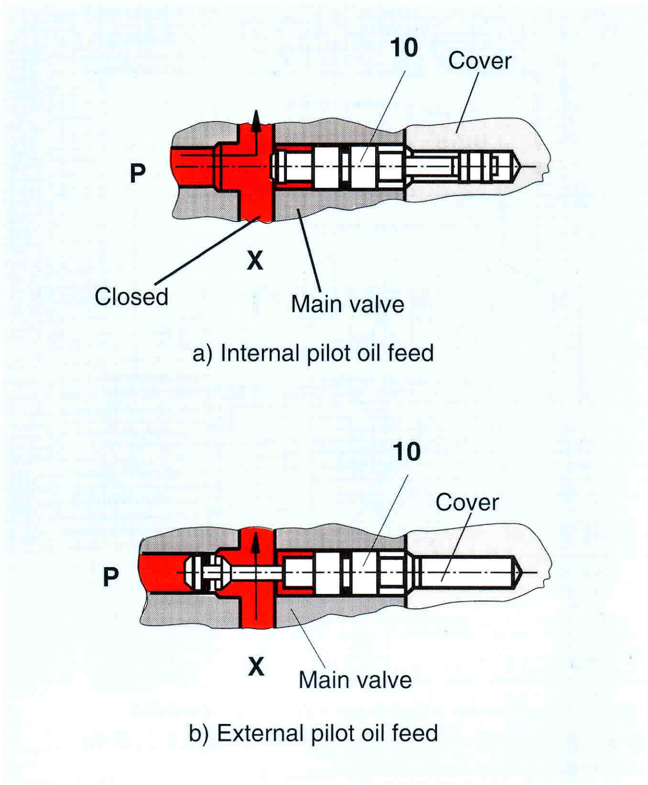


Fig. 19: *Possible pilot oil feed (Section A-A from fig. 15)*

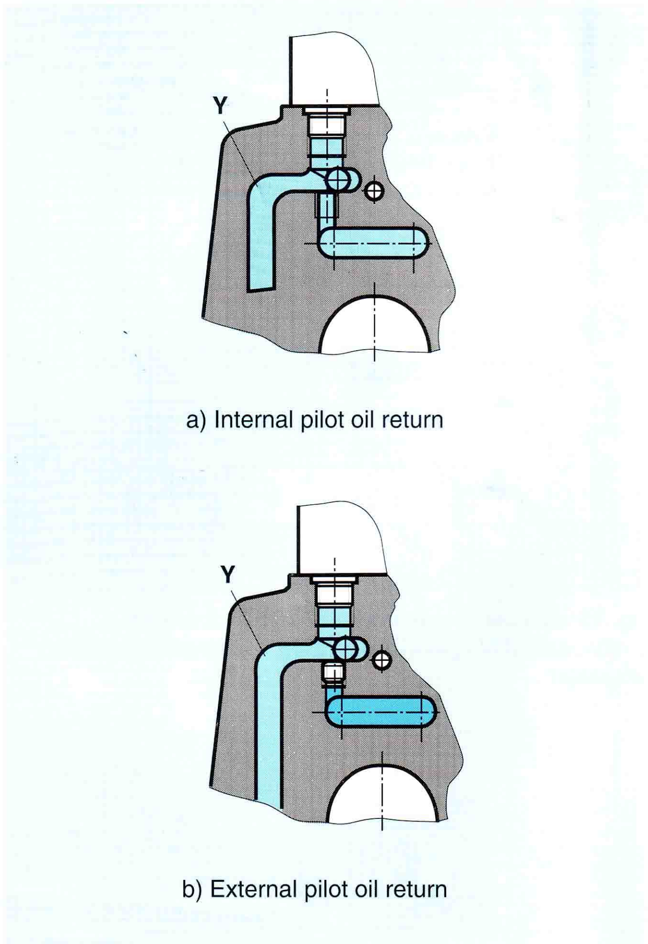


Fig. 20: *Possible pilot oil return (Section B-B from fig. 15)*

2.2.4.2 Stroke adjustment

By adjusting the stroke, it is possible to roughly throttle the main flow for the current direction of flow.

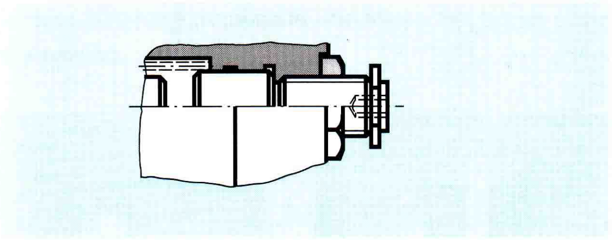


Fig. 21: *Stroke adjustment*

2.2.4.3 End position control

In safety circuits it is essential that the exact spool position of the spool is known. In this case, limit switches are used to monitor the end positions of the main spool. The switches may be operated either mechanically (contact) or inductively (proximity) (*Fig. 22*).

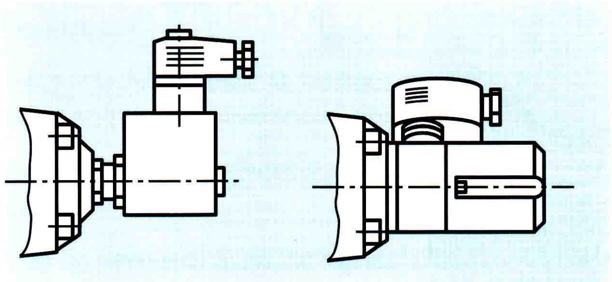


Fig. 22: *Electronic end position control; left: inductive (no movement), right: mechanical (contact)*

In simple terms, in end position control, the position of the main spool may be monitored by means of visual windows. Visual control is carried out via the visual window in the casing.

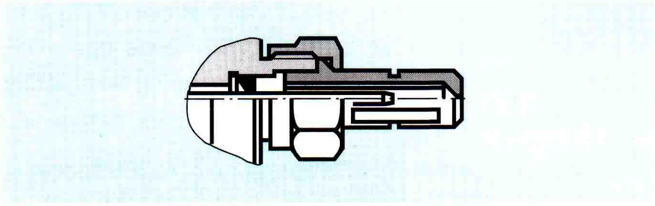


Fig. 24: *End position control via visual window*

2.3 Leak free directional spool valves

The main feature of this special type of valve is that additional sealing elements are arranged between the spool and the spool bore. The additional frictional forces which result must be overcome by higher operating forces.

In principle, this model may be either direct operated (usually manually) or pilot operated (*fig. 23*). Either a standard directional spool valve or a leak free directional poppet valve (section 4) may be used as a pilot valve.

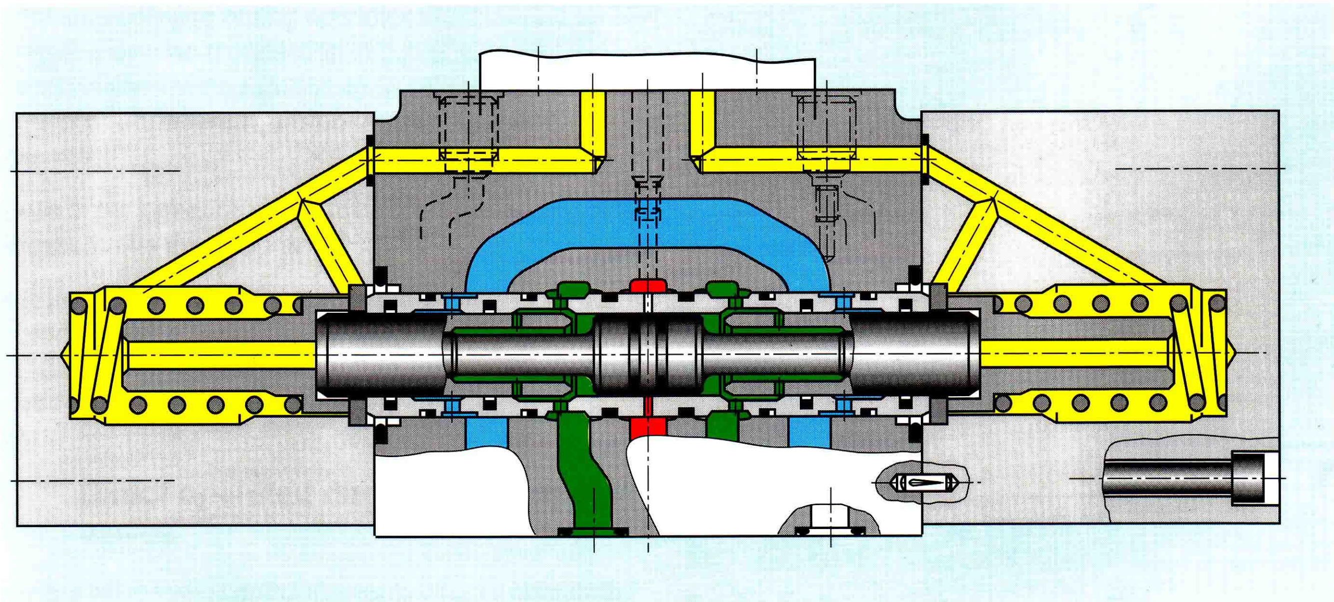


Fig. 23: *Leakage free directional spool valve*

3 Rotary directional spool valves

Rotary spools (*fig. 25*) were often used in the early days of oil hydraulics for operating pressures of up to 70 bar. Due to the development of applications using higher operating pressures, this type of valve is becoming less and less common. This is due to the large operating forces required due to the pressures not being completely balanced.

In addition, electro-magnetic operation of rotary spools is only possible with extensive complications in the mechanical design.

Apart from a few special models and special applications, the rotary directional spool valve is of little importance in oil hydraulics nowadays.

Fig. 25 shows a 3/2 way rotary spool valve. In this valve the various ports are connected together via longitudinal bores by means of rotating the control shaft. It is easy to understand that the control shaft will be pressed onto the housing wall on one side due to the varying pressures in the ports.

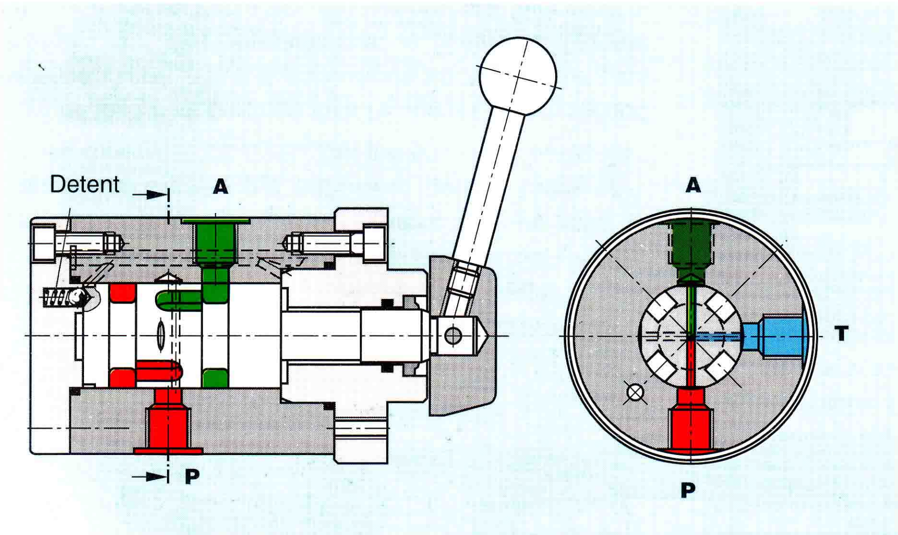


Fig. 25: *Rotary spool valve with detent*

4 Directional poppet valves

Directional poppet valves are directional valves in housing bore(s) of which one or more suitably formed seating elements (moveable) in the form of balls, poppets or plates are situated (*fig. 26*). With this design as the operating pressure increases, the valve becomes more tightly sealed.

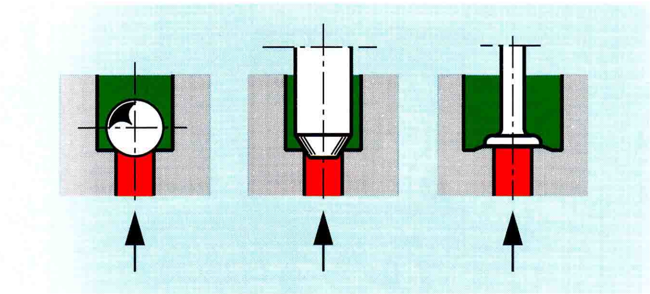


Fig. 26: *Principle of ball (left), poppet (centre) adn plate seat (right)*

The main features of directional poppet valves are:

- No leakage
- Long idle times possible, as their are no leakage oil flows and throttle clearances which could float
- Isolating function without additional isolating elements
- May be used with even the highest pressures, as no hydraulic sticking (pressure dependent deformation) and leakages occur in the valve
- Large pressure losses due to short strokes
- Pressure collapse during operational phase due to negative overlap (connection of pump, actuator and tank channels at the same time). In section 4.1, a way is described, whereby this connection may be bypassed.
- Loss of performance due to incomplete balancing of pressures on the valve axis.

Directional poppet valves may be either direct or pilot operated. Whether a valve is direct or pilot operated depends mainly on the size of the operating force required and on the size of the valve.

4.1 Direct operated directional poppet valves

These are valves with control elements directly operated by a mechanically acting device.

Due to the static and dynamic forces which occur in the directional poppet valve as a result of pressure and flow, direct operated directional poppet valves are usually only available up to a size 10. This limit corresponds to power of approx. 36 L/min at an operating pressure fo 630 bar and is primarily valid for solenoid operated directional poppet valves.

Of course, direct operated directional poppet valves of sizes larger than size 10 could be made available. However considering the required operating forces, e.g for the size of solenoid required, for reasons of operation reliability and due to the pressure shocks (which are difficult to control), it is not normally sensible to have direct operated valves of sizes above size 10.

The function of the most commonly used electrically operated model is described below.

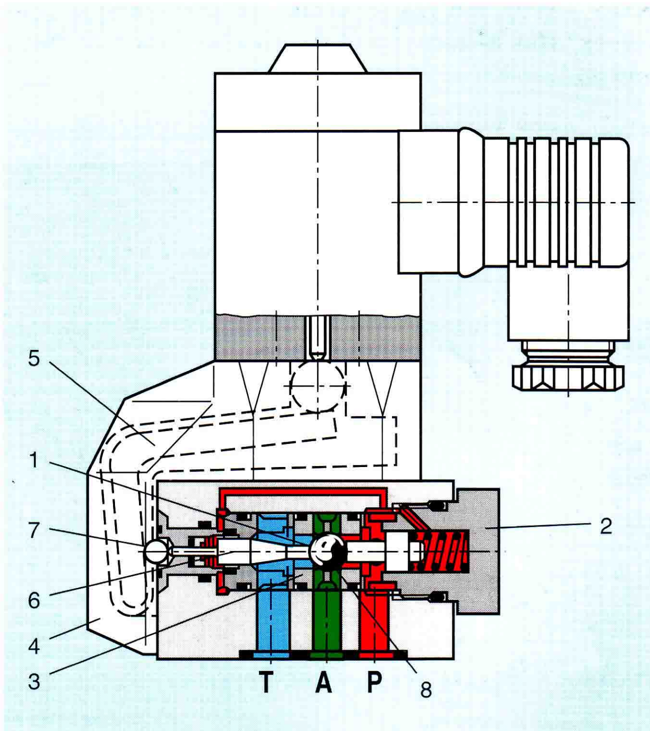


Fig. 27: *Electrically operated 3/2 way poppet valve as a single ball valve*

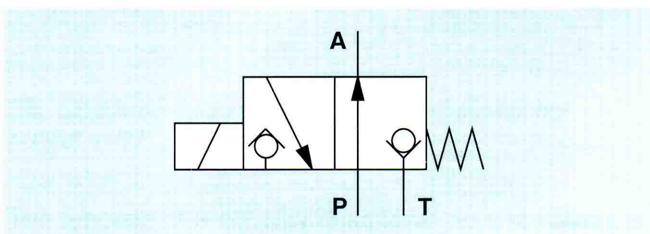


Fig. 28: *Single ball valve*

In the initial position, the seating element which is a ball (1) is pushed to the left onto seat (3) (*fig. 27*) by spring (2).

In the initial position, the connection from P to A is opened, port T is closed. The spool position of the valve is changed by solenoid force. The force affects the seat element (1) by means of a lever (5) supported by bearings, ball (7) and operating plunger (6) in the housing (4). The ball is pushed to the right against spring (2) and pushed on its seat (8). Port P is now closed and the connection from A to T opened. Operating plunger (6) is sealed in both directions. The chamber between the two seals is connected to channel P. Pressure balance is thus achieved on the valve axis, i.e. no pressure force acts on the seat area. This results in only low operating forces being required.

During the operation process, the ports are connected to each other for a short period (see negative overlap).

The variety of spool positions available for directional spool valves are not available for directional poppet valves. This is because of the special design of these valves.

If you wish to exchange the two spool positions shown on the ball valve, a two ball valve design must be used (*figs. 29 and 30*).

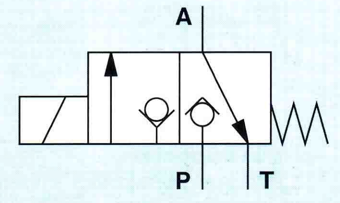


Fig. 29: *2 ball valve*

On a two ball valve, the connection A to T is open and port P closed initially. The spring pushes the ball in channel P onto its seat. In the spool position, the right ball is lifted from its seat, while the left ball is pushed onto its seat.

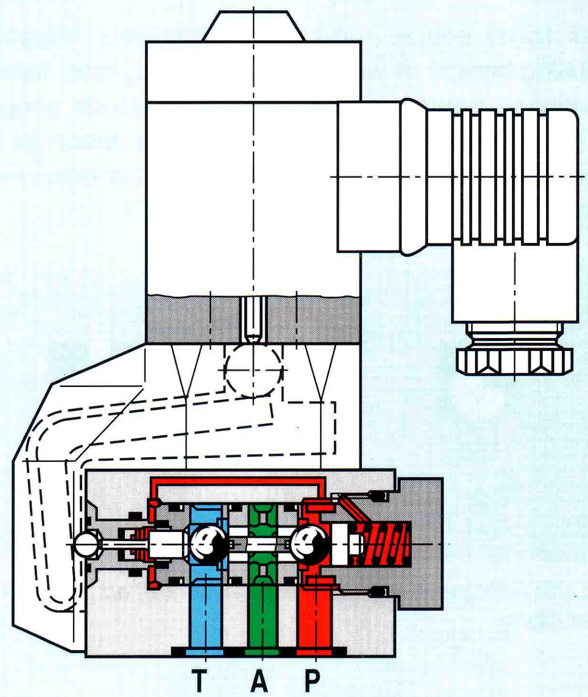


Fig. 30: *Electrically operated 3/2 way poppet valve as a 2 ball valve*

Using a sandwich plate under a 3/2 way directional poppet valve, the function of a 4/2 way valve can be obtained. The schematic diagram below shows the method of operation (*figs. 31 and 32*).

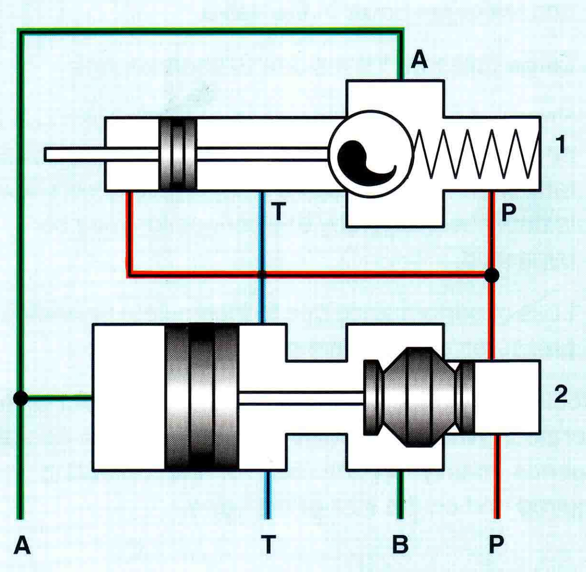


Fig. 31: *Principle of 4/2 way poppet valve in rest position*

The upper part (1) represents the 3/2 way directional poppet valve, the lower part (2) the sandwich plate. Initially the ball of (1) is on its seat. The connection from P to A is opened. A control line runs from A to the spool of valve (2). This surface is greater than that of the right seat element, which is therefore pushed to the right onto the seat. Port B in the sandwich plate is connected to T and port P is closed.

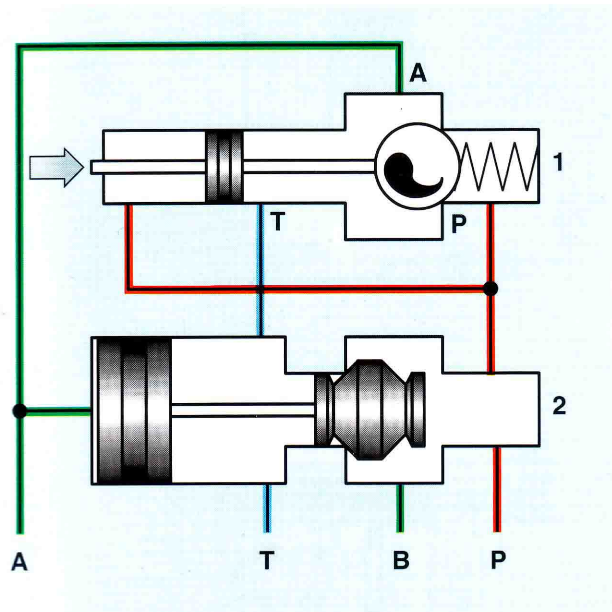


Fig. 32: *Principle of 4/2 way poppet valve in spool position*

When opening a 3/2 way directional poppet valve (1), port P is closed. The connection from A to T is hence opened. At the same time, the large spool in the sandwich plate is unloaded.

Pressure at P pushes the spool with seat element to the left and closes the connection from B to T. Port P is now connected to B and port A to T.

The operating element in the sandwich plate has "positive overlap".

In order to avoid pressure being intensified when single rod cylinders are used, the annulus area of the cylinder must be closed at A.

4.2 Pilot operated directional poppet valves

Direct operated (solenoid operated) directional poppet valves of a smaller size are used for the pilot operation of larger directional poppet valves.

4.2.1 Pilot operated 3/2 way directional poppet valves

A pilot operated 3/2 way directional poppet valve is shown in *fig. 33* the function of which is shown in *fig. 34*.

At rest, control spool (2) is pressurised with pump pressure by pilot valve (1). The pressurised surface of control spool (2) is larger that of the seating element (3). Hence the seating element is pressed onto its seat and port P is closed, whilst port A is connected to T.

If the pilot valve (1) is operated (solenoid energised), control chamber (4) is then connected to port T. The pump pressure lifts the seating element from its seat, port T is closed and port A is connected to P.

The main stage of the valve has a positive overlap (sleeve 5) and therefore during a cross-over, ports P, A and T are closed.

As control of the pilot valve is internal, a minimum pump pressure is required for the operations to be reliable.

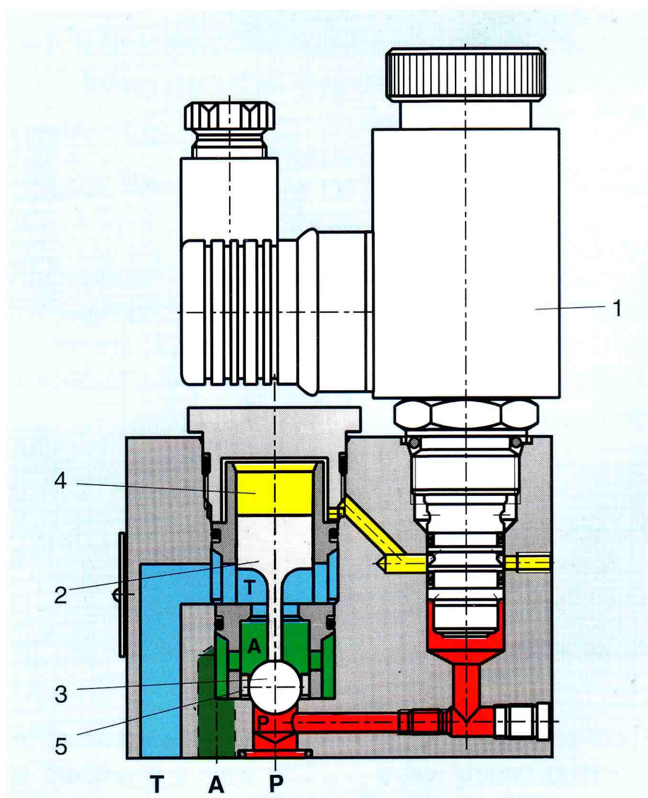


Fig. 33: *Electro-hydraulically operated 3/2 directional poppet valve*

The function of a 4/2 way directional poppet valve may also be obtained by means of a pilot operated 3/2 way directional poppet valve and sandwich plate (see *section 4.1*).

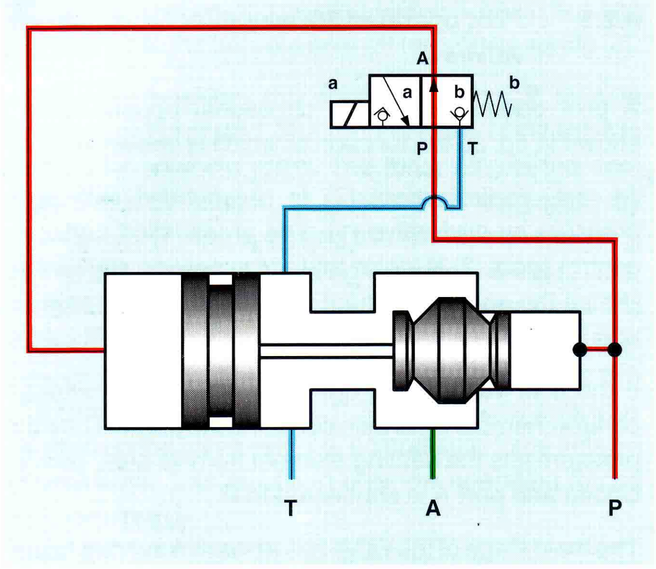


Fig. 34: *Principle of electro-hydraulically operated 3/2 way poppet valve*

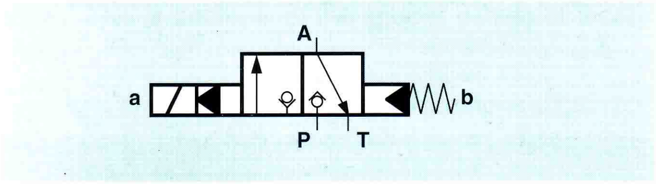


Fig. 35: *Electro-hydraulically operated 3/2 way poppet valve*

4.2.2 Pilot operated 4/3 way directional poppet valves

Fig. 37 shows a pilot operated 4/3 way directional poppet valve in its initial or zero position (see *fig. 36* for function). The 2-way cartridge elements (1,2,3 and 4) are held in closed positions by springs as a result of the balance in pressures.

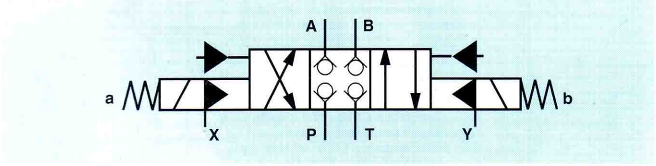


Fig. 36: *Electro-hydraulic 4/3 way poppet valve*

Spool position "b" (P to A and B to T) is achieved by operating control valve "I". The control chambers of cartridge valves (1) and (3) are unloaded and hence opened. The remaining cartridge valves stay closed. By de-energising control valve "I", the zero position is once again assumed.

The same applies for spool position "a" (P to B and A to T). However, now cartridge valves (2) and (4) and control valve "II" are considered.

Pilot valves I and II are supplied via control line (5) with fluid. This supply may be obtained either externally or internally from the pump circuit.

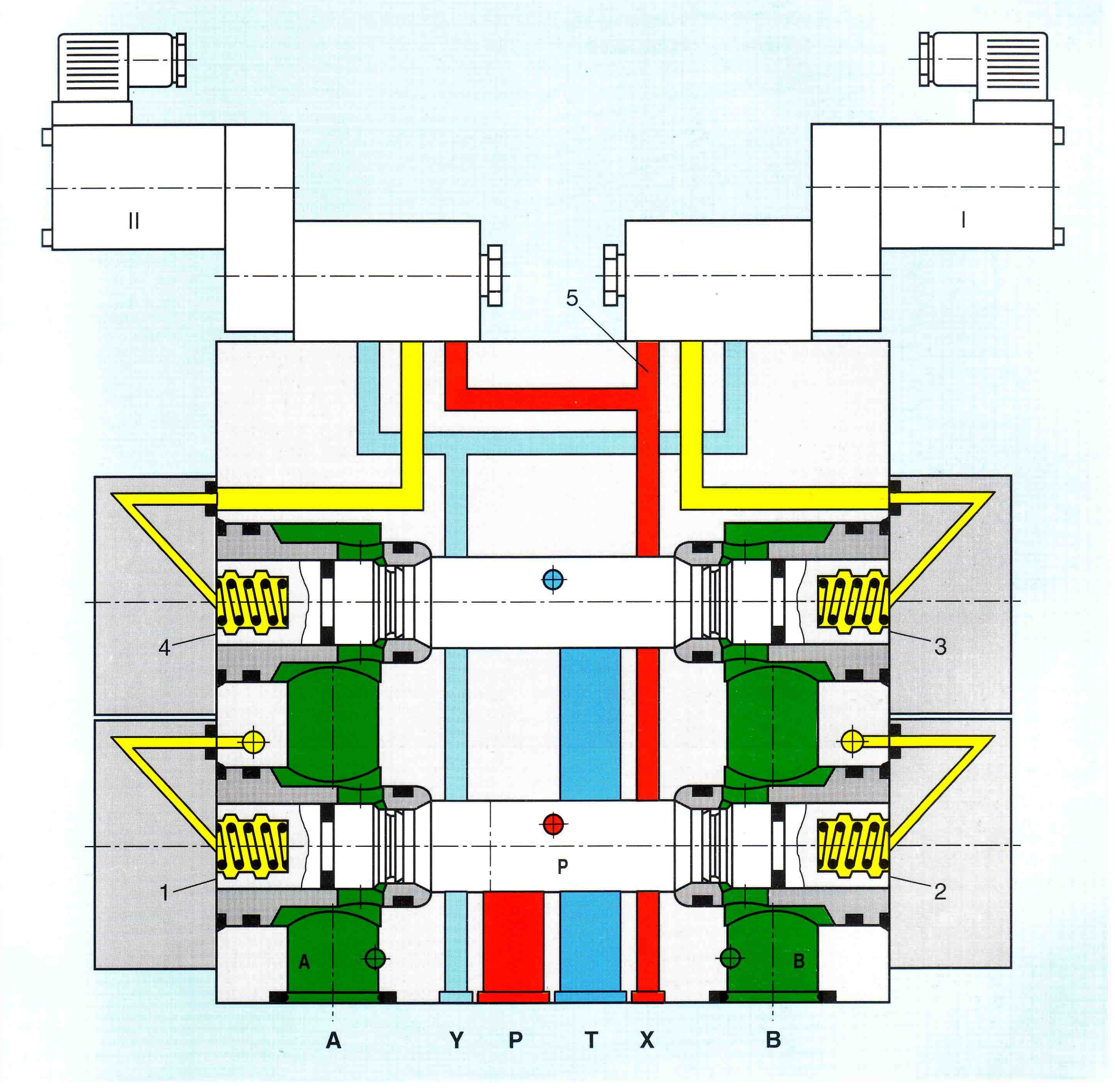


Fig. 37: *Electro-hydraulically operated 4/3 way poppet valve*

4.3 Symbols

There is no distinction made between the symbols for directional spool and directional poppet valves according to DIN ISO 1219. However, in practice it has been found useful to make a distinction between the two. As shown in *table 4*, the seat elements of directional poppet valves are represented by check valves.

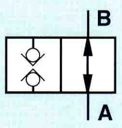
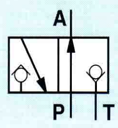
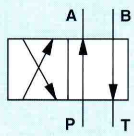
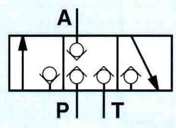
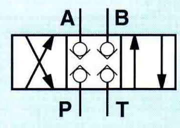
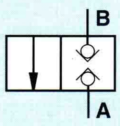
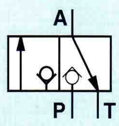
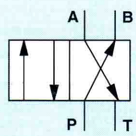
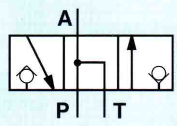
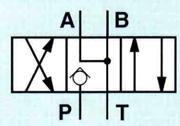
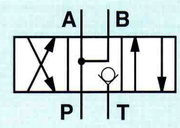
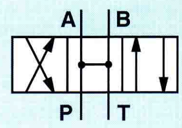
2 spool positions, 2 working ports	2 spool positions, 3 working ports	2 spool positions, 4 working ports	3 spool positions, 3 working ports	3 spool positions, 4 working ports
U 	U 	D 	E 	E 
C 	C 	Y 	H 	J 
				M 
				H 

Table 4: *Symbols for directional poppet valves*

5. Comparison of directional spool valves with directional poppet valves

	Directional spool valves	Directional poppet valves
Function	In a housing with a central axial bore, radial channels fixed distances apart merge. These channels are fed to the outside as line ports. In the main axial bore, a spool with turned control grooves (annular grooves) is set at a pre-defined position with respect to the housing bore by means of the operating element (e.g. solenoid). This is so that the channels may be isolated from or connected to each other via the annular grooves.	In a housing there are one or more valve seats with balls or poppets as the closing elements. These elements are automatically pushed on the seats via springs and then lifted off the seats by means of pins. Flow always in the direction which would tend to close the valve, as only then is the flow controllable (closed or free flow). In the opposite direction a check valve effect would be present and flow independent of the operating position would always be present.
Design notes	Very simple design. Particularly advantageous especially for complex formations of flow. Clear function. Low surface forces due to complete balancing of pressures, long service life. With respect to the dimensions of the spool large flow openings exist, hence in comparison to size low resis-tances to flow exist. Direction of flow may usually be chosen and is not limited to the symbolic flow.	Easier and clearer design in 2/2 and 3/2 way directional poppet valves. Flow formation, e.g. in 4/3 way model is only possible if a complex design is carried out and a lot of effort put into it. Directions of flow are fixed. Pump and actuator must be connected to specific ports, or else the control behaviour will be changed.
Density	Due to the annular clearance present between the housing bore and spool, a leakage flow is continually present between the high pressure and the low pressure sides. Hermetically sealed closure only possible by means of additional devices (isolating valves) or special designs *(see section 2.3)*. Disadvantageous for clamping hydraulics.	The points of contact between the seat and closing piece are ground and lapped, so a hermetic seal is produced, which is required in the pre-installation for clamping hydraulics.
Sensitivity to contamination	Not very sensitive to large dirt particles due to the large openings to flow. Sensitive to microscopic flowing dirt, which is squeezed together with the leakage oil in the annular clearance and which may lead to sticking of the spool, especially at high pressures.	Not very sensitive to microscopic flowing dirt. However with larger dirt particles the danger does exist that such particles might become stuck between the closing piece and seat. Such contamination is caused when the pipes are installed without thoroughly cleaning and flushing the system. As fixed clearances do not exist, rigid sticking as in spool valves will not occur.
Permissible operating pressures	Depending on the design and housing material up to 350 bar. Use of smaller spool sizes for high pressures and small pump flows in jig and tool design are not very advantageous, as due to the leakage flow the fraction of the flow loss may be relatively high.	Depending on design up to 1000 bar.

Table 5

6 Design notes for the selection of a valve size

The parameters required by the project engineer to determine which directional valve to use are shown in catalogue sheets.

6.1 Dynamic performance limit

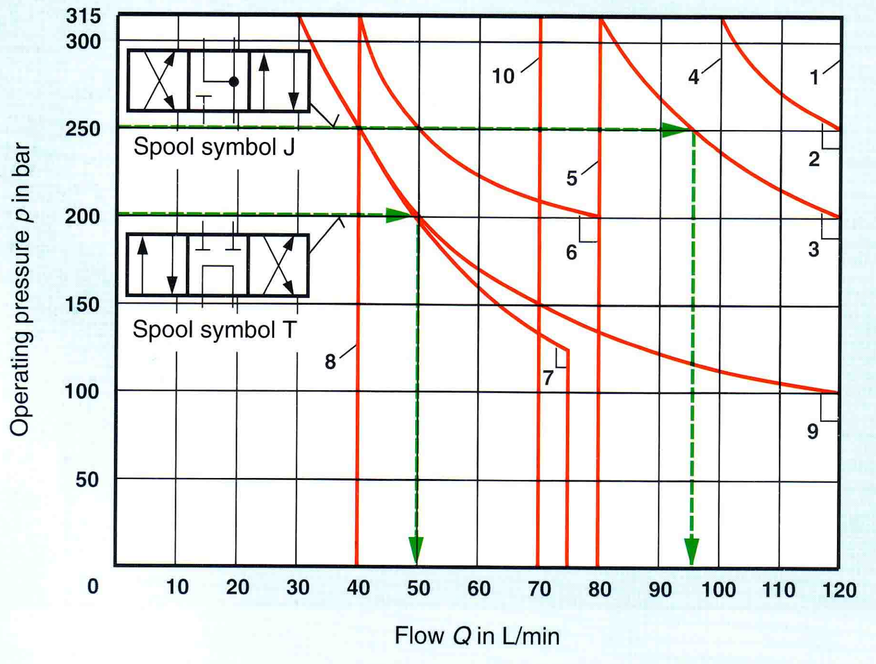
The operation performance limits shown in catalogue sheets are valid for 2 directions of flow, e.g. from P to A and at the same time from B to T.

By changing the direction of flow or by closing working ports, large drops in performance are obtained due to the flow forces acting in the valves.

In such applications the valve manufacturer must be consulted.

The direction of flow cannot be changed in directional poppet valves.

Performace limits are measured to the international standard ISO DIS 6403.



Op. curve	Symbols *
1	C, C/O, C/OF D, D/O, D/OF Y, M
2	E
3	A/O, A/OF L, U, **J**, Q, W
4	H
5	R
6	G
7	**T**
8	F, P
9	A, B
10	V

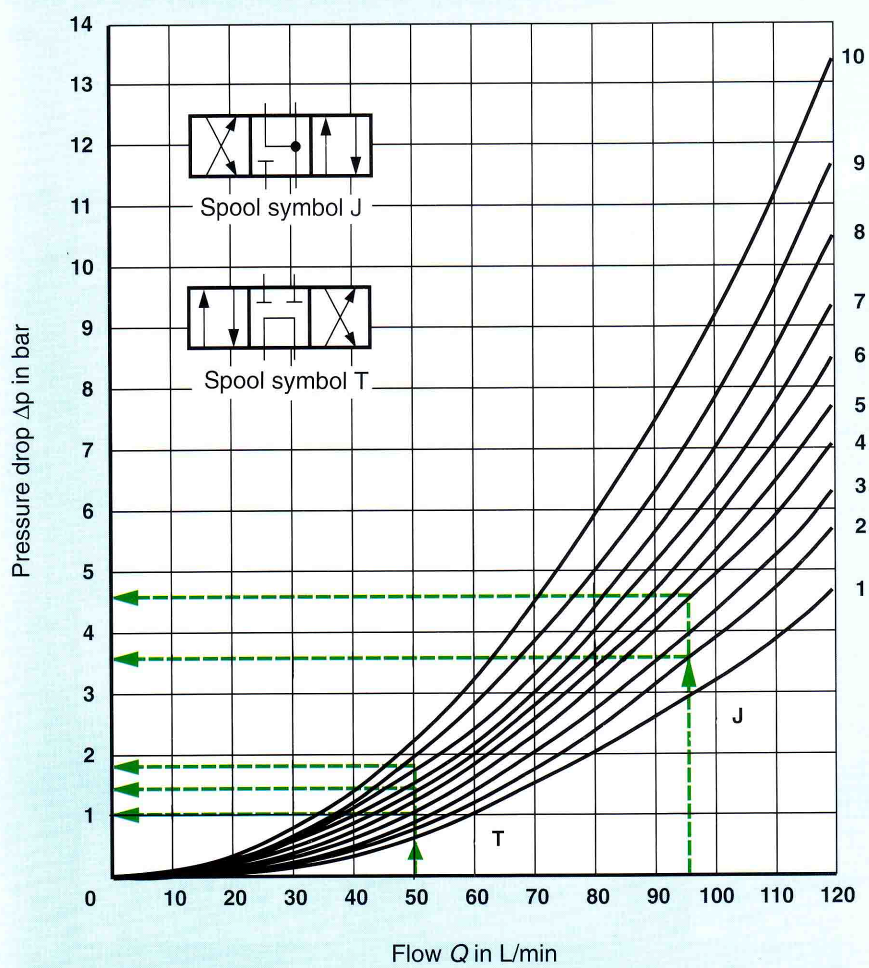
* Spool symbols are shown in table 2.

Diagram 6: *p-Q operating curves for directional spool valves, 3 chamber model, size 10, with DC solenoids*
Examples: Spool symbol J: at an operating pressure of p = 250 bar, an controllable flow of up to 95 L/min is possible
Spool symbol T: at an operating pressure of p = 200 bar, an controllable flow of up to 50 L/min is possible

6.2 Pressure difference in directional valves

The operating curves in catalogue sheets (see *diagram 7*) only consider the pressure differences in directional valves. The pressure drops in the sandwich plate and connecting lines must be added to the pressure difference for the valve.

The pressure difference Δp of a directional valve for spool type J is 3.8 bar from P to A and 4.6 bar from B to T at a flow of $Q = 95$ L/min. Pressure differences of the same magnitude occur in the directions of flow from P to B and A to T. In spool type T, the pressure difference is 1 bar from P to A and P to B, 1.5 bar from A to T and 1.8 bar from B to T at a flow of $Q = 50$ L/min



Symbol	Direction of flow			
	P → A	P → B	A → T	B → T
A, B	4	4	–	–
C	4	4	5	6
D, Y	6	6	7	7
E	2	2	5	5
F	1	2	6	5
G	4	4	7	8
H	2	2	7	8
J	2	2	4	4
L	3	3	4	6
M	2	2	5	6
P	1	3	6	7
Q	2	3	2	4
R	4	7	5	–
T	4	4	7	8
U, V	3	3	4	4
W	3	3	5	6
Centre position		B → T	A → T	P → T
F, P		9	8	9
G, T		–	–	10
H		–	–	4
Spool position	P → A	B → A	A → T	P → T
R	–	10	–	–

Diagram 7: *Δp-Q operating curve for directional spool valves, 3 chamber model, size 10*