Chapter 12

Pressure Control Valves

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1 Introduction

Pressure control valves are valves which influence the system pressure in a system or part of a system in a particular way. This is achieved by changing the size of throttle openings, which may be done by the use of mechanical, hydraulic, pneumatic or electrically operated adjustment elements.

Depending on how the throttle opening is sealed, pressure control valves may be either spool or poppet valves.

With respect to function, these valves may be put into four groups:

– Pressure relief valves

– Pressure sequence valves

– Pressure shut-off valves and

– Pressure reducing valves

The valves may be either direct operated or pilot operated.

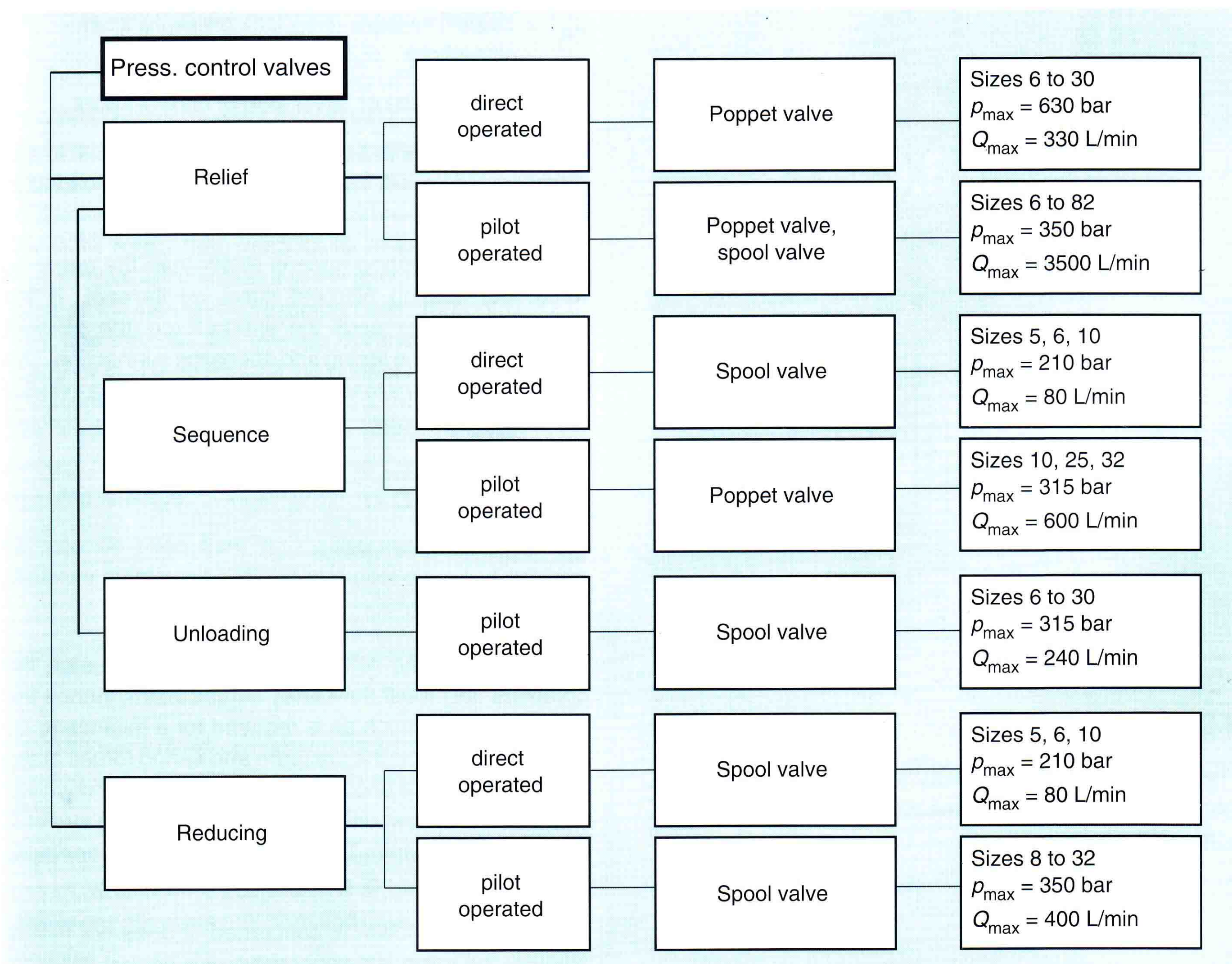


Fig. 1: *Functions, features and power datas of pressure control valves*

2 Pressure relief valves

2.1 Task

Pressure relief valves are used in hydraulic systems to limit the system pressure to a specific set level. If this set level is reached, the pressure relief valve is activated and feeds the excess flow (difference between pump and actuator flow) from the system back to the tank.

Fig. 2 shows a circuit with a pressure relief valve. This valve is always arranged as a bypass valve. Because of its task, the pressure relief valve is also known as a safety valve.

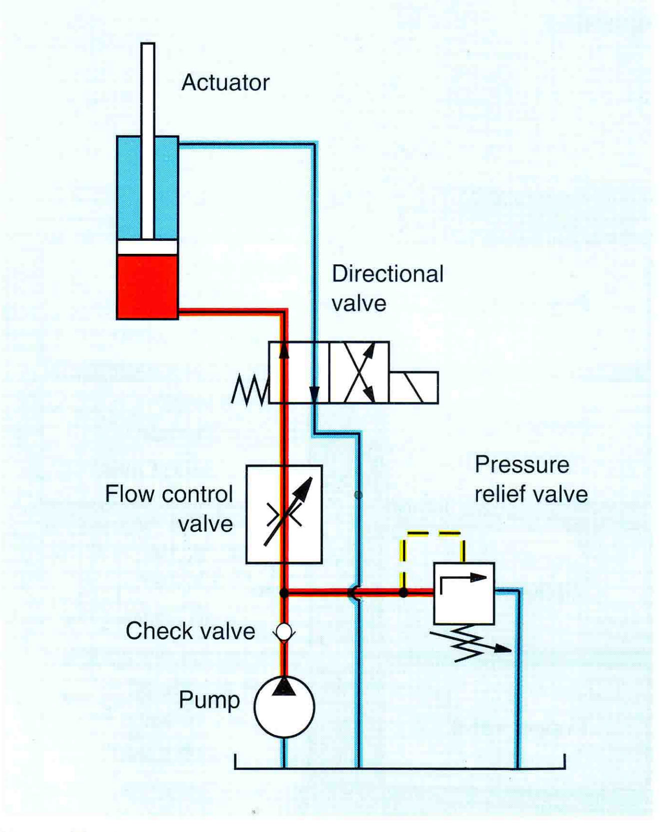


Fig. 2: Typical arrangement for a pressure relief valve

2.2 Function

The basic principle of all pressure relief valves, is that the inlet pressure is fed to a measuring surface, which is acted on by a force (*fig. 3*).

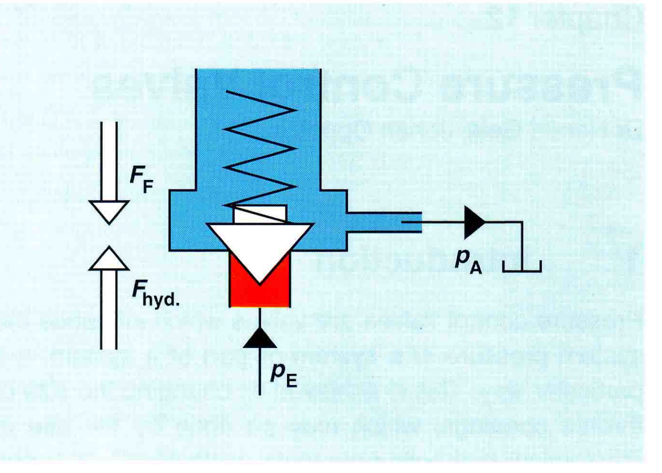


Fig. 3: *Principle of poppet valve used as a pressure relief valve*

The inlet pressure loads the poppet or lower side of the control spool with a hydraulic force.

$$F_{hyd} = p_E \cdot A = F_F + p_A \cdot A \qquad (1)$$

p_E = inlet pressure

p_A = output pressure (also tank pressure when unloading)

A = seat surface or lower side of control spool

The force of the pre-tensioned spring F_F acts in the direction of closure. The spring chamber is unloaded to tank.

As long as the spring force is larger than the pressure force, the seating element stays on its seat. If the pressure force exceeds the spring force, the element pushes against the spring and opens the connection. The excess fluid returns to tank. As the fluid flows away via the pressure control valve, hydraulic energy is converted into heat.

$$W = \Delta p \cdot Q \cdot t \qquad (2)$$

Δp = pressure difference
Q = flow
t = time

If, for example, no fluid is taken from the actuator, the complete flow must flow away via the valve. Hence the valve opens as much as is required for a balance to be produced between the pressure and spring forces at the seat element. The opening stroke continuously changes with the rate of flow, until the maximum opening stroke is reached (power limit). The set pressure corresponding to the spring force is not exceeded.

As far as the function is concerned, it does not matter whether the valve is a spool valve or a poppet valve.

In addition to providing leak-free sealing, the poppet valve shown in *fig. 3* has the advantage of a quick response time. This is because relatively large flows may be removed even with fairly small valve movements.

On the other hand, the spool valve (*fig. 4*) offers fine control small flows by means of grooves in the spool.

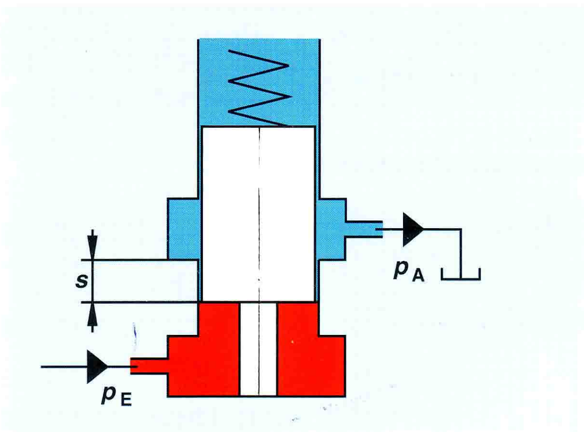


Fig. 4: *Principle of spool valve used as a pressure relief valve*

The control spool here is a measuring element (end area) and control element (control land). In the closed position, leakage oil flows continuously from the inlet of the valve via the clearance between spool and housing to the outlet (pressure free). With respect to response times, the poppet valve is far superior to the spool valve. In a spool valve, as the inlet pressure rapidly rises, the control spool must first traverse the overlap distance *s* (idle stroke) before oil is able to flow via the control lands. During the overlap phase, pressure increases at the inlet of the valve until it reaches the set opening pressure again. The overlap distance is a compromise between response time and leakage.

As may be seen from *fig. 1*, there are two types of pressure relief valves: direct and pilot operated valves.

2.3 Direct operated pressure relief valves, type DBD

Fig. 3 shows a direct operated pressure relief valve. The function considered so far was only with respect to the static forced in the valve.

From the dynamic point of view, we have a spring-mass system, which causes oscillations when it moves. These oscillations affect the pressure and must be eliminated by damping.

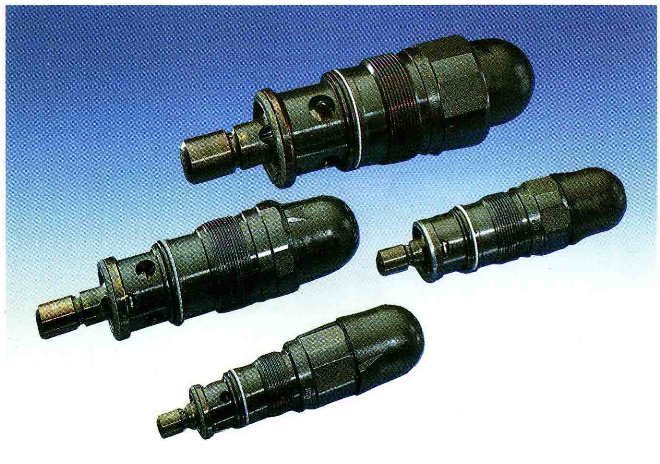


Fig. 5: *Direct operated pressure relief valve*

Possible ways in which damping can be achieved (*fig. 6*) are, for example:

- damping spool and orifice (1) to the spool chamber
- damping spool with one surface (2) or
- damping spool with correspondingly large tolerance play (3) (damping groove).

The spool is fixed rigidly to the closing element. When the spool moves, the fluid must be fed via the orifice or damping groove. A damping force occurs opposite to the direction of movement.

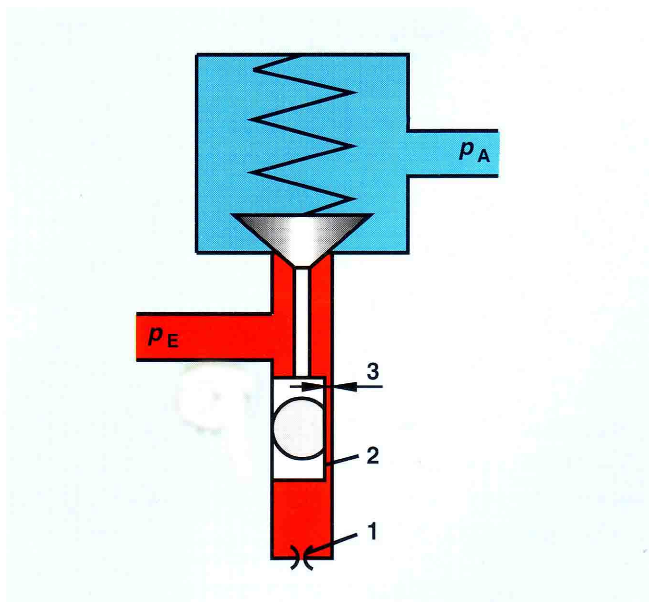


Fig. 6: *Cushioning possibilities for direct operated pressure relief valves*

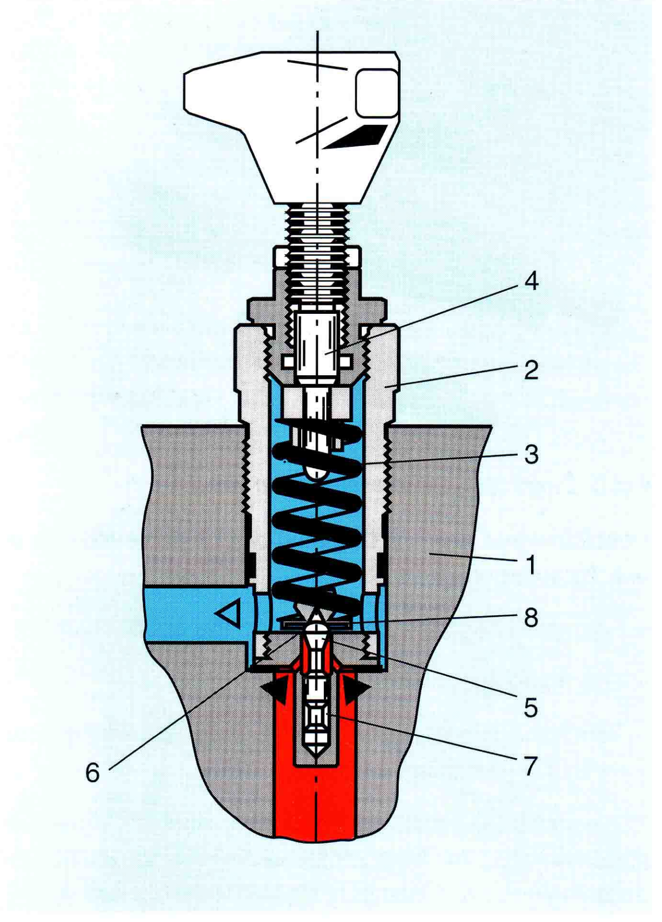


Fig. 7: *Screw-in pressure relief valve*

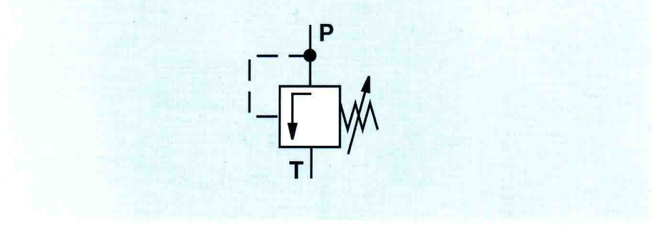


Fig. 8: *Direct operated pressure relief valve*

The valve which is screwed into a housing or control block (1) comprises sleeve (2), spring (3), adjustment mechanism (4), poppet with damping spool (5) and hardened seat (6).

The spring pushes the poppet on to its seat. The spring force can be steplessly adjusted by means of the rotary knob. The pressure is thus also set accordingly. Port P (red) is connected to the system. Pressure in the system acts on the poppet surface. If pressure lifts the poppet from its seat, the connection to port T (blue) is opened. The poppet stroke is limited by a pin in the damping bore (7).

As the spring force also increases with respect to the spring constant as the stroke increases, the underside of the spring retainer is a special shape. The flow forces of the oil flow are used in such a way that the increase in spring force is almost balance out.

In order to maintain a good pressure setting and a flat Δp-Q curve over the complete pressure range (lowest pressure increase possible with increasing flow), the total pressure range is sub-divided into stages. One pressure stage corresponds to a certain spring for a certain maximum set operating pressure.

Important parameters

Sizes	6 to 30
Flow	up to 330 L/min
Pressure stages	25, 50, 100, 200, 315, 400 and 630 bar

2.4 Pilot operated pressure relief valves

Direct operated valves are limited as the flow increases due to the space required for the control spring (see *section 2.5.2*). A larger flow requires a larger poppet or spool diameter. The area and hence the spring force increase proportionally to the diameter squared.

In order to keep the space required for these valves down to a sensible level, pilot operated valves are used for larger flows. They are used to limit the operating pressure(DB) or limit and unload the operating pressure by means of solenoid operation (DBW) (*fig. 9*).

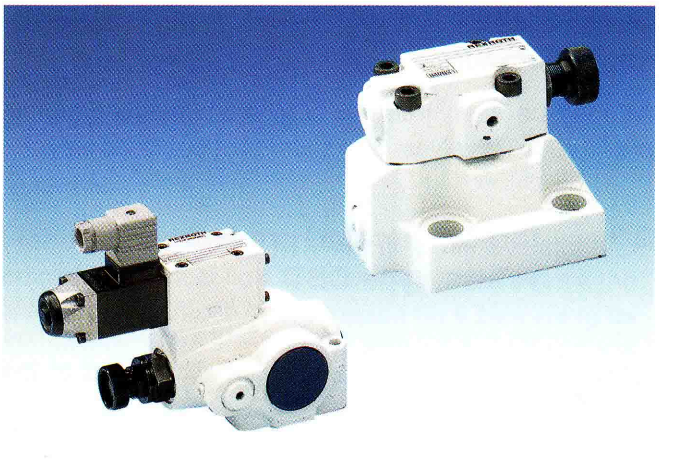


Fig. 9: *Pilot operated pressure relief valves; right without and left with directional valve unloading*

2.4.1 Pressure relief valve, type DB

Pressure relief valve, type DB basically comprises a main valve (1) with main spool cartridge (3) and pilot valve (2) with pressure setting element. The pilot valve is a direct operated pressure relief valve.

The pressure present in channel A acts on main spool (3). At the same time, the pressure is fed to the spring-loaded side of the main spool (3) via control lines (6) and (7) containing orifices (4, 5 and 11) and also to the ball (8) in the pilot valve (2). If the pressure increases in channel A to a level above that set by spring (9), ball (8) opens against spring (9).

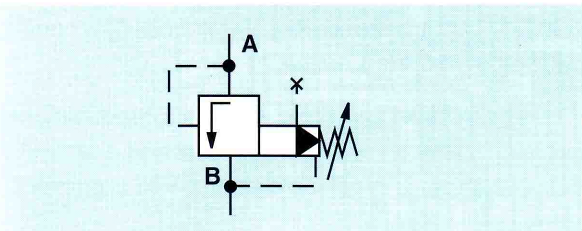


Fig. 10: *Pilot operated pressure relief valve*

The pilot oil flow on the spring-loaded side of the main spool (3) now flows via control line (7), orifice (11) and ball (8) into the spring chamber (12). From here, the flow is fed internally via control line (13) or externally via control line (14) without pressure to tank. Dependent on orifices (4) and (5) a pressure drop exists at main spool (3). Hence the connection from channel A to channel B is opened. Now fluid flows from channel A to channel B maintaining the set operating pressure .

The pressure relief valve may be unloaded via port "X" (15) or by connecting it to a lower pressure (two pressure stages).

The pilot oil may be returned separately (externally) to tank via port (14) (with closed bore (16)). By doing this the effects of backpressures from channel B on the set pressure are avoided.

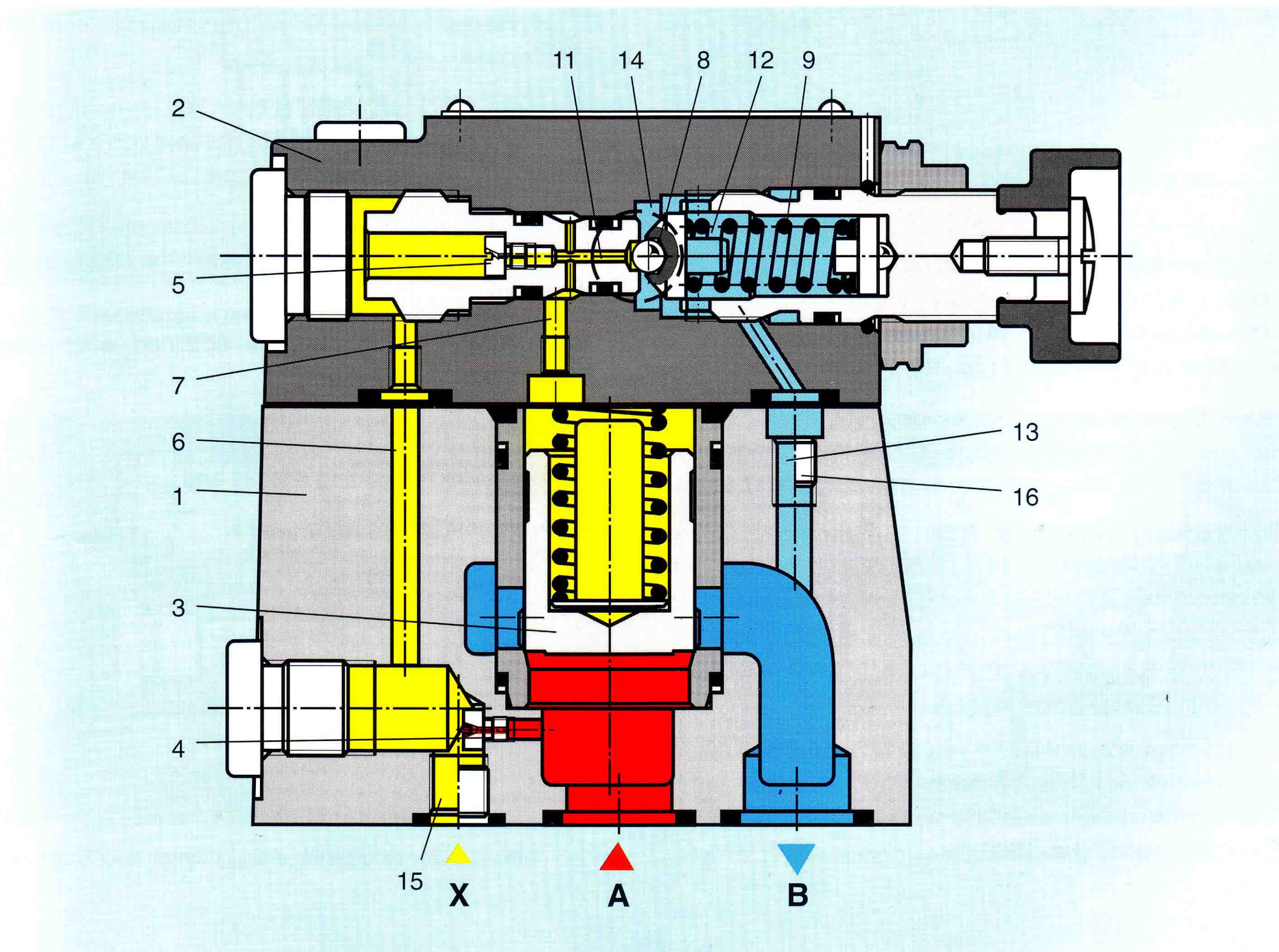


Fig. 11: *Pilot operated pressure relief valve, type DB*

2.4.2 Pressure relief valve, type DBW

The function of this valve corresponds in principle to that of valve, type DB (*fig. 11*). However, the main spool (5) is unloaded by means of integral 3/2 way directional valve (3) (*fig. 13*).

A typical application of this valve is when it is used to run a pump up to speed at no pressure.

Important parameters

Sizes	6 to 82
Operating pressure	up to 350 bar
Flow	up to 3500 L/min

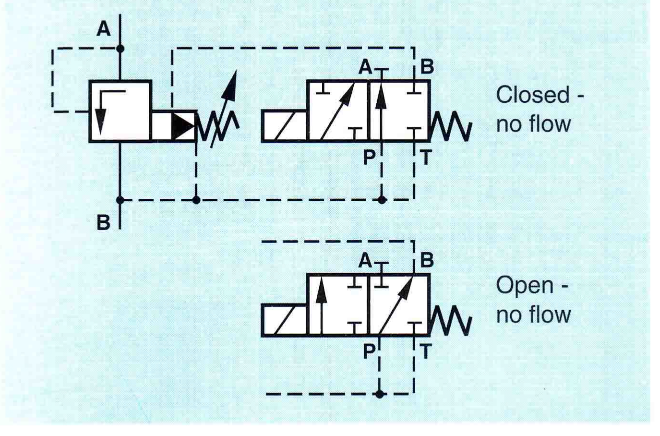


Fig. 12: *Pilot operated pressure relief valve with directional valve unloading*

By combining a pressure relief valve with a directional valve, it is possible to relatively simply switch from the pressure relief function to pressure free operation by means of a control signal (*fig. 13*).

When the directional valve is closed (no flow) (*fig. 12*) there is no connection between the spring side and channel B. The valve operates as a pressure relief valve.

By operating directional valve (3), the main spool chamber on the spring side (1) is connected to channel T (2) of the directional valve. Hence the main spool (5) is lifted from its seat (4). Fluid may now flow from channel A to channel B at a very low pressure (bypass operation; flow resistance is dependent on the system).

This process occurs within a very short time. The system pressure falls rapidly to the much lower bypass pressure. This results in high pressure peaks and considerable acoustic unloading shocks.

In order to solve this problem, various models are used with varying degrees of success, such as

- the use of a spool main spool instead of a poppet main spool
- active piloting
- attenuators or
- shock damping plates.

Shock damping plate

The operation time of a pressure relief valve may be influenced using an shock damping plate and hence the switching process may be carried out more softly. The function of this plate is basically that of a flow control valve with a downstream orifice.

The shock damping plate (6) is situated between pilot valve (7) of the pressure relief valve and directional valve (3). A orifice (8) must be inserted into channel B of the directional valve.

When the directional valve is closed (pressure relief function) (*fig. 14*) spool (9) is pushed against spring (10) by the pilot pressure and hence the connection from B2 to B1 is closed.

When the directional valve is open (*fig. 15*) (the pilot oil may flow via channel B of the directional valve to tank) a constant pressure drop is present at orifice (8).

After a delay, spring force (10) opens the connection from B2 to B1 and hence pressure peaks in the return line are avoided.

The following advantages are obtained when using shock damping plates:

- no dependence on viscosity
- no acoustic unloading shocks and
- much smaller pressure peaks.

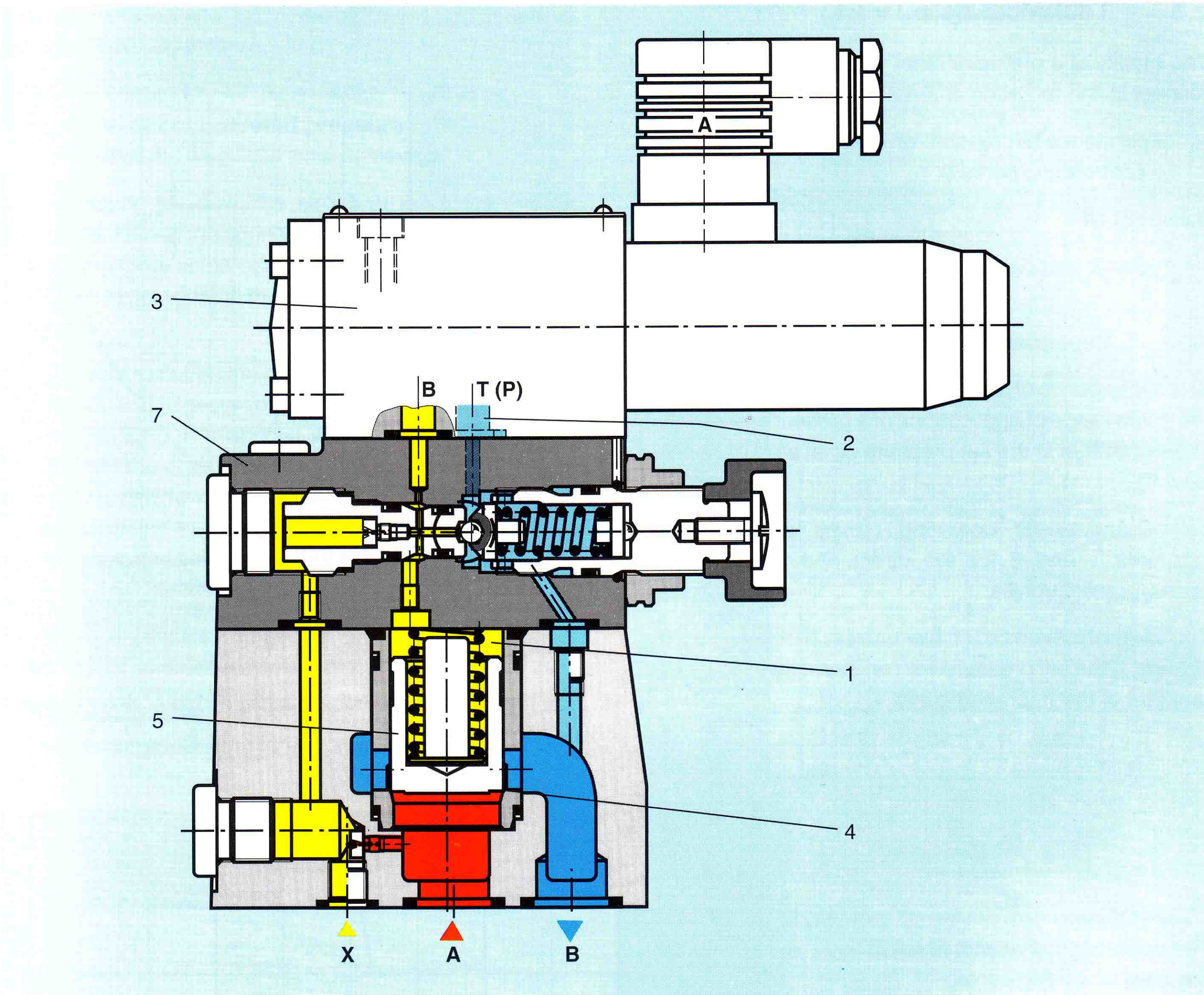


Fig. 13: *Pilot operated pressure relief valve with solenoid operated unloading, type DBW*

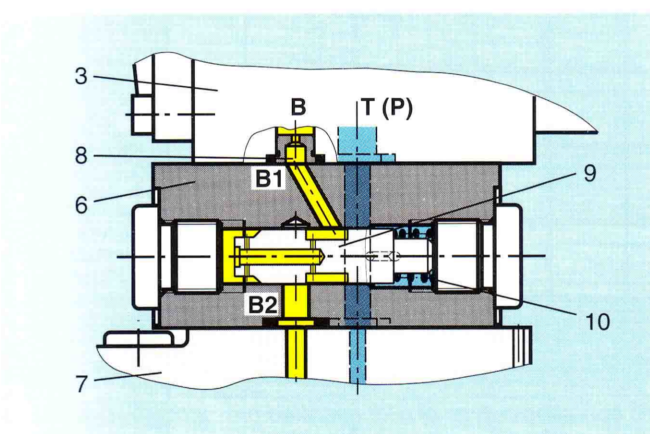


Fig. 14: *Shock damping plate, directional valve closed*

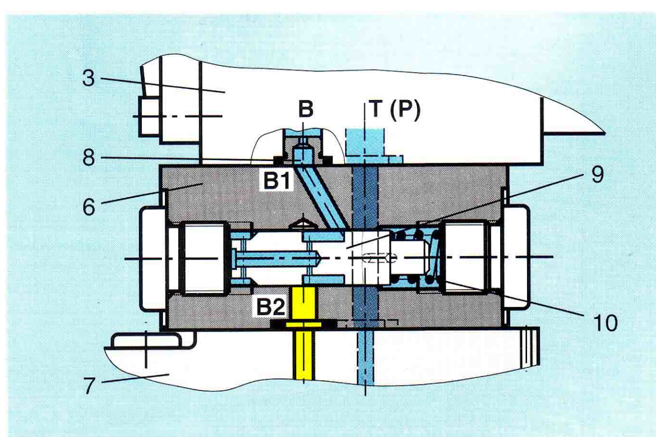


Fig. 15: *Shock damping plate, directional valve open*

2.5 Technical data

The quality of a pressure relief valve is determined with respect to the following criteria:

- dependence of pressure on flow (p-Q operating curve)
- power limit
- dynamic response

2.5.1 Dependence of pressure on flow

The dependence of pressure on flow may be used to view the entire range of applications of a pressure relief valve. The parameter is the set pressure p_E at start of opening ($Q > 0$).

The characteristic operating curves are shown in diagrams 1 and 2 for the direct and pilot operated pressure relief valves.

The control deviation of the valves R represents the change in the set pressure with an increase in flow or the gradient of the operating curve.

$$R = \frac{\Delta p_{Ei}}{\Delta Q} \qquad (3)$$

$$R = \frac{p_{EiQ} - p_{Ei\,(Q=0)}}{\Delta Q} \qquad (3)$$

The operating curve with $R = 0$ is the ideal operating curve.

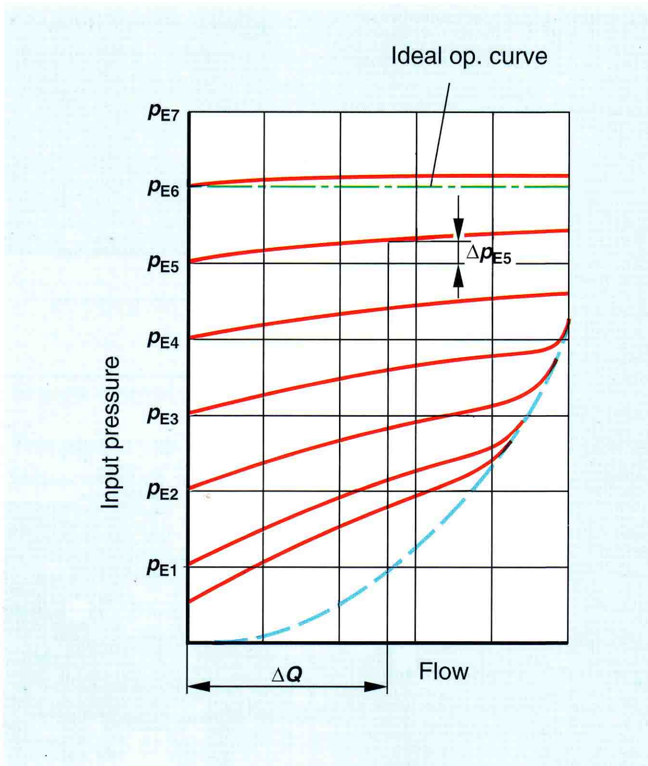


Diagram 1: *Characteristic operating curves of direct operated pressure relief valves*

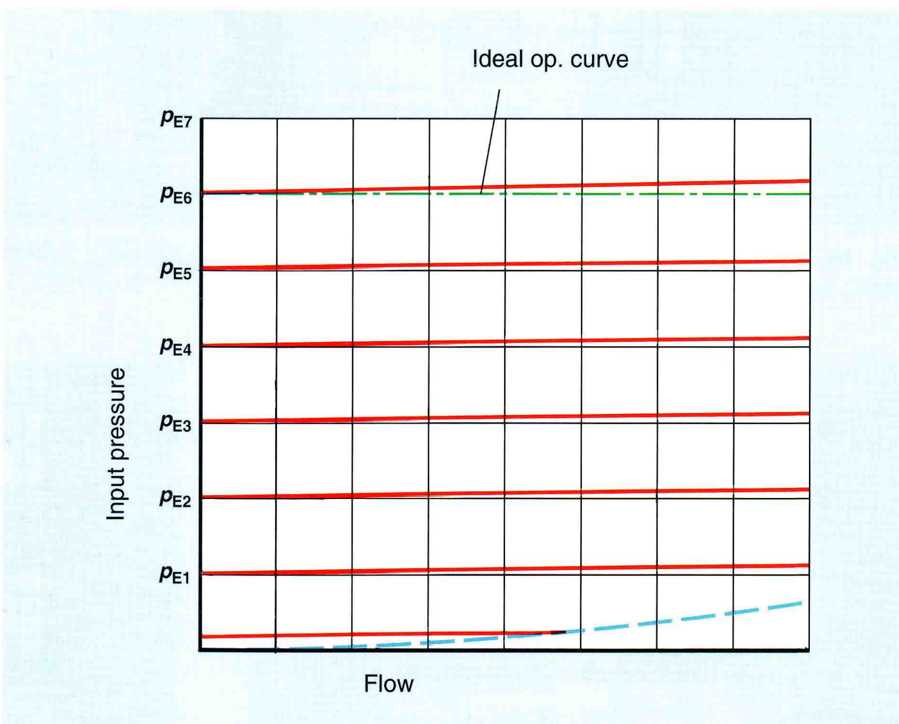


Diagram 2: *Characteristic operating curves of pilot operated pressure relief valves*

The following reasons cause the gradient to deviate from the ideal operating curve.

2.5.1.1 In direct operated pressure relief valves (*fig. 7*)

By increasing the flow, the stroke of the valve poppet increases. Hence the spring is increasingly compressed. The spring force is increased by a considerable amount (*diagram 1*). In addition the pressure loss and flow force increase.

It is possible to flatten the gradient of the operating curve in direct operated pressure relief valves by using a spring retainer shaped in a special way (*fig. 7* (8)). The flow forces from the outlet flow are used on the underside of the spring pad to compensate for the increase in the spring force and to compensate for the flow force acting on the valve poppet.

By matching the spring force to the current setting range (divided into pressure stages) a "practical pressure-flow relationship" is achieved (*diagrams 3 and 4*).

The operating curve with the lowest gradient is attained at the value corresponding to the pressure stage.

Legend to *diagrams 3 and 4*

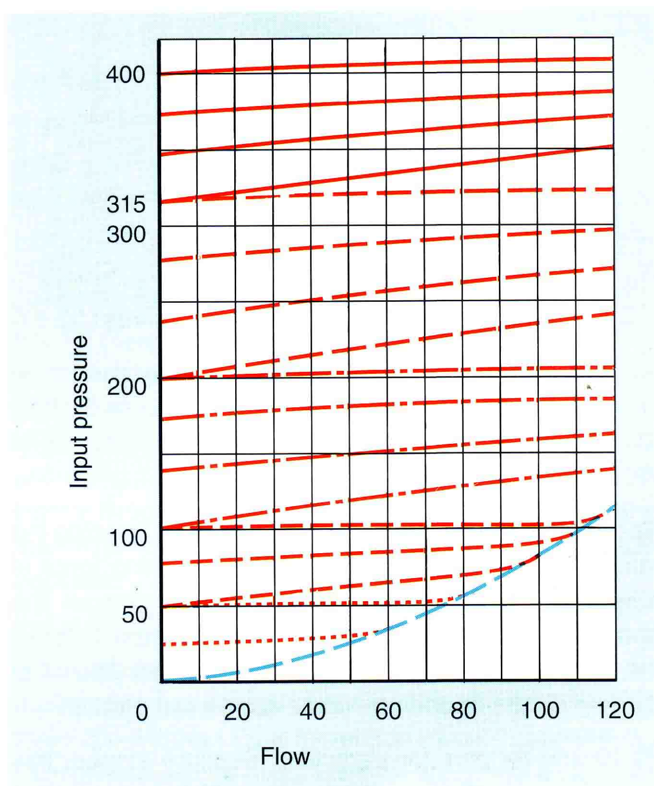


Diagram 4: p_E-*Q operating curves for direct operated pressure relief valves, sizes 8 and 10*

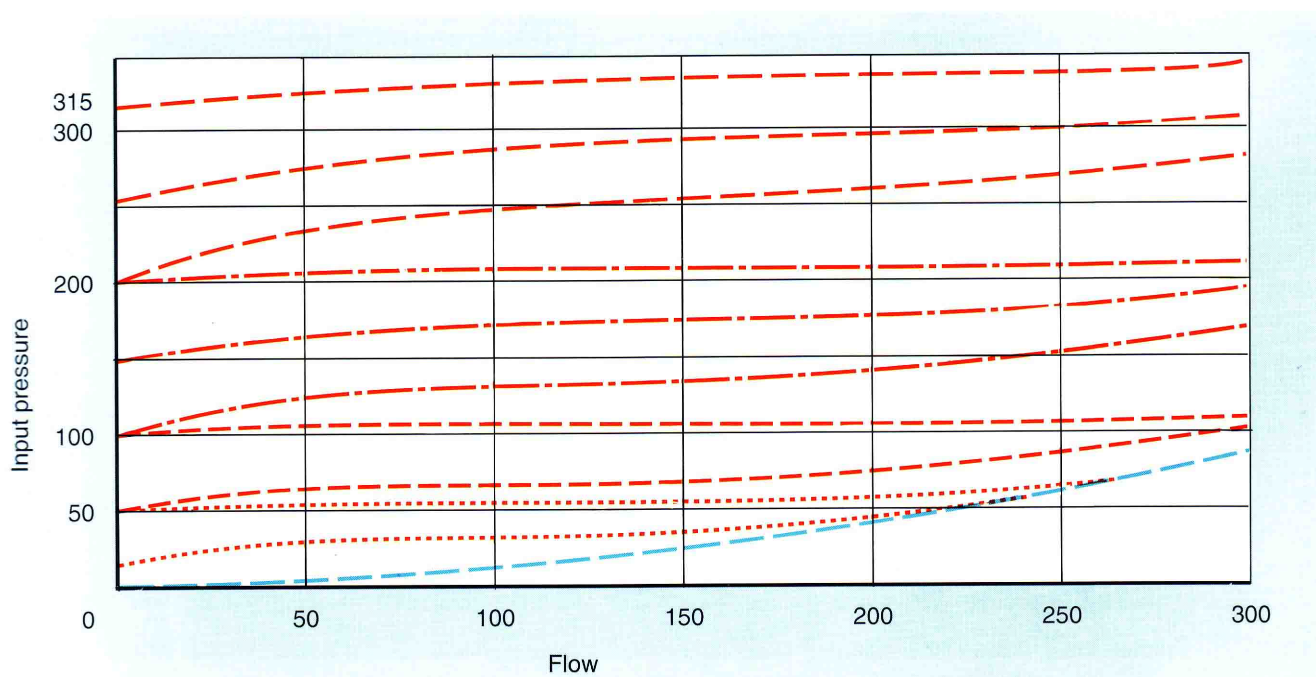


Diagram 3: p_E-*Qoperating curves for direct operated pressure relief valves, sizes 25 and 30*

Direct operated pressure relief valves are usually only used in the recommended pressure setting range.

For example: Pressure rating 200 bar
Setting range 100 to 200 bar or

Pressure rating 300 bar
Setting range 200 to 300 bar.

Pressures may also be set which are below the recommended setting range, theoretically down to p_E = 0 (complete unloading of the spring). However, a large control deviation then needs to be taken into consideration (*diagrams 3 and 4*).

2.5.1.2 Pilot operated pressure relief valves (*fig. 11*)

The gradient of the operating curve for pressure relief valves as the flow increases (diagram 5) is due to the flow force ($F_S \approx Q \bullet \sqrt{\Delta p}$) acting in the direction of closing of the main spool (3).

As the main spool spring only has the task of keeping the main spool (3) in a certain position, its spring force is relatively low. Hence the effect of the spring on the operating curve is negligibly small in comparison to that of the direct operated pressure relief valve. As shown in diagram 5, the operating curves are almost parallel.

By having models for particular pressure stages, this leads to an improvement in the "sensitivity" of pressure setting.

For very small flows (Q < 0.5 to 1 L/min) the pressure-flow curve forms a hysteresis curve. This means that as a valve is closed (decreasing flow) a smaller pressure pS is produced than on opening p_O (increasing flow) (*diagram 6*).

This difference between the opening and closing characteristics is due to the mechanical and hydraulic frictional forces at the control elements (main spool (3) pilot ball (8)) as well as to the contamination in the fluid.

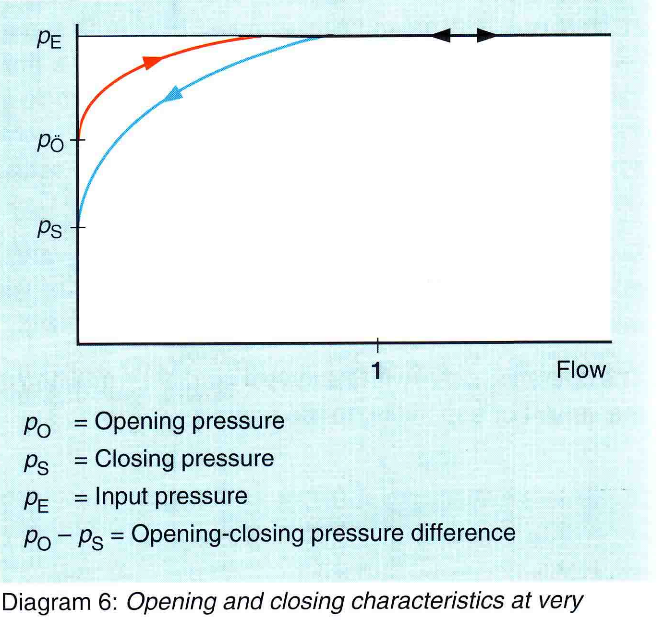


Diagram 6: *Opening and closing characteristics at very small flows*

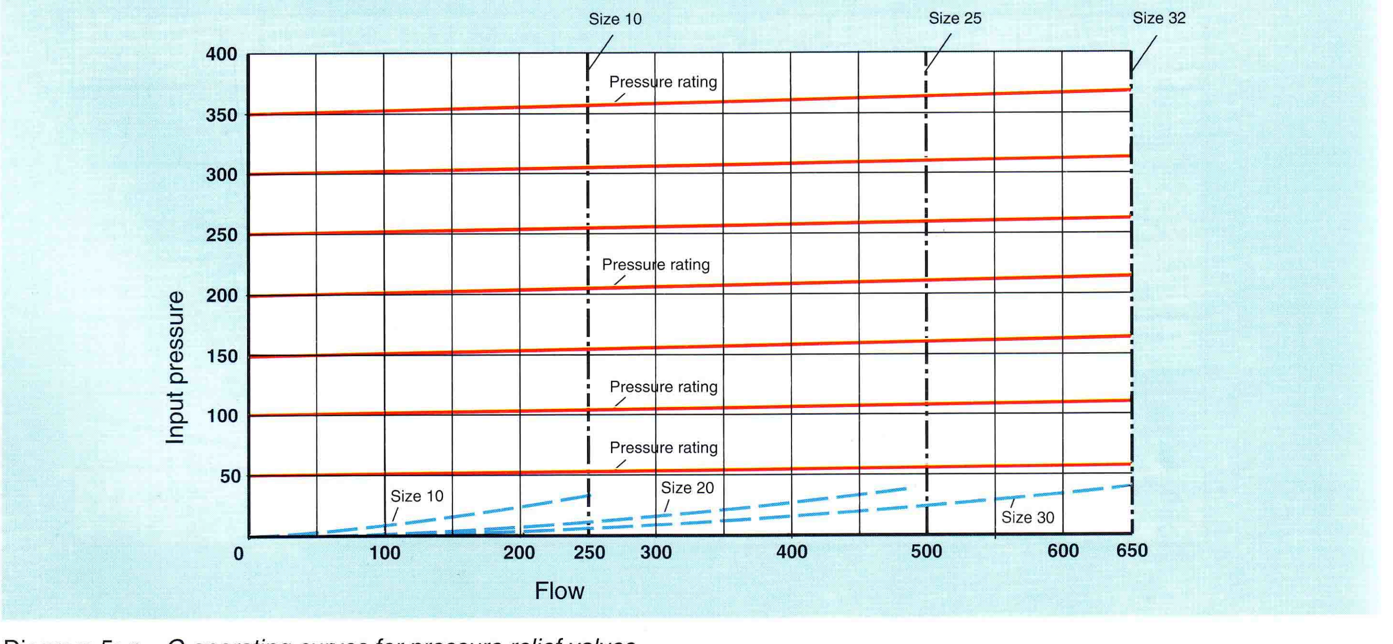


Diagram 5: *p_E-Q operating curves for pressure relief valves*

2.5.2 Power limit

In pressure relief valves there are two power limits: upper and lower limits (*diagrams 7 and 8*).

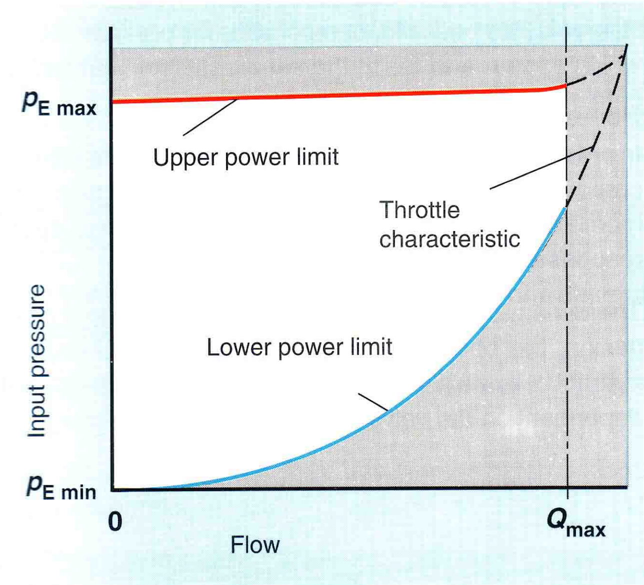


Diagram 7: *Operating range for a direct operated pressure relief valve*

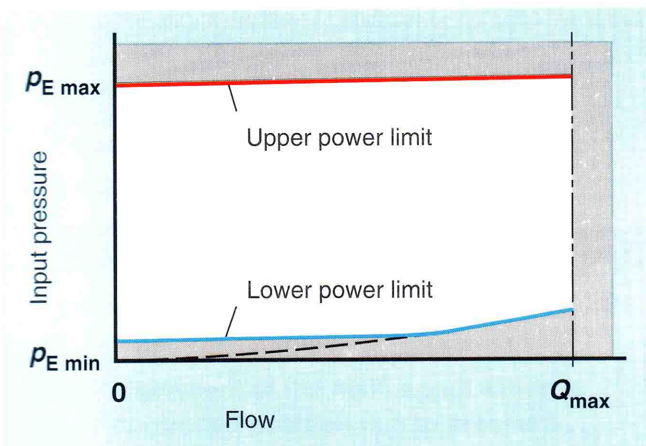


Diagram 8: *Operating range for a pilot operated pressure relief valve*

2.5.2.1 Upper power limit
(highest set pressure and max. flow)

The pressure setting p_E determines the upper working range of the pressure relief valve. This pressure is formed from the maximum spring force F_F and the corresponding seat opening A_V of the pilot valve (*fig. 14*).

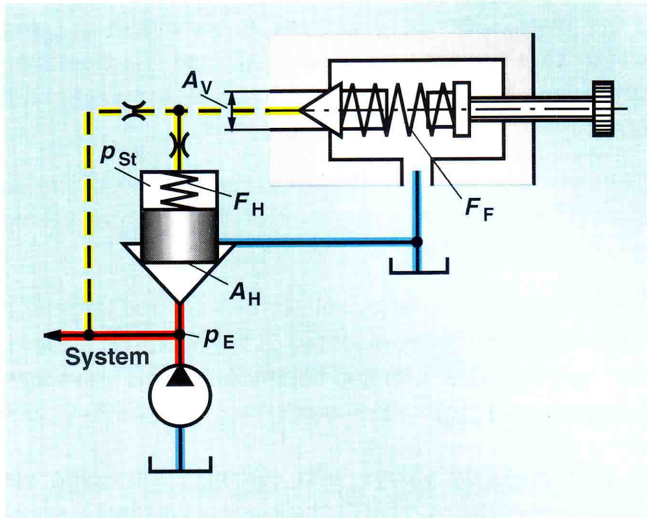


Fig. 16: *Principle of a pilot operated pressure relief valve*

Higher flows require larger seat openings and hence according to $p_E = F_F/A$ larger spring or setting forces. Hence direct operated pressure relief valves are soon in the range where a manual adjustment of p_E is no longer possible.

Therefore pilot operated pressure relief valves are used in for higher pressures, as larger seat diameters A_H in the main stage are easily achieved. The small force of the main spool spring F_H is increased by pilot pressure p_{St}. Pilot pressures due to the low pilot flow may be easily set by direct operated pressure relief valves (no adjustment forces).

2.5.2.2 Lower power limit

a) Direct operated pressure relief valves

In direct operated valves the lower power limit is reached, when the valve poppet has carried out its maximum opening stroke. The max. opening pressure corresponds to the throttling characteristic shown in *diagram 7*.

At any setting the *p-Q* operating curve may cut the throttling characteristic and the this determines the power limit of the valve (fully open control opening). This means that if the flow is increased further, pressure increases in accordance with the throttling characteristic.

b) Pilot operated pressure relief valves

In pilot operated valves the lowest pressure setting at the start of opening is determined by the force of the main spool spring and the pilot pressure. This value is usually between 1.5 and 4.5 bar for standard valves.

If the main spool has reached its maximum opening stroke as a result of the increasing flow, the operating curve cuts the throttle characteristic at the lowest set pressure (*diagram 8* – dotted line).

Dependent on the much larger opening area of the valve main stage, the lower power limit for pilot operated valves is only attained at low set pressures.

In order to avoid flow velocities which are too large and hence to avoid pressure losses in the hydraulic system, the maximum flow is limited dependent on the valve size (*diagram 8*, Q_{max}).

In pilot operated valves with electrical unloading via directional valve, type DBW, the lower power limit is equal to the "bypass" pressure. This is determined by the pre-tensioning force of the main spool spring and the pilot pressure of the pilot fluid which flows via the directional valve to tank.

2.5.3 Dynamic behaviour

The dynamic behaviour of a pressure relief valve is characterised by its response to a sudden change in the flow or pressure.

The valve should be able to react quickly, that is with as little delay as possible, compensate for pressure peaks which appear and reach the set pressure within a short time.

In order to avoid pressure peaks, damping needs to be incorporated. However this together with friction and moment of inertia of the moving parts tends to reduce the response of the valve.

The dynamic behaviour of the valve is dependent on its design, the operating state of the main spool and the hydraulic system itself. The static behaviour is only dependent on the valve design.

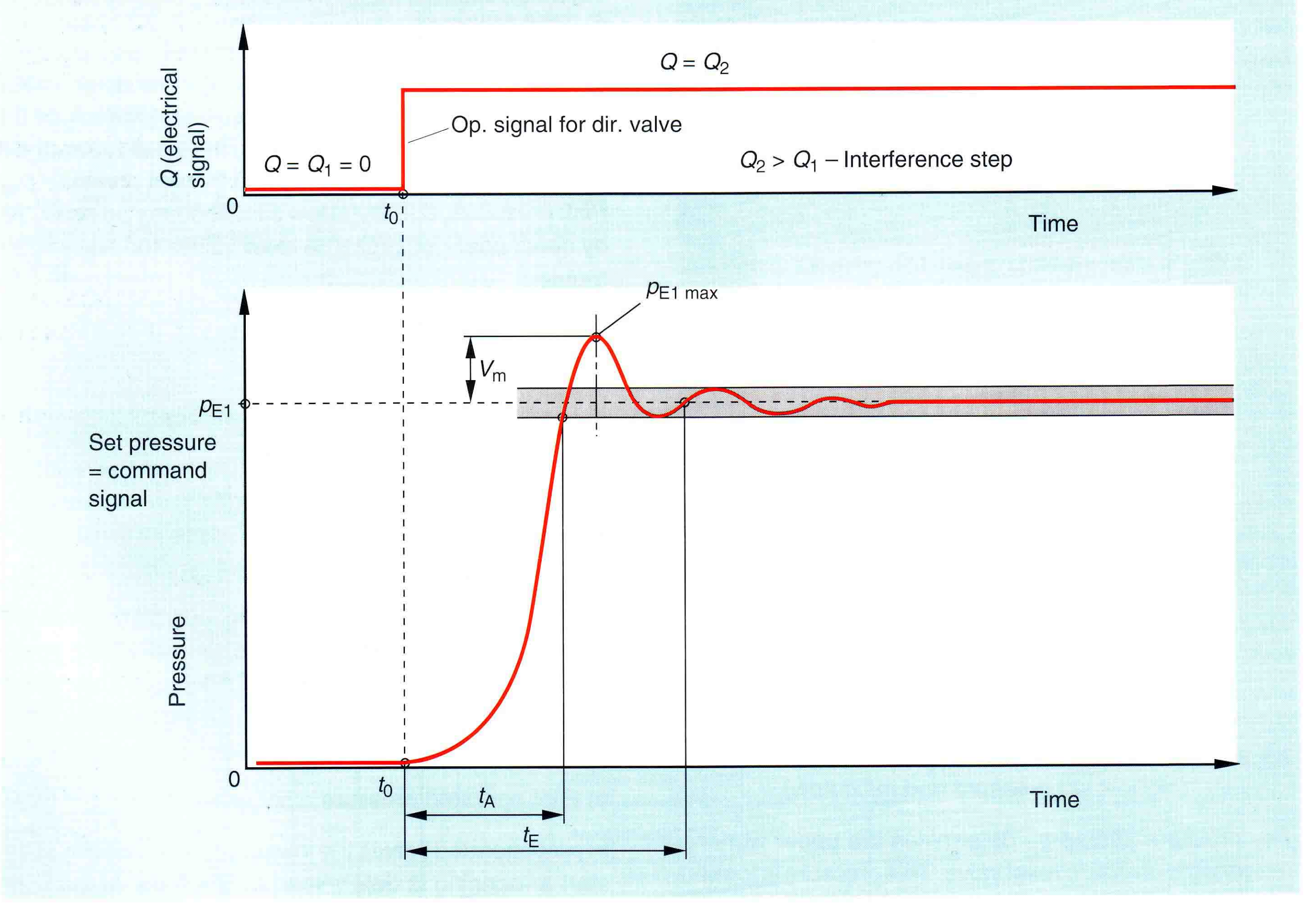


Diagram 9: *Response behaviour of a pilot operated pressure relief valve on opening*

There are two types of operating states (movement phases) for the main spool:

2.5.3.1 Movement of the main spool in another stroke position, e.g. when opening

The following reasons may cause the main spool to change its position:

a) A sudden jump or drop in pressure in the hydraulic system, due to a sudden change in the flow.

b) A sudden change in the pilot pressure due to the operation of directional valve (type DBW).

The dynamic behaviour may be examined on the basis of the response operating curve (*diagram 9*).

The operating curve is almost independent of the type of energizing.

The following parameters are used for the determination of the response:

- Build-up period t_A
  is the time which lapses from time t_0 until the pressure reaches the lower limit of the transient tolerance.
- Transient period t_E
  is the time which lapses from time t_0 until the transient tolerance is reached for the last time and then not exceeded any more.
- Pressure peak p_{Emax}
  $p_{Emax} = V_m / p_E \cdot 100$ in %

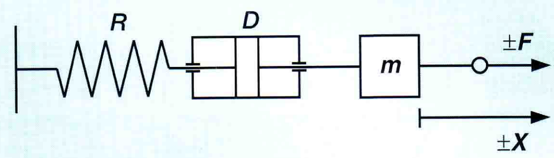
The maximum overshoot V_m is the largest deviation of the response from the set command value after the transient tolerance has been overshot for the first time.

2.5.3.2 Movement of the main spool within a controlled position due to pressure oscillations in the hydraulic system

In practice, flows in a hydraulic system due to pressure pulses from the hydraulic pump amongst other things are not free of oscillations.

Pressure relief valves may be encouraged to oscillate creating noise due to these pressure pulses. Depending on the frequency of this noise, the valve noise is known as "chatter, buzzing, whistling or screaming".

The cause of this is the spring-mass system, which consists of the moving valve parts of mechanical spring and oil column acting as a spring.



R = Spring rate
D = Damping proportional to velocity
F = Energizing force
X = Movement of system

Fig. 17: Principle of spring-mass system

The relationship between force *F* and movement *x* of the mechanical system is described by equation 4.

$$m \cdot x = F - D \cdot x - R \cdot x \qquad (4)$$

The oscillations which appear may be removed by suitable damping measures. See *fig. 6* (damping spool in direct operated valves).

Pilot operated valves are hydraulically cushioned (*fig. 14*). Orifices between the main stage and the pilot valve limit the pilot flow and hence the movement of the main spool.

It is important for undisturbed hydraulic system operation that the pressure relief valve compensates for any oscillations which occur and hence enables the operational behaviour to be stable.

If this is not done, high frequency oscillations as well as noise will lead to an increase in wear (cavitational erosion).

This results in as shorter service life for the valves and a lower hydraulic system availability.

2.5.3.3 Influence of valve design

In spool valves a certain length of overlap must always exist, in order to limit the internal leakage. Due to this idle stroke, this results in a dead period, e.g. when the valve is opened, where the inlet pressure continues to rise. This results in pressure peaks.

On the other hand in poppet valves, the valve poppet opens immediately on the inlet pressure reaching the set command level. As expected the pressure peaks are considerably lower.

3 Pressure sequence valves

Pressure sequence valves are similar in design to pressure relief valves. Depending on application, they may be divided into sequence, by-pass, pre-load or deceleration valves.

Pressure sequence valves are arranged in the main flow of a hydraulic system and connect or disconnect a further hydraulic system when a set pressure is reached.

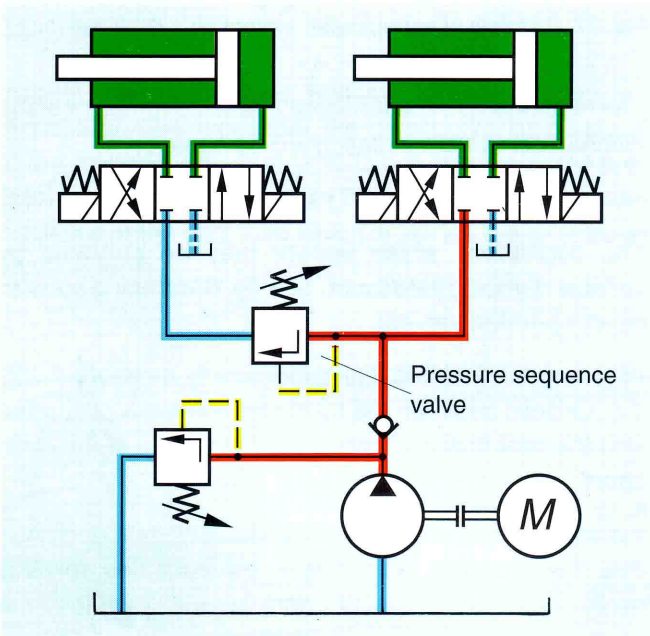


Fig. 18: *Control with pressure isolating valve*

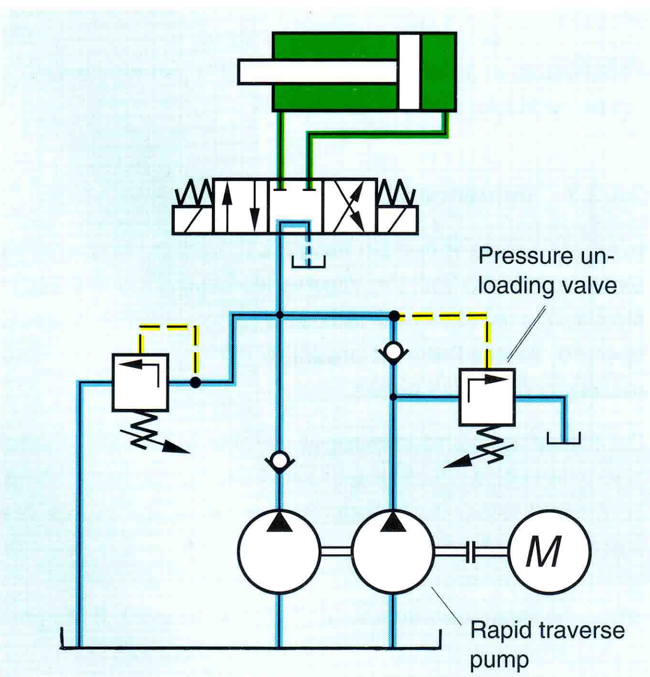


Fig. 19: *Control with shut-off rapid traverse pump*

3.1 Sequence valves

Basically pressure relief valves may be used as sequence valves. The pre-requisite for this is that the pressure in channel T (in direct operated pressure relief valves) or in channel B (in pilot operated pressure relief valves) cannot change the set pressure. This is achieved by feeding the leakage oil in direct operated pressure relief valves and the pilot oil in pilot operated pressure relief valves externally and pressure free to tank.

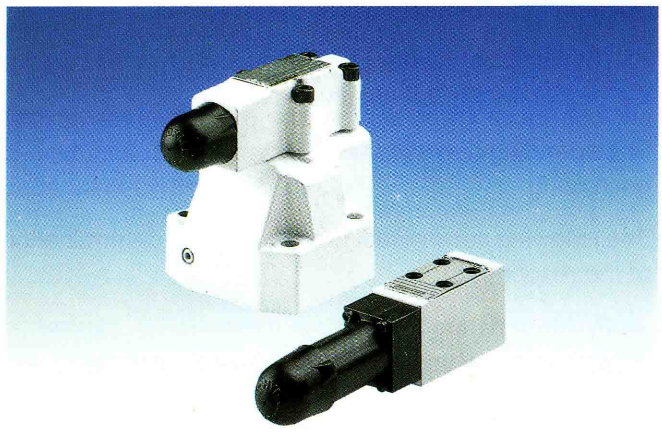


Fig. 20: *Direct and pilot operated pressure isolating valve*

3.1.1 Direct operated sequence valve, type DZ.D (*fig. 21*)

The adjustment element (4) is used for setting the sequence pressure. The compression spring (3) keeps the control spool (2) in its initial position. The valve is closed.

Pressure in channel P acts on surface (8) of the control spool (2) via control line (6) and hence acts against the force of spring (3). If the pressure in channel P exceeds the value set at spring (3), control spool (2) is pushed against compression spring (3). The connection from channel P to channel A is opened. The system attached to channel A is connected without the pressure in channel P falling.

The control signal is fed either internally via control line (6) and orifice (7) from channel P or externally via port B (X).

Depending on the application, leakage oil is returned externally via port T (Y) or internally via port A.

A check valve may be optionally built into the system to allow free return flow of the fluid from channel A to channel P. Pressure gauge port (1) is fitted so that the sequence pressure may be monitored.

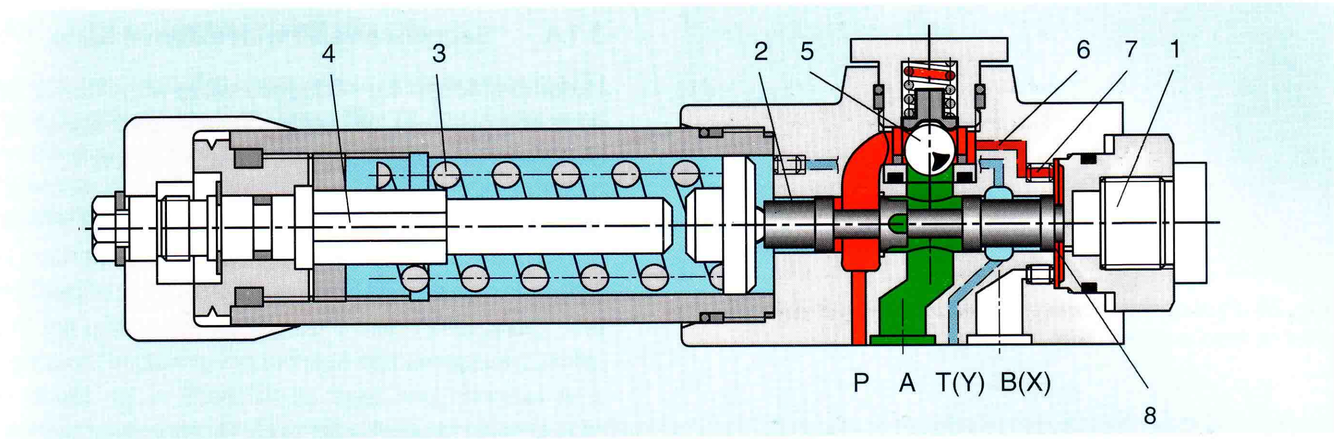


Fig. 21: *Direct operated pressure sequence valve*

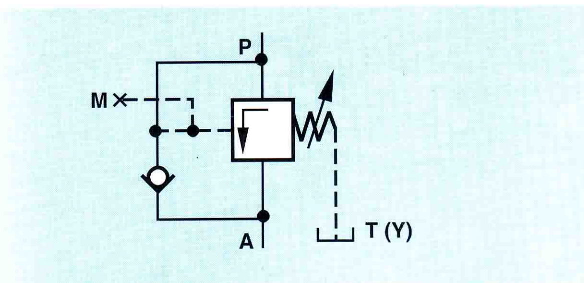


Fig. 22: *Direct operated pressure sequence valve; internal pilot oil feed, external pilot oil return*

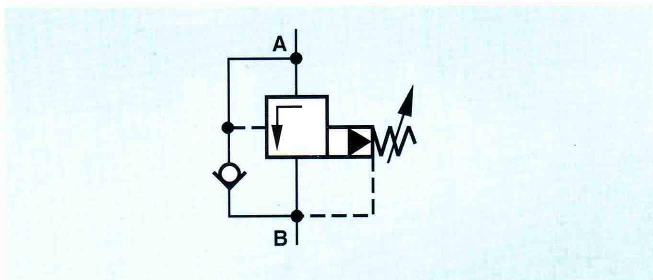


Fig. 23: *Pilot operated pressure sequence valve; internal pilot oil feed, internal pilot oil return*

Important parameters:

Sizes	5, 6 and 10
Flow	up to 80 L/min
Max. input pressure	315 bar
Max. set sequence pressure	210 bar

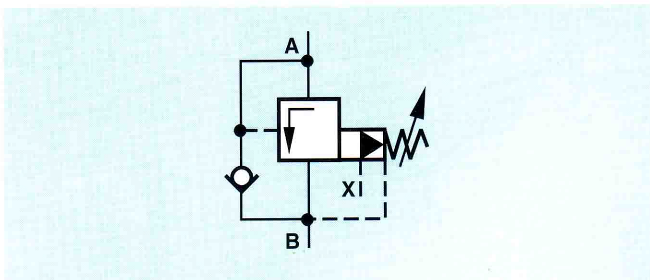


Fig. 24: *Pilot operated pressure sequence valve; external pilot oil feed, internal pilot oil return*

3.1.2 Pilot operated sequence valve, type DZ (*fig. 27*)

Pilot operated sequence valves basically comprise main valve (1) with main spool insert (2) and pilot valve (3) with adjustment element (11).

A check valve (4) may be optionally built into the system to allow free return flow of the fluid from channel A to channel B.

Dependent on the application (pre-load, sequence or by-pass) pilot oil is fed and/or returned either internally or externally.

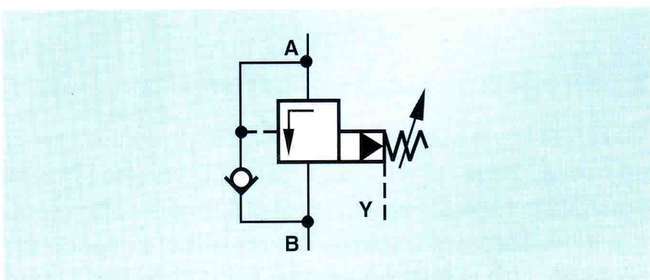


Fig. 25: *Pilot operated pressure sequence valve; internal pilot oil feed, external pilot oil return*

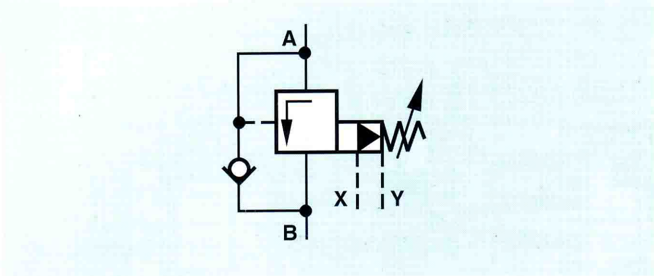


Fig. 26: *Pilot operated pressure sequence valve; external pilot oil feed, external pilot oil return*

3.1.4 Sequence valve with external drain

In comparison to the sequence valve with internal drain. here the leakage oil arising at the pilot spool is fed externally and pressure free to tank via port Y.

The pilot oil is fed internally via line (9) into channel B.

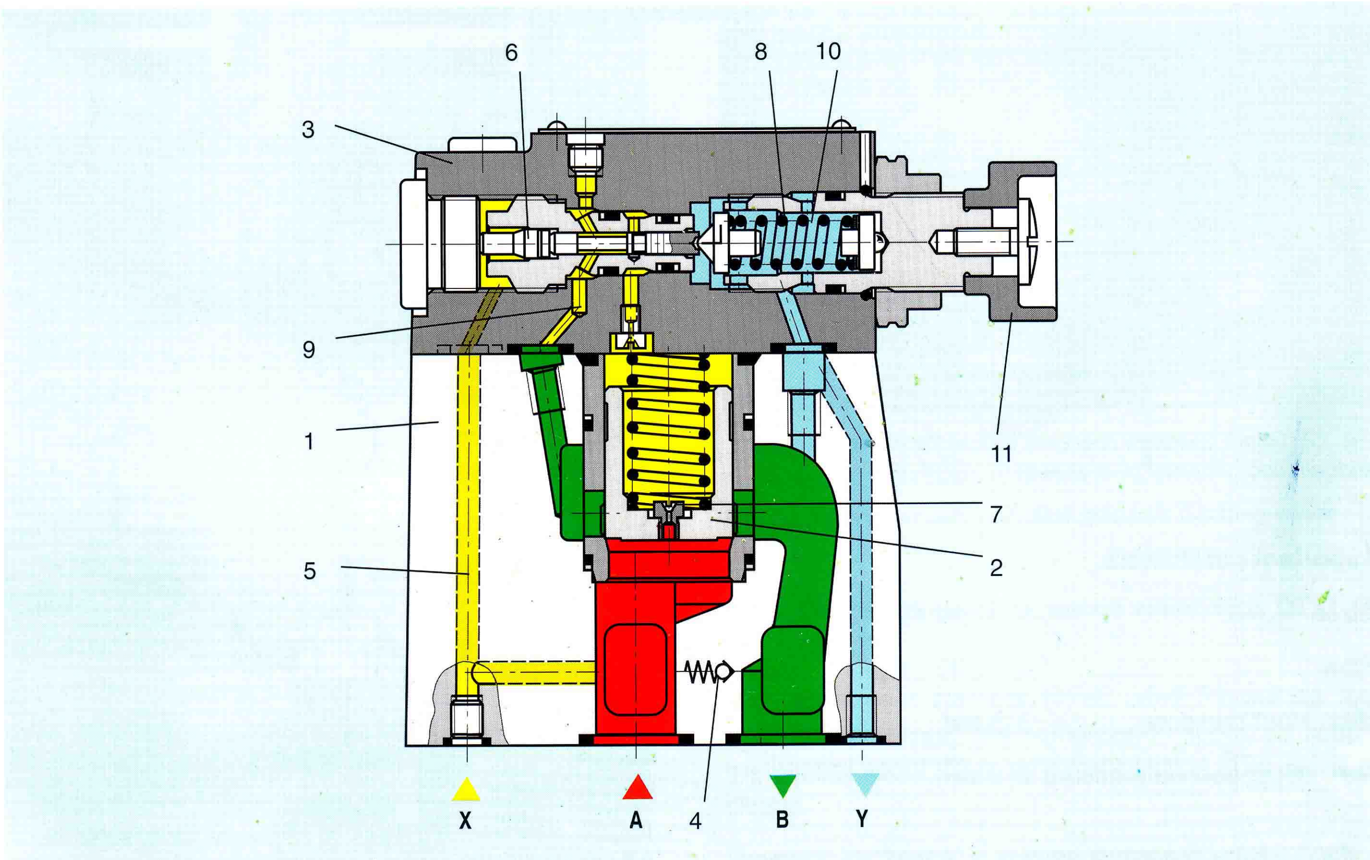


Fig. 27: *Pilot operated pressure sequence valve; internal pilot oil feed, internal pilot oil return*

3.1.3 Sequence valve with internal drain (*fig. 27*)

The pressure present in channel A acts via control line (5) on pilot spool (6) in pilot valve (3). At the same time the pressure acts on the spring loaded side of the main spool (2). If the pressure exceeds the value set at spring (8), pilot spool (6) is pushed against spring (8). The control signal for this is fed internally via control line (5) from channel A. The fluid on the spring loaded side of main spool (2) now flows via control line (9) into channel B. A pressure drop is produced across main spool (2). The connection from channel A to channel B is free whilst the pressure set at spring (8) is maintained. The leakage arising at pilot spool (6) is fed internally into channel B.

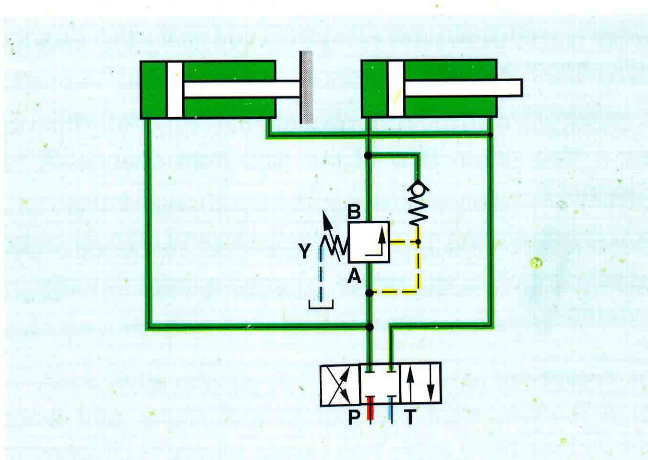


Fig. 28: *Pressure sequence valve*

3.1.4.1 Use as bypass valve (*fig. 29*)

The pressure present in channel X acts via control line (5) on pilot spool (6) in pilot valve (3). At the same time pressure in channel A acts on the spring loaded side of the main spool (2) via orifices (7). If the pressure in channel X exceeds the value set at spring (8), pilot spool (6) is pushed against spring (8). Now fluid flows from the spring loaded side of the main spool (2) to spring chamber (10) of the pilot valve via the bore in the pilot spool. The pressure on the spring loaded side of main spool (2) falls. Main spool (2) is lifted off its seat and channel A is connected to channel B. Fluid now flows at almost zero pressure from channel A to channel B.

In this model, pilot oil from spring chamber (10) is returned pressure free via port Y.

Important parameters

Sizes	10, 25 and 32
Flow	up to 450 L/min
Max. operating pressure	315 bar
Max. set sequence pressure	315 bar

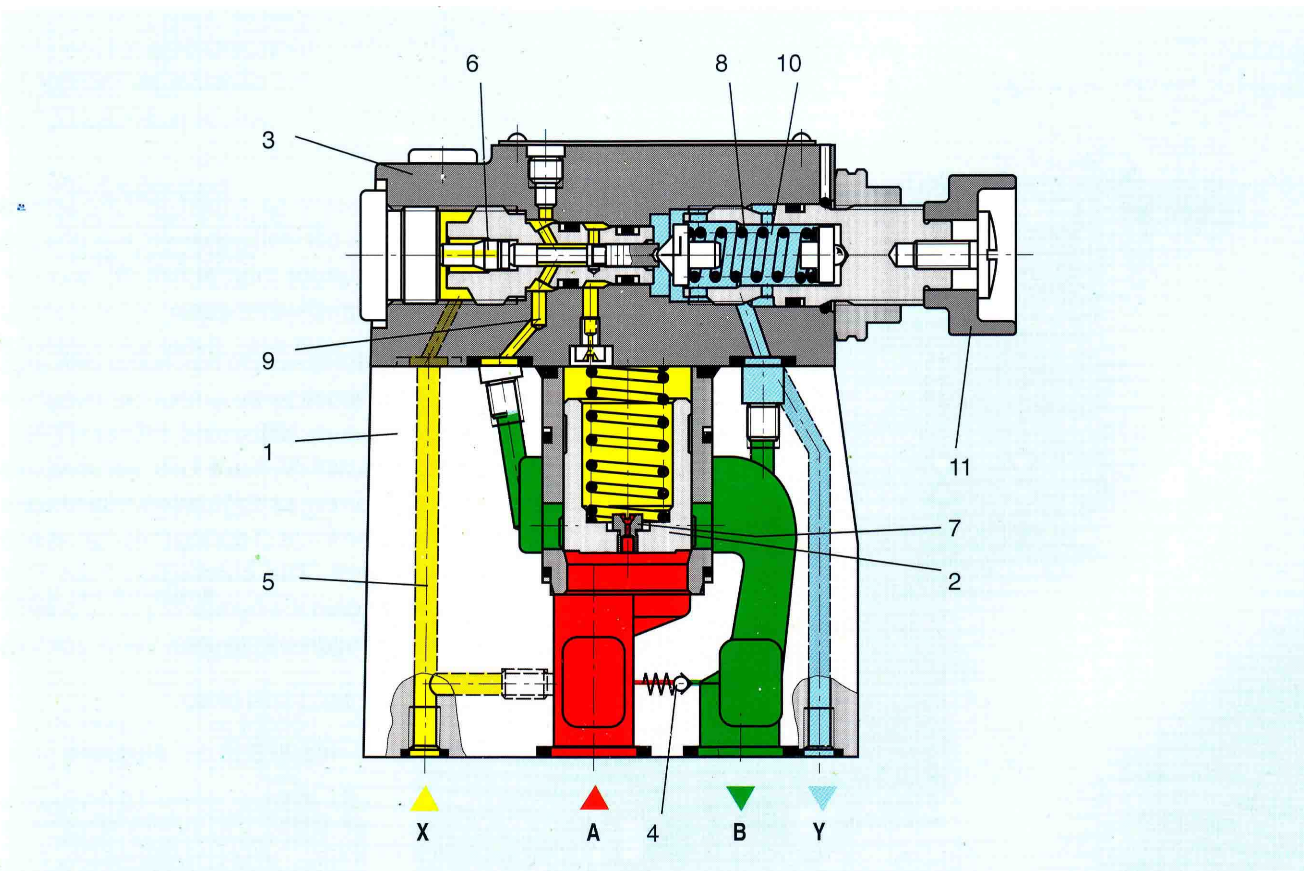


Fig. 29: *Pilot operated pressure sequence valve; external pilot oil feed, external pilot oil return*

3.2 Accumulator charging valves

Accumulator charging valves, also known as pressure unloading valves, are mainly used in hydraulic systems with accumulators. Their main task is to switch pump flow to pressure free flow once the accumulator has been charged.

Accumulator charging valves are also used in hydraulic systems with high and low pressure pumps (dual circuit systems). In these cases, the low pressure pump is switched to pressure free flow as soon as the set high pressure has been reached.

Accumulator charging valves (*fig. 31*) basically comprise main valve (1) with main valve insert (3), pilot valve (2) with pressure setting element (16) and check valve (4). The check valve is built into the main valve in valves of size 10, but is built into a separate plate arranged below the main valve for valve sizes 25 and 32.

3.2.1 Pilot operated accumulator charging valves, type DA

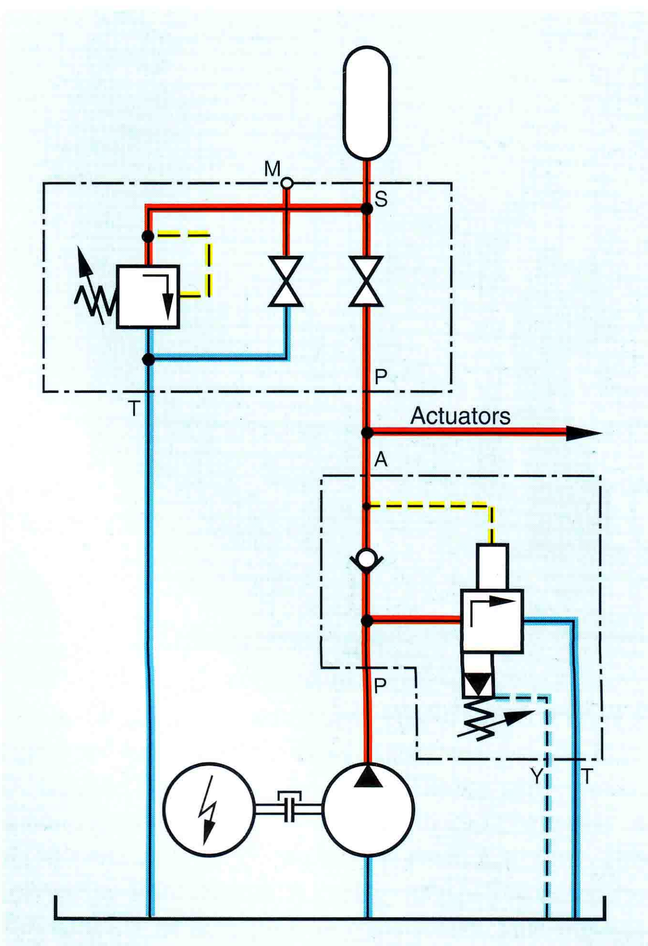


Fig. 30: *Hydraulic system with accumulator and pressure unloading valve*

3.2.1.1 Change of pump flow from P to A into P to T

The hydraulic pump delivers fluid to the system via check valve (4). The pressure present in channel A acts on pilot spool (6) via control line (5). At the same time pressure in channel P acts on the spring loaded side of main spool (3) and ball (9) in pilot valve (2) via orifices (7) and (8). As soon as the shut-off pressure for the hydraulic system set at pilot valve (2) is reached, ball (9) opens against spring (10). Fluid now flows via orifices (7) and (8) into spring chamber (11). From here, fluid is fed internally or externally via control line (12) and channel T into the tank.

Dependent on orifices (7) and (8) a pressure drop exists across main spool (3). Due to this, main spool (3) is lifted from its seat and the connection from P to T is opened. Check valve (4) now closes the connection from A to P. Ball (9) is now held open by the pressure in channel P.

3.2.1.2 Change of pump flow from P to T into P to A

The end surface area of pilot spool (6) is 10 % (may even be 17 %) larger than the effective surface at ball (9). Hence the force at pilot spool (6) is 10 % (17 %) larger than the effective force at ball (9).

Pilot spool (6) is pressure balanced until the set pressure is reached. If the pilot control is opened, then the pressure at pilot spool (6) is larger than at ball (9) and the spool position of pilot spool (6) changes.

If the pressure at pilot spool (6) has fallen with respect to the set shut-off pressure by an amount corresponding to the switching pressure difference (10 or 17 %), then spring (10) pushes ball (9) back onto its seat. Hence a pressure builds up on the spring loaded side of main valve (3). Together with the force of spring (14) main spool (3) is pushed onto its seat. The connection from P to T is interrupted. Once again the hydraulic pump delivers fluid from P to A into the hydraulic system via check valve (4).

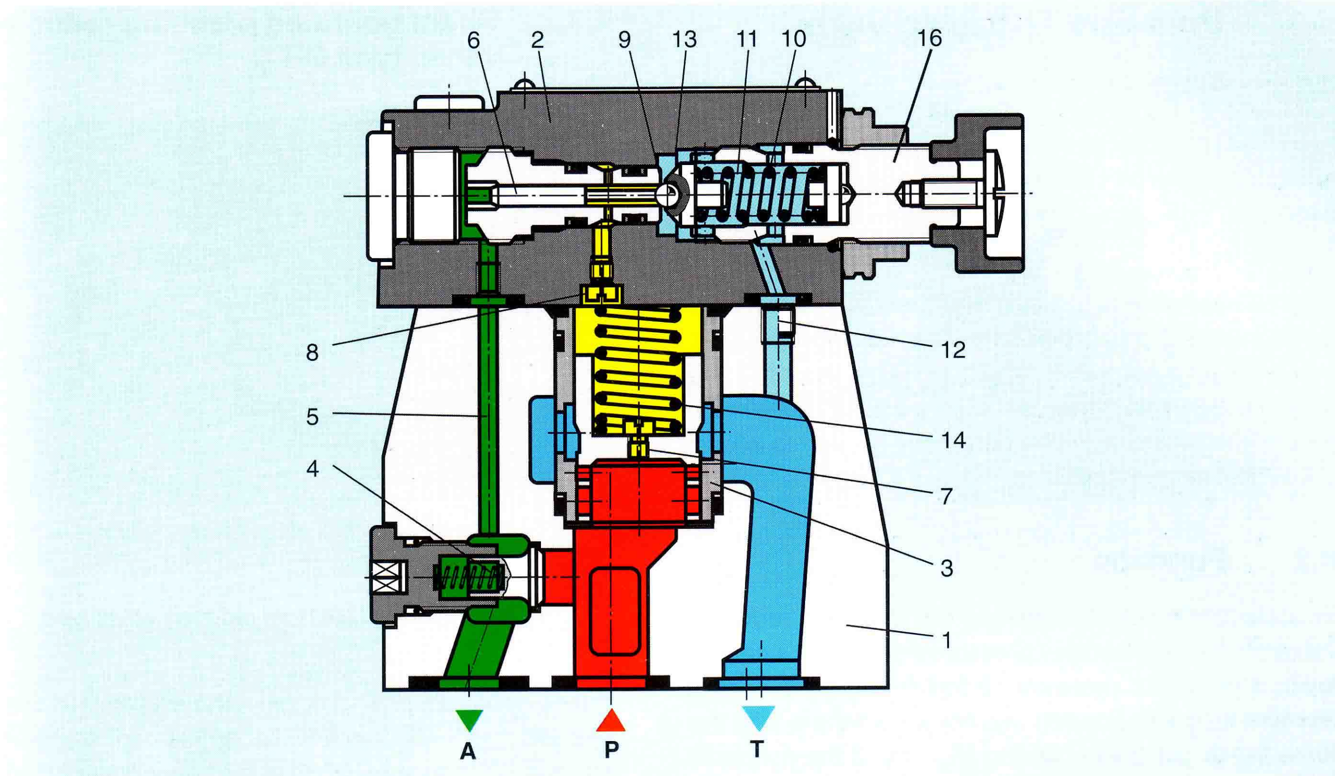


Fig. 31: *Pilot operated pressure shut-off valve, type DA*

3.2.2 Pilot operated accumulator charging valve, type DAW

The function of this valve is the same as the function for valve, type DA.

However, by operating directional valve (15) pressure below the shut-off pressure set at pilot valve (2) may be switched at random from P to T and P to A.

Important parameters

Sizes	10, 20 and 30
Flow	up to 250 L/min
Operating pressure	up to 315 bar

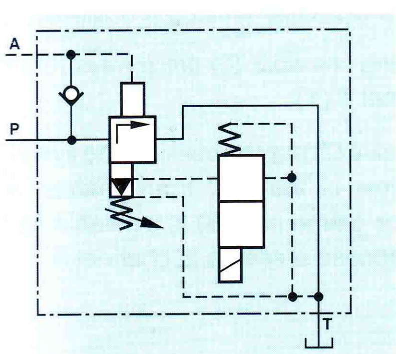


Fig. 32: *Pilot operated shut-off valve, type DAW*

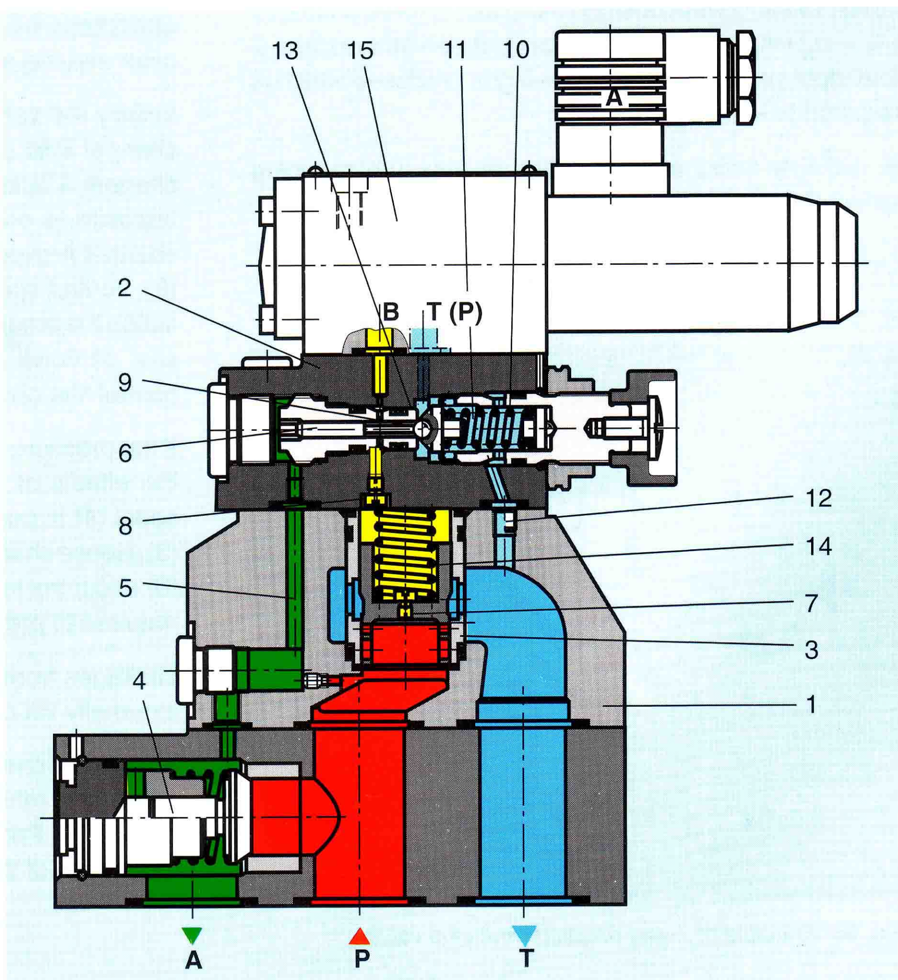


Fig. 33: *Pilot operated pressure shut-off valve, type DAW*

4 Pressure reducing valve

4.1 Task

In contrast to pressure relief valves which affect the input pressure (pump pressure), pressure reducing valves are used to influence the output pressure (actuator pressure).

The reduction of input pressure (primary pressure) or the maintenance of output pressure (secondary pressure) is achieved at a set value, which is below the charging pressure available in the main circuit. It is thus possible to reduce the pressure in one part of the system to a level lower than system pressure.

4.2 Function

In accordance with the task of the pressure reducing valve not to let the output pressure rise above a certain level, this output pressure is fed to the end control element (spool or poppet) and compared there with the force set at the control spring (*fig. 34*). If the hydraulic force $p_A \cdot A_K$ exceeds the set spring force, the spool moves upwards in the closing direction of the control lands. In the control position the spool is force balanced ($F_F = p_A \cdot A_K$). At the control land, dependent on flow Q and input pressure p_E, an opening is produced which is required to keep p_A constant.

In principle there are two types of pressure reducing valve: direct and pilot operated.

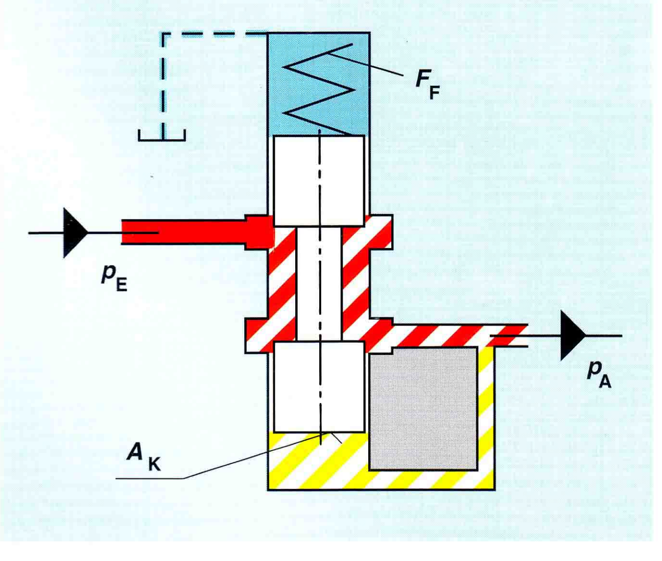


Fig. 34: *Principle of 2-way pressure reducing valve*

4.3 Direct operated pressure reducing valve, type DR.D

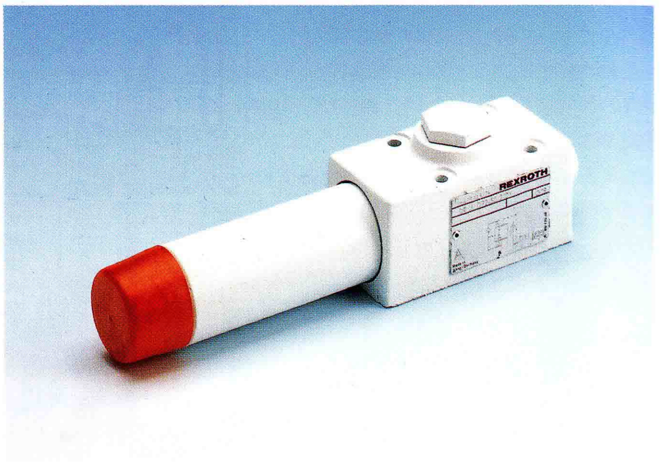


Fig. 35: *Direct operated pressure reducing valve, type DR6DP*

Direct operated pressure reducing valves are mainly designed as 3-way models, i.e. adjustment element (1) ensures the pressure safety of the secondary circuit (*fig. 36*). Whether the adjustment is made by rotary knob as shown or by simple screw with protective cap or lockable rotary knob with scale, is only dependent on the individual case and the requirements of the user.

Initially the valves are open, i.e. there is free flow from channel P to channel A. At the same time pressure in channel A acts via control line (2) on the spool surface opposite to compression spring (3). If the pressure in channel A exceeds the value set at compression spring (3), control spool (4) moves to the control position and keeps the pressure set in channel A constant. Signal and pilot oil flows are taken internally from channel A via control line (2).

If the pressure in channel A continues to increase due to the effects of external forces on the actuator, control spool (4) is pushed further against compression spring (3). Hence channel A is connected to tank via control land (5) at control spool (4). As much fluid flows to tank as is required to prevent the pressure rising any further.

Leakages from spring chamber (6) are always returned externally via channel T (Y).

An optional check valve (7) may be built into the system to allow free return flow of the fluid from channel A to channel P. Pressure gauge port (8) is available for the monitoring of the reduced pressure in channel A.

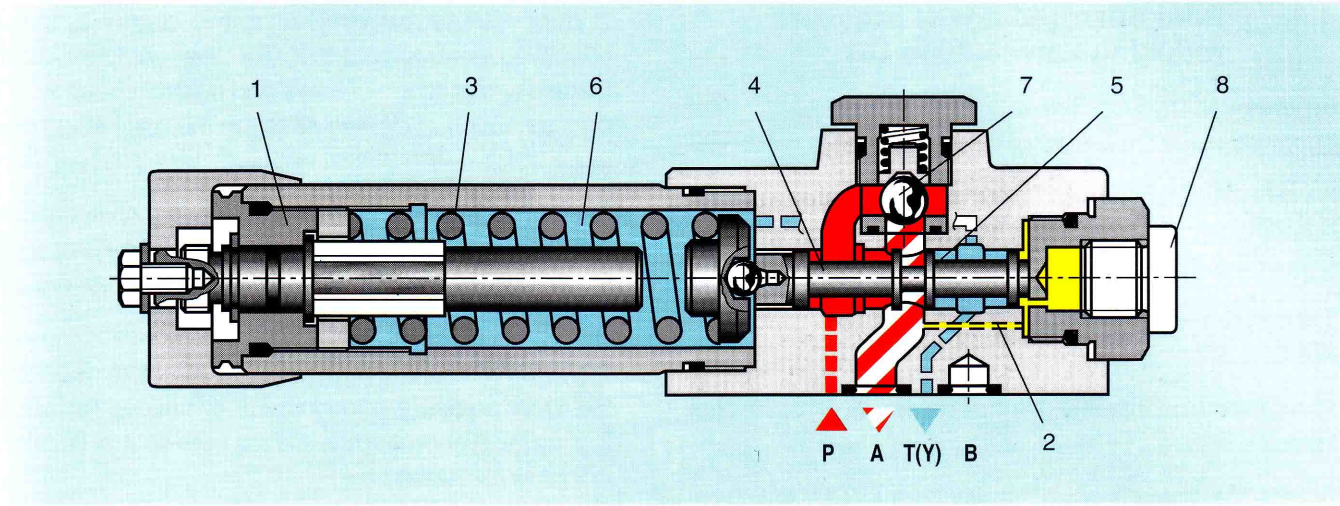


Fig. 36: *Direct operated pressure reducing valve*

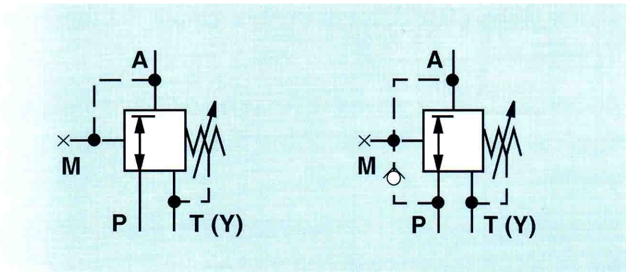


Fig. 37: *Direct operated pressure reducing valves; left without, right with check valve*

Important parameters

Sizes	5, 6 and 10
Max. input pressure	315 bar
Max. output pressure	210 bar (315 bar)
Flow	up to 80 L/min

4.4 Pilot operated 2-way pressure reducing valves, type DR

In order to reduce pressures at larger flows, pilot operated pressure reducing valves are used.

As with the pilot operated pressure relief valve, a direct operated pressure relief valve is connected to the spring side of the control spool (*fig. 39*)

The pilot operated valve is the measuring element of the system.

The desired output pressure is set at spring (1) of the pilot valve.

At rest, the valve is open, i.e. fluid may freely flow from channel B via main spool insert (2) to channel A.

The pressure to be controlled present in channel A acts on the bottom of the main spool. At the same time, pressure acts on the spring loaded side of main spool (4) via orifice (3) and on ball (6) in pilot valve (7) via channel (5). The pressure also acts on ball (6) via orifice (8), control line (9), check valve (10) and orifice (11). Depending on the setting of spring (1) a pressure builds up in front of ball (6), in channel (5) and in spring chamber (12). This pressure keeps the control spool (13) in its open position. If p_A reaches the pressure set at spring (1), the pilot valve reacts (ball (6) lifts off its seat).

Hence pilot oil flows from the valve output via orifices (8) and (5) to the pilot valve. The pressure drop existing at the orifices acts on the control spool in the main stage and moves the main spool against the spring. The desired reduced pressure is attained, once a balance is present between the pressure in channel A and the pressure set at spring (1).

Pilot oil is returned from spring chamber (14) always externally via control line (15) to tank.

In the pressure reducing valve, two control circuits are effective: control circuit 1 for the compensation of instability due to small flows and control circuit 2 for the compensation of closing effect on the main spool due to large flows.

Control circuit 1 is effective from channel A via orifice (8), control line (9), ball (10) and orifice (11) to the pilot control. Control circuit 2 is effective from channel A via orifice (3) and control line (5) to the pilot control.

Whether control circuit (1) or (2) is effective depends on the local pressure relationships at orifices (3) and (8). During most operating conditions both control circuits are active at the same time.

At very high flow velocities, a lower pressure drop exists at orifice (8) than at orifice (3). In order to avoid the direction of flow changing from orifice (3) to orifice (8), check valve (10) isolates control circuit 1 from control circuit 2.

An optional check valve (16) may be built into the system to allow free return flow of the fluid from channel A to channel B.

Pressure gauge port (17) is available for the monitoring of the reduced pressure in channel A.

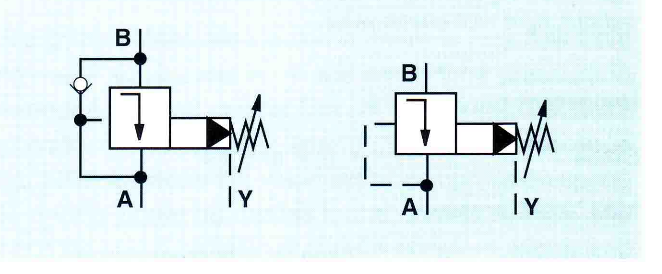


Fig. 38: *Pilot operated pressure reducing valve; left with, right without check valve*

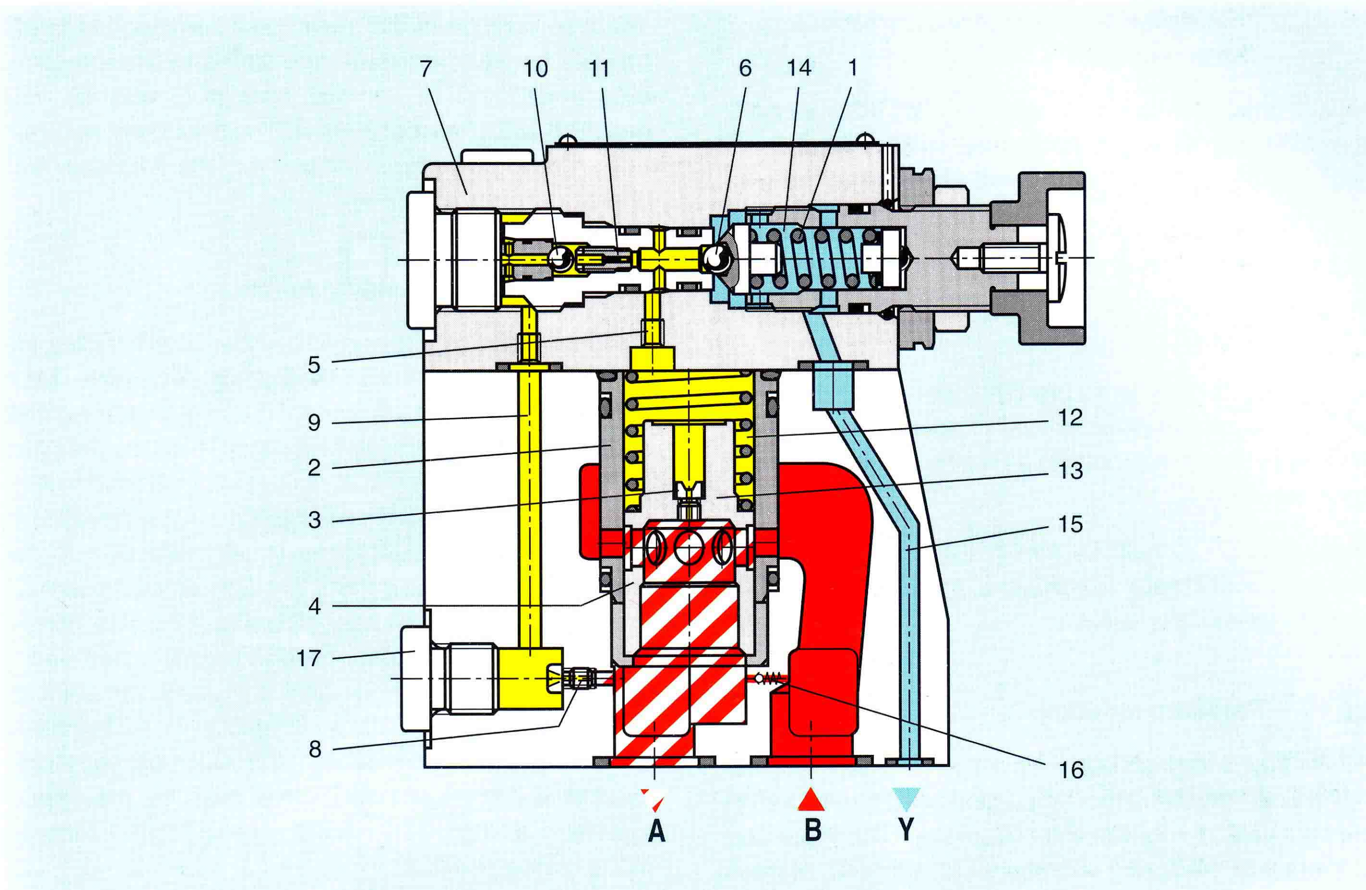


Fig. 39: *Pilot operated pressure reducing valve*

Important parameters

Sizes	10, 25 and 32
Operating pressure	up to 315 (350) bar
Flow	up to 400 L/min

4.5 Pilot operated 3-way pressure reducing valve, type 3DR

3-way pressure reducing valves (fig. 40) basically comprise main valve (1) with control spool (2) and direct operated pressure reducing valve (3) used as the pilot valve.

Initially control spool (2) is held at rest against spring (6) via spring (5) and spring pad (4). Connections P to A and A to T are closed.

Spring (5) is slightly more pre-tensioned than spring (6), so that the rest position of main spool (2) is precisely defined by the apring pad (4) as a stop in the housing of main valve (1).

Pilot spool (7) is held by spring (8) in an open initial position. 3 pressure functions (diagram 10) may be carried out with this valve.

4.5.1 Pressure reducing function

Pilot oil flow is fed from port P via control line (9) to the pilot valve. This flow then proceeds via the open connection in the pilot valve to control line (10) of the main valve and further on to the spring chambers (11) and (12) of main spool (2) as well as to port A via control line (13).

If the pilot flow at port P is sufficient, a pressure builds up at port A as a result of the actuator resistance. This pressure acts via control line (13), main spool orifices (14 and 15), lines (10 and 16) on pilot spool (7) and pushes this spool against spring (8). At the variable opening between bore (17) and control land (18) of the pilot spool (7) the input pressure (port P) is reduced to the pilot pressure set at spring (8). (Pilot oil flow proceeds from the pilot valve output into control line (10), spring chamber (11) and from here via main spool orifices (14 and 15) onto spring chamber (12) and further via control line (13) onto port A). A pressure drop is present at orifices (14 and 15). When the required actuator flow in A becomes larger than the available pilot oil flow, the pressure drop at orifices (14 and 15) increases and pushes the main spool to the left against spring (5). Connection P to A is opened and the actuator is supplied with the required flow.

The new position of the main spool corresponds to the balance between pressure and spring forces (pressure drop at orifices (14 and 15), springs (5 and 6)). The pressure in A is held constant with respect to the value set at pilot spring (8) and whilst obeying the pressure- flow characteristic of the valve.

4.5.2 Pressure holding function

If no flow is required at port A (cylinder or motor idle), the pressure drop at orifices (14 and 15) decreases. Main spool (2) is pushed via spring (5) to the right against spring (6) and so to the closing position. As the pressure in P is greater than that in A, leakage flows from P to A as well as via line (13), orifices (14, 15) and via line (10) to pilot valve (3). The increase in pressure due to the leakage flow acts via control line (16) on pilot spool (7) and pushes this further against spring (8) until its control land (19) opens the connection to pressure free port Y (tank). The pressure in A is still kept constant in accordance with the value set at spring (8). As a result of the low leakage flow the pressure drop at main spool orifices (14 and 15) is not sufficient to push the main spool against spring (6). Main spool (2) remains in the closed position.

4.5.3 Pressure limiting function

If the pressure increases in A due to the influence of external forces on the set value, a larger amount of pilot oil flows via line (13), orifices (14 and 15), line (10) and control land (19) of pilot spool (7) and then via Y to tank. The direction of pilot oil flow is now in the opposite direction to that occurring in the pressure reduction function. If the pressure drop at orifices (14 and 15) exceeds the value which corresponds to the force of spring (6), main spool (2) is pushed to the right against spring (6) and the connection of A to T is opened. The new position of the main spool corresponds to the balance of pressure and spring forces (pressure drop at orifices (14 and 15), spring (6)). The pressure in A is held constant with respect to the value set at pilot spring (8) and whilst obeying the pressure- flow characteristic of the valve.

Pilot flow is always externally returned, as pressure free as possible, via line (20) to port Y.

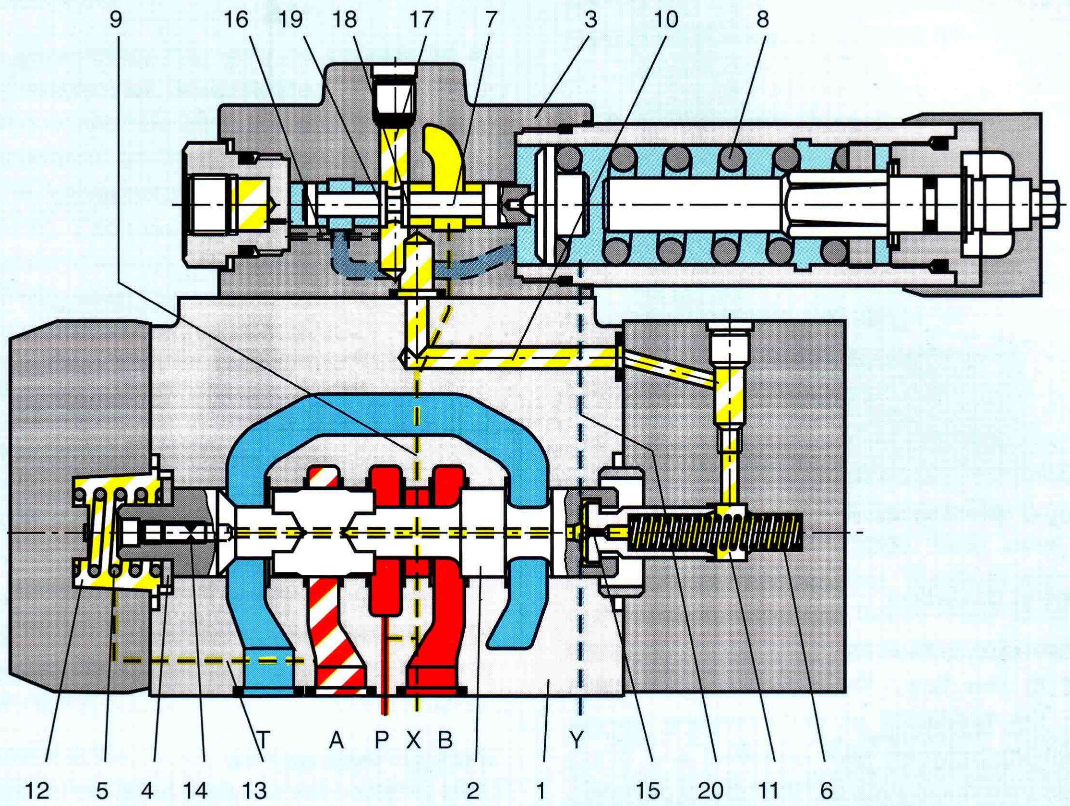


Fig. 40: *Pilot operated 3-way pressure reducing valve*

Important parameters

Sizes	10, 25 and 32
Operating pressure	up to 210 (350 bar)
Flow	up to 400 L/min

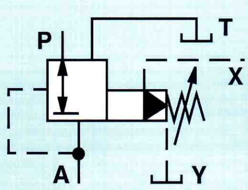


Fig. 41: *3-way pressure reducing valve; left external, right internal pilot oil feed*

4.6 Technical Data

4.6.1 Stationary operating curves

The same operating curves apply to the pressure reducing valve as to a pressure relief valve, though there are some exceptions. The flow described is the flow to the actuator and the setting pressure is the output pressure p_A.

The operating curve field (diagram 10) shows the change in output pressure p_A with respect to the flow at a constant input pressure p_E. In pressure reducing functions, the dotted line represents the lowest actuator resistance dependent on flow. This operating curve is used when considering the application limit for the valve in the hydraulic system.

When considering the pressure relief function (only 3-way pressure reducing function) the characteristic of the return resistance (tank line) is also shown as a dotted line. This represents the limit of application for a controlled pressure limiting function and is dependent on the hydraulic system used.

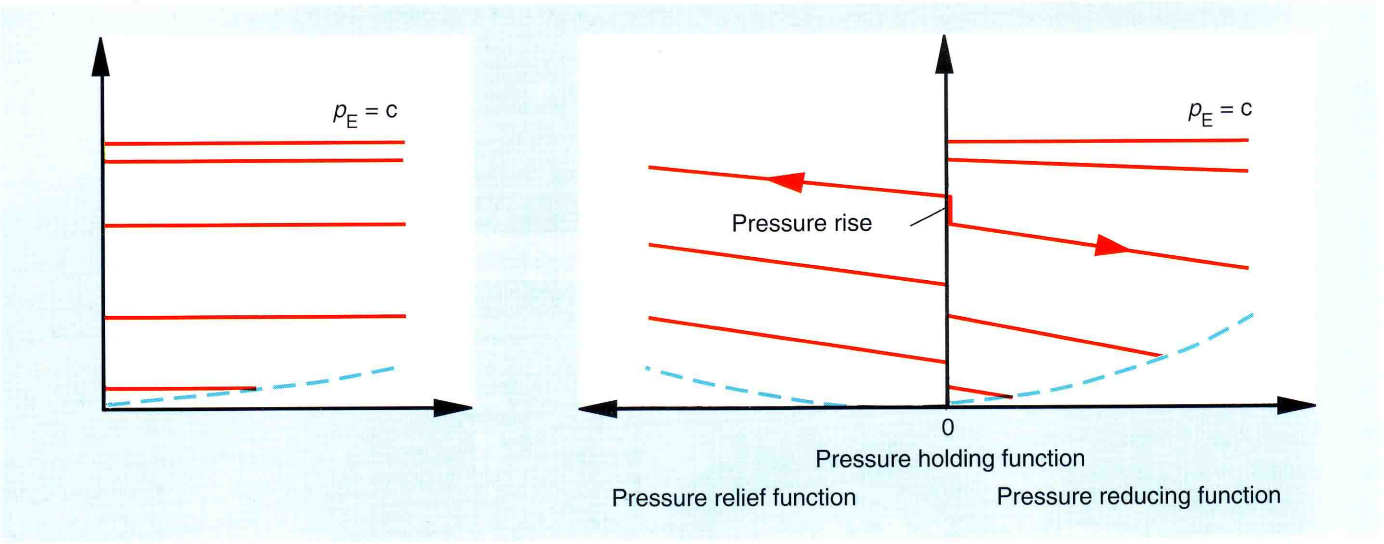


Diagram 10: *p_A-Q operating curves for pilot operated pressure reducing valves, left: 2-way model, right: 3-way model*

4.6.1.1 Control deviation

The control deviation is the change in the set pressure with respect to the flow. There is a considerable difference in the gradients of the operating curves (control deviation) between pilot operated and direct operated pressure reducing valves. The control deviation in direct operated valves is larger than in pilot operated valves, as the change in spring force with respect to the stroke of the main spool is larger. On the operating curve field of the 3-way model (*diagram 10*), there is a clear pressure increase set during the pressure holding function in the cross-over from pressure reducing function to pressure relief function. This pressure increase is produced as a result of the positive overlap of the control lands of pilot spool (7) and main spool (2). During the cross-over, pilot spool (7) carries out an "idle stroke", during which both pilot ports are closed. Accordingly the force of the pre-tensioning spring is increased and hence the pressure at valve output A is increased.

This increase in pressure may be avoided by using a negative overlap in the pilot spool. However, an increase in the leakage flow must then be reckoned with.

4.6.1.2 Pilot oil flow

In 3-way pressure reducing valves, the pilot oil always flows to the actuator during the pressure reducing function. In the pressure holding function the leakage drains away via port Y. In pilot operated 2-way pressure reducing valves the complete pilot oil always drains away via port Y. This is dependent on the actuator flow, the pressure difference between valve input and output and the level of the set pressure.

The pilot oil flow curve as a parameter for the pressure reducing valve, size 10 (2-way pressure reducing valve) is shown in diagram 11 with respect to the pressure difference ($\Delta p = p_E - p_A$).

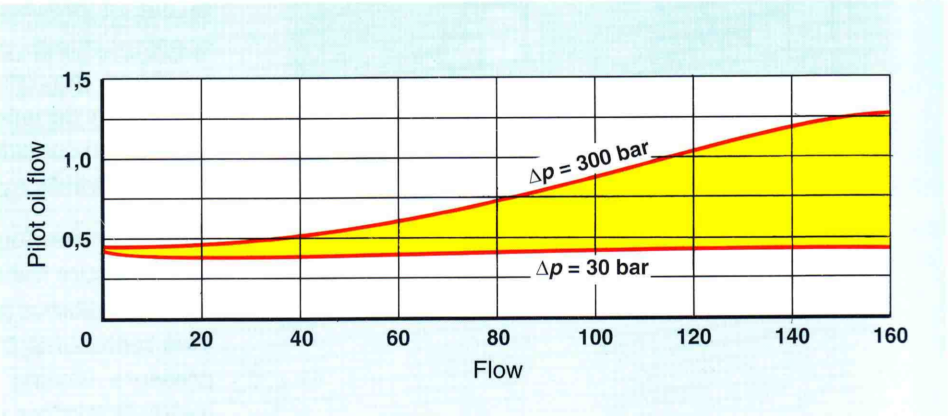


Diagram 11: *Q_{St}-Q operating curve at Δp ($p_E = p_A$) of 30 and 300 bar*

4.6.1.3 Lowest pressure setting and maximum actuator flow

Both of these parameters may only be considered in conjunction with each other. Basically the valve is set at a flow of zero. The dotted operating curve of the actuator resistance dependent on flow represents the lowest pressure at the valve output (*diagram 10*, pressure reducing function). Each point on this operating curve represents a specific setting value for the valve. At the same time this is the lowest pressure which may be set for the particular application being considered.

If a lower value is set, the desired flow may no longer be obtained. In theory, in direct operated pressure reducing valves the lowest pressure of $p_A = 0$ may be set. However, no actuator flow is available then, as the origin of the operating curve for the actuator resistance is also at zero (*diagram 10*). In pilot operated pressure reducing valves, the lowest pressure set is determined by the force of the main spool spring in addition to the backpressure of the pilot flow acting on the main spool. This pressure is generally in the region of 3 to 7 bar when the flow is zero.

An exception to this is the 3-way pressure reducing valve, as here the pilot oil flow is fed from a direct operated pilot operated pressure reducing valve directly to the actuator.

A further application limit in pressure reducing valves is found in the minimum pressure difference required between input and output. If the selected value is too low, the control spool reaches its max. stroke before the desired actuator flow is available. A further pressure reduction is then not possible in such cases.

For these reasons, the operating curves supplied by the manufacturer for the minimum pressure difference dependent on flow must be taken into account (*diagram 12*).

In summary, the lowest set pressure is attained, when the appropriate control operating curve cuts the actuator resistance curve at the desired flow.

4.6.2 Dynamic characteristics

In practical applications, good dynamic characteristics are demanded of pressure reducing valves. The pressure peaks which occur when the actuator (cylinder of motor) is suddenly idle should be kept as low as possible. The pressure drops which occur when the machine is restarted after an idle period should also be kept low.

With the exception of pilot-operated 3-way pressure reducing valve, the main spool in pressure reducing valves is open initially. If the actuator flow is suddenly decreased, the control spool must close against the spring as quickly as possible. The delay which occurs due to the frictional and flow forces leads to an undesirable increase in pressure (pressure peak) in the actuator circuit.

On the other hand, if the flow suddenly increases the main spool must open as quickly as possible, in order to avoid the actuator pressure sinking by a large amount over a short time. The size of pressure peaks and pressure drops are dependent on the dynamic characteristics of the valve (type, pilot circuit), actuator (cylinder or motor), parameters (p_E, p_A, Q), as well as to a large extent on the actuator flow (e.g. cylinder and pipe volume).

4.6.2 Notes on applications

A critical application is that of pressure holding, if no flow is required on the actuator side. The control spools working in the range of the overlap are prone to being contaminated (dirt particles entering the control clearance) due to the continuous and considerable flow of pilot oil. This leads to pressure oscillations on the actuator side.

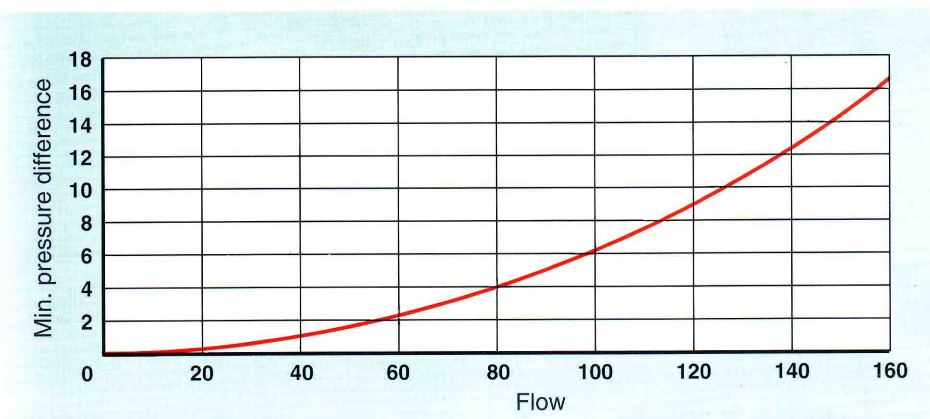


Diagram 12: Δp_{min}*-Q operating curve*

In order to avoid this, it is sensible to add a by-pass line for a small flows (0.5 to 1.5 L/mm). In addition, it is especially important to filter the fluid really well.