Controlling low and high flows with screw-in cartridge valves

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This article describes the function and application of on/off and proportional directional valves.

In industrial applications, Cetop directional valves from ISO 03 to ISO 10 are common. They can be used in open and closed loop circuits to meter flows. Some valves have an internal closed loop position control of the piston; they are very precise and can be used at high cycle rates in industrial applications.

In mobile applications, sandwich or custom manifolds see high pressures but typically lower cycle rates than in industrial applications. Often, pistons are guided by the cast iron manifold itself. That design is cost-effective but only in large quantities.

Screw-in cartridges are less common in controlling high flows. Valves with 3 positions, such as 3 position 4 way valves, lend themselves to symmetrical designs that allow actuation from both ends to leave a spring-centred position. Screw-in cartridges have a disadvantage in that the piston is easily accessible only from one side. The piston must be pushed or pulled. The advantage of screw-in cartridges is that the volume of manifolds is utilised. The reason manifolds for Cetop valves are big is often to provide enough surface area to mount the directional valves. The advantage of screw-in cartridges over cast iron mobile manifolds is that manifolds can be easily manufactured using form tools to generate the cavities for cartridges. That allows the production of special manifolds at reasonable prices in low to medium quantities.

Design and function of hydraulically operated directional valves

The lower part of *Figure 1* shows the cross section of older 4/3 way cartridge valves. They are hydraulically operated by pilot pressures on ports 5 and 6. The porting simplifies the design of the manifold if all pilot valves are requested to be located on one side of the manifold.

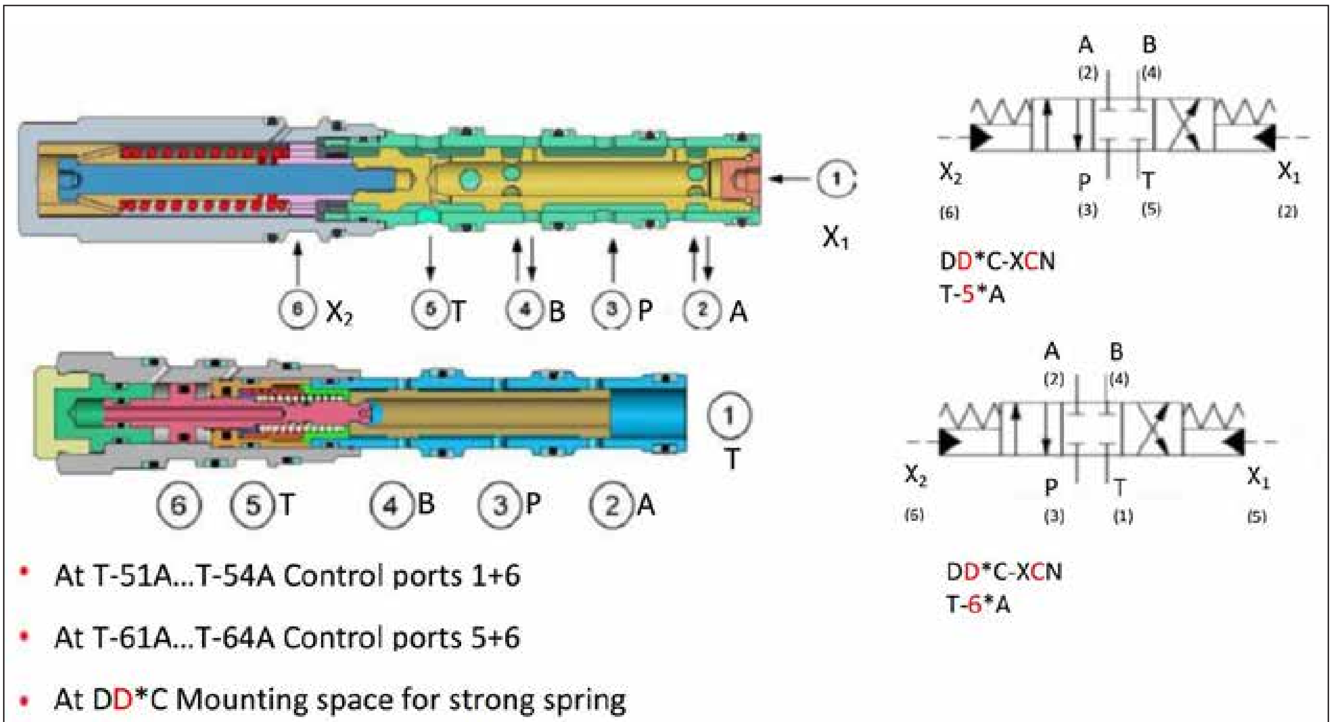

Figure 1. *Cross section of two 4/3 way valves. Below: pilot pressure on ports 5 and 6. Top: pilot pressure on ports 1 and 6.*

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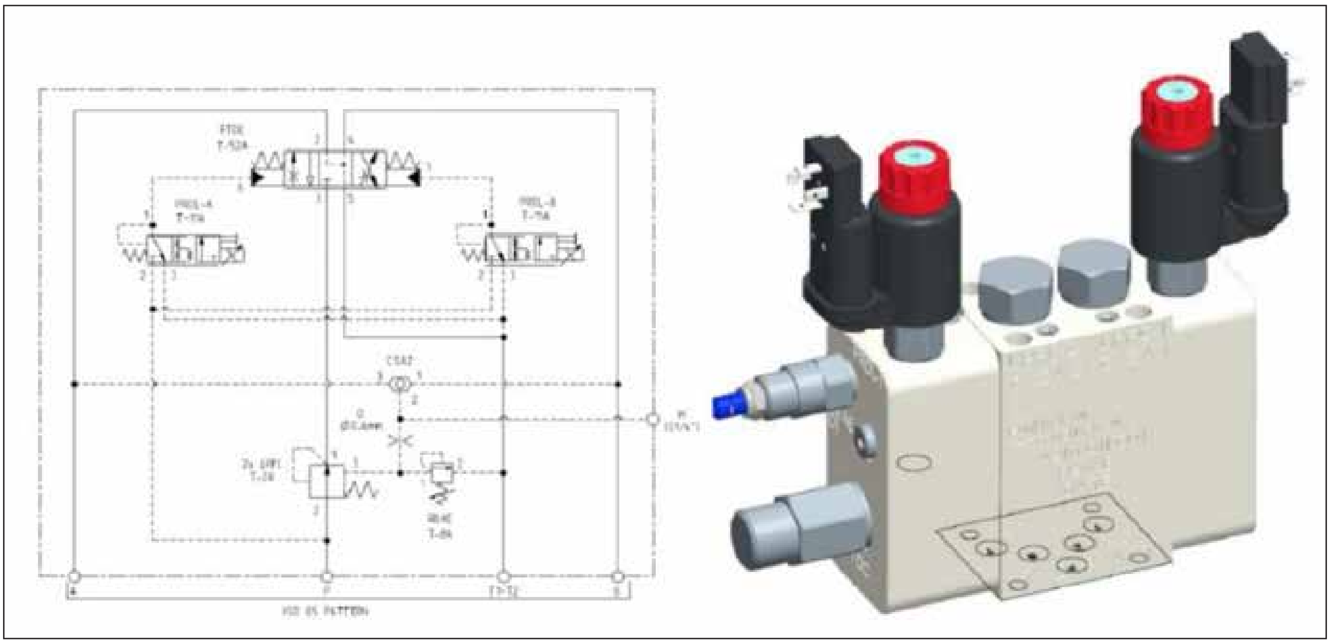

Figure 2. *Proportional 3/4 way valve as pressure compensated flow control valve (size Cetop ISO 05 – NG10) with Cetop interface*

But the design of the cartridge valve itself is complicated since the pilot piston needs to push and pull on the main piston. That requires a differential area pilot piston with seals on the effective area. The upper part of Figure 1 shows a less expensive design. Pilot pressures are effective on the opposing front end areas of the piston. A disadvantage is using the large port 1 for small pilot flows only. It no longer allows opening a large flow path from port 2 to 1 to unload port 2 with a low pressure drop. The two designs have about the same pressure drop between the supply P and ports A and B. For the return flow to tank, the design with pilot pressure on ports 5 and 6 has an advantage. The main advantage of the upper design is a larger room for the spring: with a stronger, stiffer spring, the valve can be built as a proportional valve.

Figure 2 shows how proportional flow control valves can even be designed into a cover plate with ISO 05 interface. That design is difficult due to the restrictions of the interface. But the cavity of the new cartridges offers wide ring areas for all ports so that drilling into the ring areas is possible from the Cetop interface. *Figure 3* shows the new cavities for flow control valves. So far, 3 frame sizes T-52A, T-53A and T-54A are available. The largest frame size allows nominal flows up to 400 l/min.

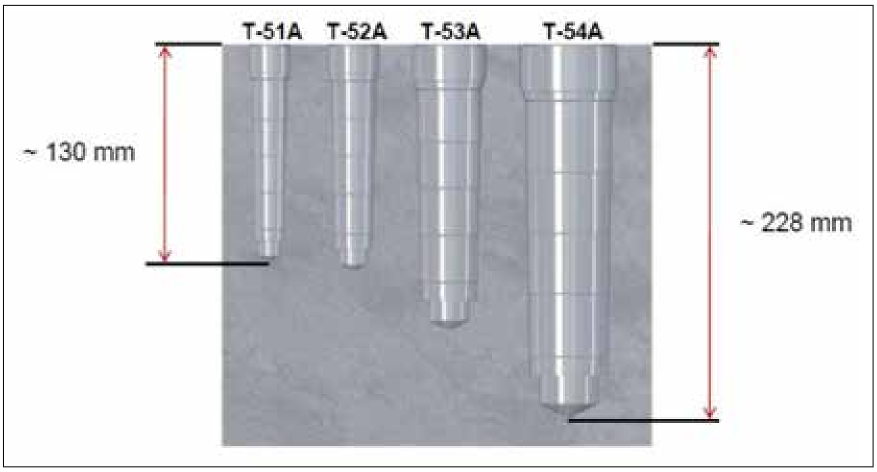

Figure 3. *Cavities for new proportional, hydraulically operated flow control valves with 6 ports; available cavities for flow control valves T-51A, T-52A, T-53A, T-54A*

The circuit in Figure 2 shows a 4/3 way valve with a restrictive 2 way pressure compensator upstream. The additional valve keeps the pressure drop between the supply and the highest of the A and B pressures constant. The load sensing signal is sent through a shuttle valve and can also be used to control a variable displacement pump with LS port.

Bidirectional pressure compensator, normally closed pressure compensator to avoid overshoot in flow control

A common problem in controlling the velocity of cylinders and motors is an overshoot: when the directional valve opens, the pressure compensator is also fully open. Only after the pressure drop across the directional valves exceeds about 13.7 bar (200 psi), the compensator starts to throttle the flow. By then, the cylinder has often been moved already by an initial flow of oil resulting in a jerky movement. In applications with electrically controlled valves, one can limit the rate of change in command signals to ramp proportional valves open. That helps to smo-

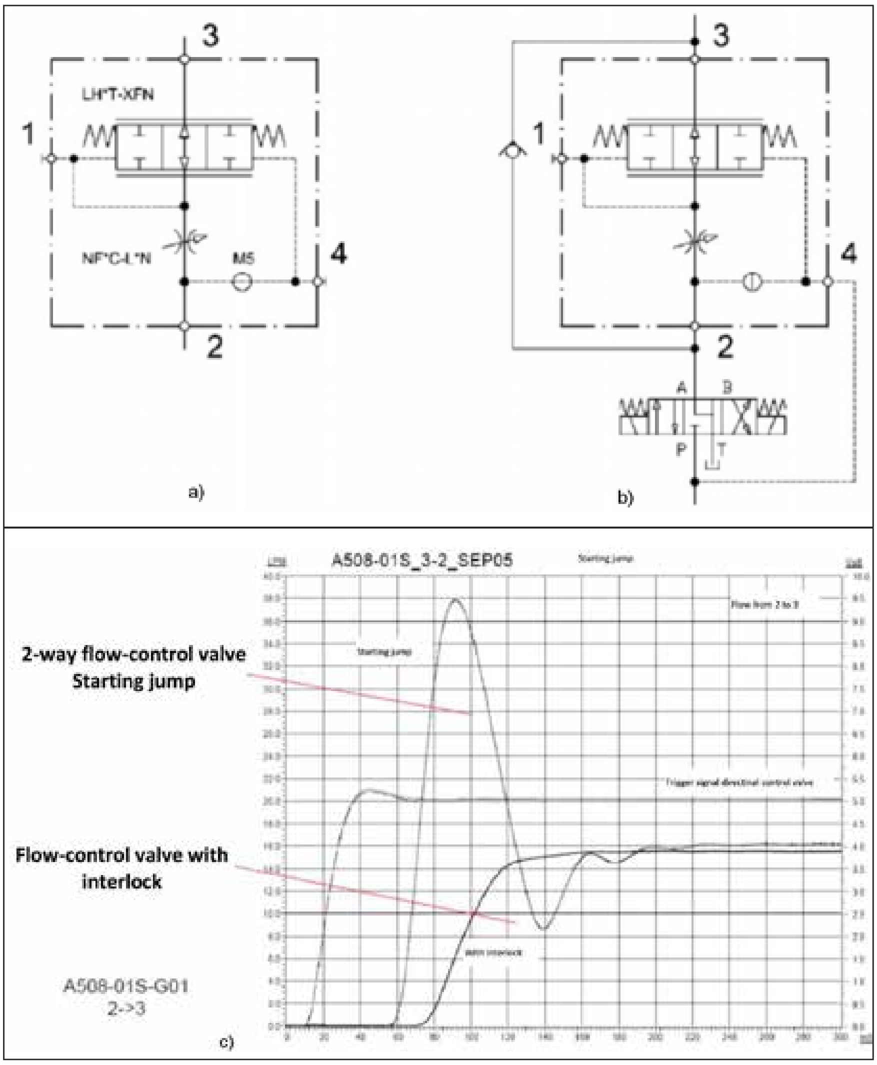

Figure 4. *Bidirectional pressure compensator used as a normally closed pressure compensator*

othly accelerate cylinders or motors. However, it does not prevent jerky movements caused by sudden changes in supply pressure. *Figure 4.a* shows a pressure compensator with 4 ports that works in both directions. It pressure compensates the directional or proportional valve for both directions of flow.

The same pressure compensator can be connected (*Figure 4.b*) so that it is closed by the supply pressure. Only after the directional valve opens (trigger signal in *Figure 4.c*), the compensator starts to open because the pressure on port 1 rises. Figure 4.c shows flows vs. time. The standard pressure compensator shows the well-known overshoot. Under the same conditions, the normally closed pressure compensator shows no overshoot.

3/3 directional valves instead of 3/4 way valves

It can be difficult to match the nominal flow of proportional valves to the actual flow to and from the cylinders. Different pistons are required for different flows on A and B, and for metering in and metering out. In addition, one needs various spool configurations for the spring-centred position. One cannot always use the spool that opens A and B to the tank and blocks the supply. Therefore, it is difficult to cover many applications with a few standard spool configurations of 3/4 way valves. The number of required configurations can be limited, though, if one uses 3/3 valves that throttle the meter-in flow only.

Figure 5 shows the cross section and the hydraulic symbol of a proportional 3/3 way directional valve FT**. The design is based on the on/off cartridge DD" (in Figure 1). The valve offers the load sensing signal on port 5. That pressure represents the pressure on the port that receives the flow from

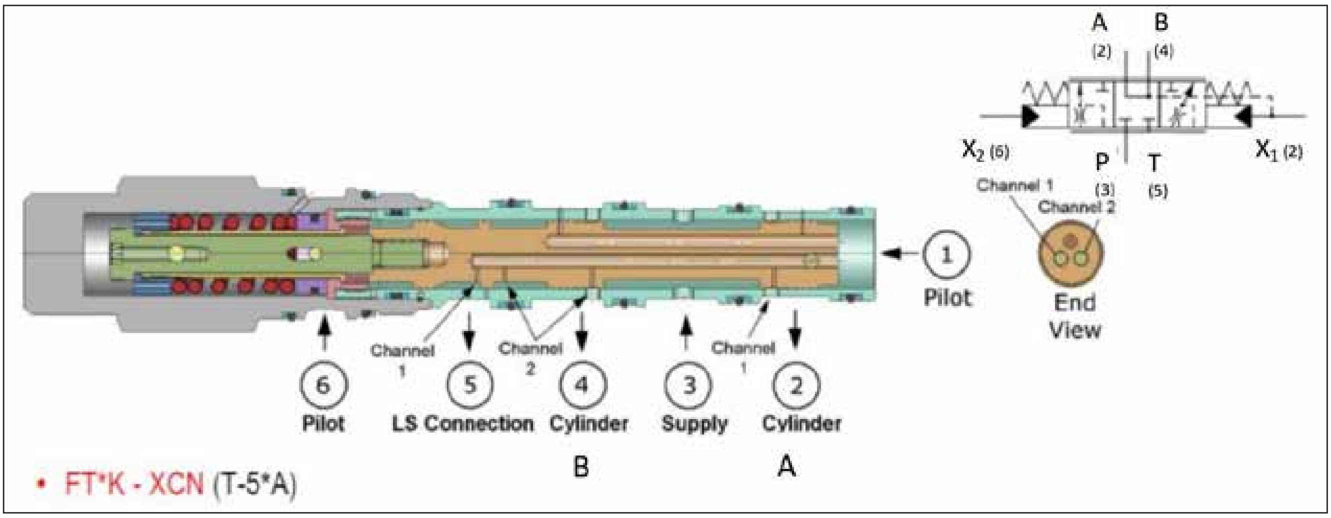

Figure 5. *Cross section and symbol of a proportional 3/3 way directional valve with hydraulic control*

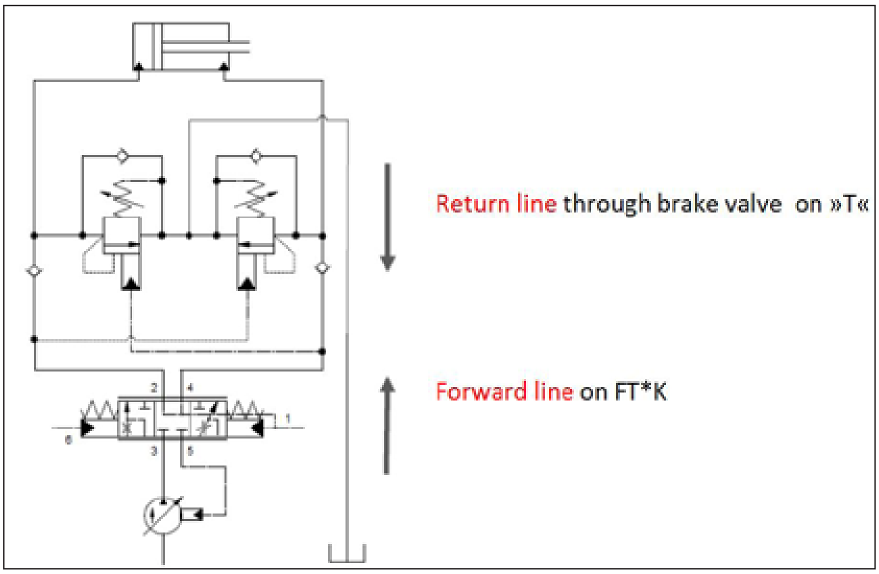

Figure 6. *Circuit with a proportional 3/3 way valve.*

the proportional valve. In its spring-centred position, port 5 is connected with port 1. That usually connects to an external pressure control valve that is controlled by a PLC or joystick. Through that valve, one can vent ports A and B of the proportional valve so that the proportional valve does not need an extra tank port.

Figure 6 shows a useful circuit with a 3/3 way valve. The so called cushion lock circuit uses counterbalance valves in the return line between the cylinder and tank. The pressure on the meter-in side opens the counterbalance valve in the meter-out side. The counterbalance valve allows flow from the cylinder to the tank. The directional valve therefore only controls the meter-in flow. The cushion lock circuit offers 4 main advantages:

1. The pressure on the cylinder is limited by the counterbalance valves. Since the counterbalance valves are always connected to the tank in their return line they are always active as relief valves regardless of the spring-centred spool configuration of the directional valve. They also limit the pressure on the cylinder or motor if the operator quickly reverses the motion. The quick reversal of the directional valve often causes pressure spikes when the attached load has a high inertia. The pressure spike cannot be limited when the counterbalance valve is connected to the directional valve in its return line.

2. The line or hose between the 3/3 way valve and the check valve is flushed with fresh oil at each movement of the cylinder. That flushes the major portion of the lines if the check valve is mounted close to the cylinder.

3. If the tank line is charged, oil from that line can fill both sides of the cylinder or motor and avoid cavitation. If the low pressure side of the cylinder is connected to the tank only through the directional valve, anti-cavitation may not be possible due to the pressure losses across that valve.

4. The counterbalance valves can be sized for the expected flow in the return line. At a low flow to the ring side of the cylinder, the flow leaving the piston side is higher. The counterbalance valve on that side can be sized accordingly, keeping a smaller, less expensive directional valve.

The cushion lock circuit with counterbalance valves in the return line also eliminates the losses in the return line to the directional valve. The circuit is useful when counterbalance valves are required anyway because of overrunning loads. If counterbalance valves are mounted close to the cylinder, the circuit requires an additional tank line.

Figure 7 shows a custom manifold with the cushion lock circuit. In addition, there is a restrictive pressure compensator that keeps the pressure upstream of the 3/3 way proportional valve at about 200 psi above the load pressure. The controlled flow is not affected by varying load pressures, and the proportional valves can be operated with a good

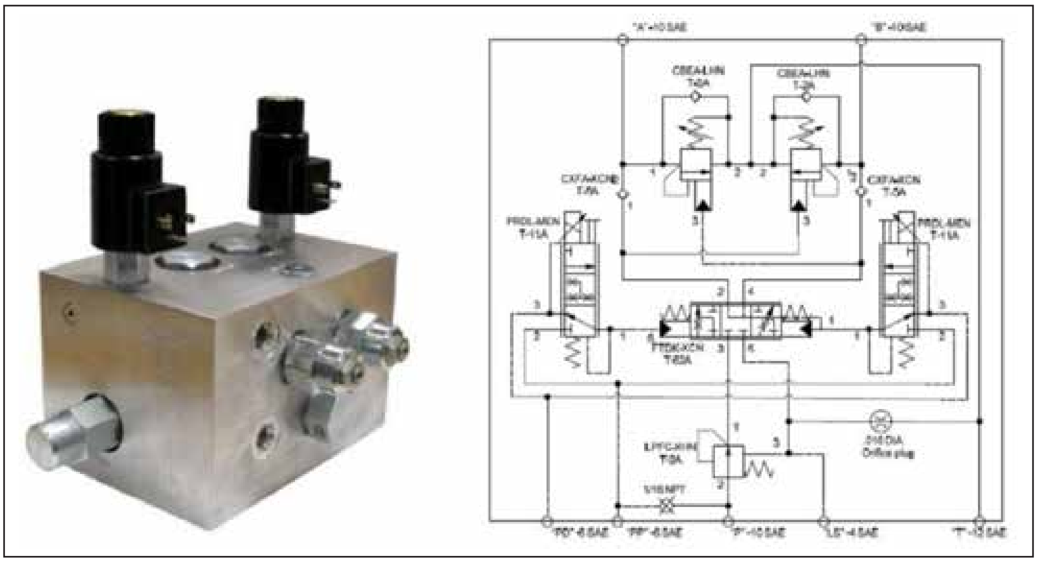

Figure 7. *A custom manifold with the cushion lock circuit and restrictive pressure compensator*

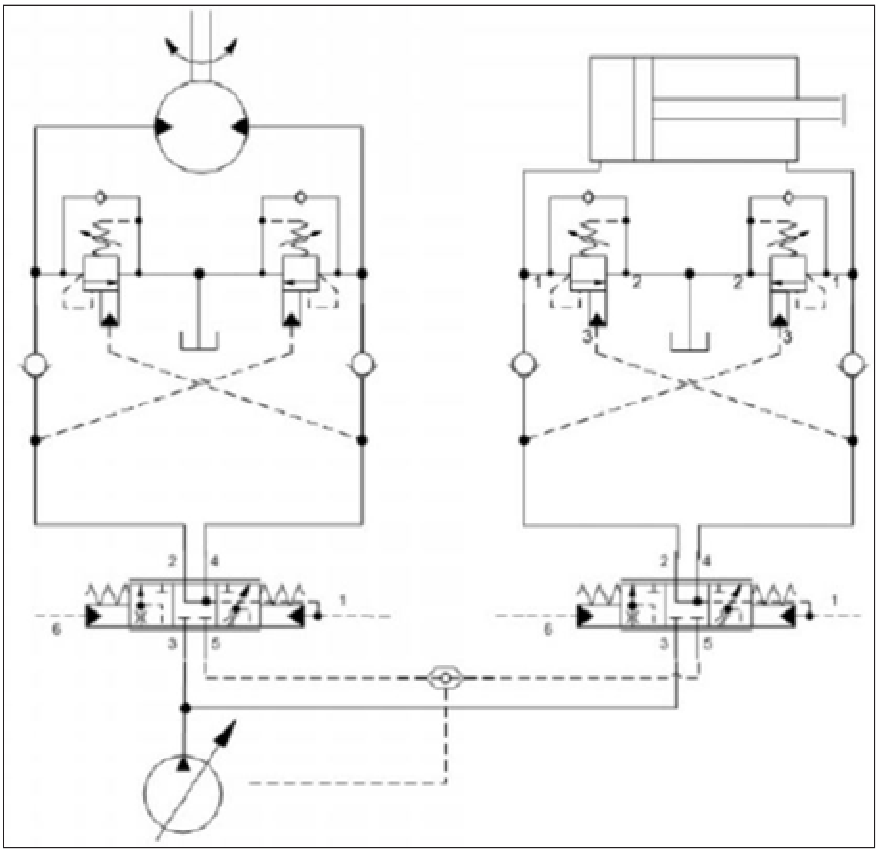

Figure 8. *LS circuit with 2 consumers (motors or cylinders)*

resolution at low flows. Different compensators are available that are interchangeable in the same cavity.

In all circuits in Figures 7 and 8**,** the load pressure is used as a feedback signal to the pump. A variable displacement pump with load sensing controls the supply pressure at a level about 20 bar above the LS signal. That way pressure and flow follow the required hydraulic power. If there is only one hydraulic motor or cylinder, one can eliminate the valves between the pump and consumer, drive the motor in a closed loop, and eliminate the losses across the valves. The proportional valves are necessary when several consumers are driven by one pump. The valves lower the supply pressure to the level required at each consumer (see *Figure 8*).

A good selection of motor and cylinder sizes helps levelling the required pressures. The pressure drop across the proportional valve that sees the lowest load pressure is small if the required pressures to move the motors or cylinders are similar. But the disadvantage of LS circuits is that feeding back the LS signal can cause instabilities. Often the variable displacement pump is not fast enough to follow the LS signal if the load pressure increases quickly. A slow controller allows only low closed loop gains. In the case of LS controls, it means that higher pressure drops across the proportional valves are necessary to compensate for the slow response of the displacement pump. Often, the supply pressure must be raised not 13.8 bar (200 psi) but 20.7 bar (300 psi) above the highest load pressure to reach stability.

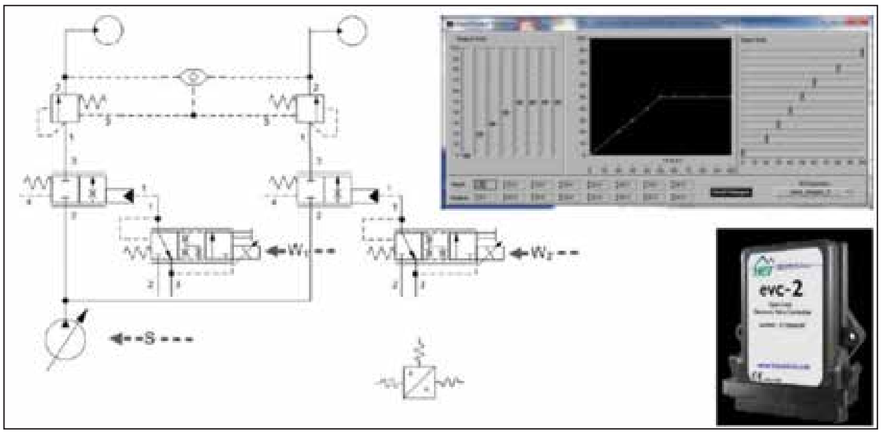

Figure 9. *Energy saving control for several consumers driven by one pump without the feedback of a load sensing signal.*

Figure 9 shows a simplified circuit that does not require the LS feedback. The variable displacement pump is set to a flow that is sufficient to satisfy the sum of all flows to all active consumers (see (2) and (3)). If the flow to all consumers is pressure compensated, one can calculate the required pump flow from the command signals (W1, W2...) to the proportional valves. If the pump flow is a little too high, the supply pressure in this circuit will not increase until a relief valve opens because the circuit divides the flow among both or more consumers. Pressure compensators downstream of the proportional valve sense the highest load pressure and preload the pressure downstream of all proportional valves to the same level. An insufficient supply will result in a lower speed of ALL consumers. At higher pump flows, ALL consumers will move faster. The operator of the machine controls the velocity of each motor/cylinder in an open loop. The ratio of the flow division is a result of the command signals. An electronic controller can calculate the signal to the variable displacement pump or to a flow control valve that bypasses excessive flow of a constant pump into the tank. It is difficult to compensate for the nonlinearities of the proportional valves. Therefore a controller is useful because it allows the allocation of different output signals to different input signals. The allocation can compensate for nonlinearities. The controller interpolates between chosen output signals.

For motors that move in one direction only, one can use a simple 2/2 way proportional valve. *Figure 10* shows such a valve with an adjustable crack pressure. To fully unload the motor to make sure it is not moving at a low speed due to leakages, one can use a 2/2 way valve that unloads the motor (on port 3) to the drain port (port 4) of the pilot (*Figure 11*). The unloading feature can handle only low flows.

Figure 12 shows a circuit that requires only small flows to unload the cylinder since the cylinder is connected to the tank trough the pilot to open check valves when the directional valve is activated. The circuit is similar to the above mentioned cushion lock circuit. The counterbalance valves can be placed in the same cavity with the pilot to open check valves if no overrunning loads i.e. no external forces in the direction of the cylinder movement are to be expected. The proportional valves are controlled by pressure control valves with an embedded controller. The controller can be set with a handheld device that communicates with the amplifier through infrared interfaces (reading and writing). That way dither frequency, max current etc. can be adjusted. But the device can also be used to check voltages and currents while the hydraulic drive is active because no electric wire needs to be contacted, which could cause dangerous movements.

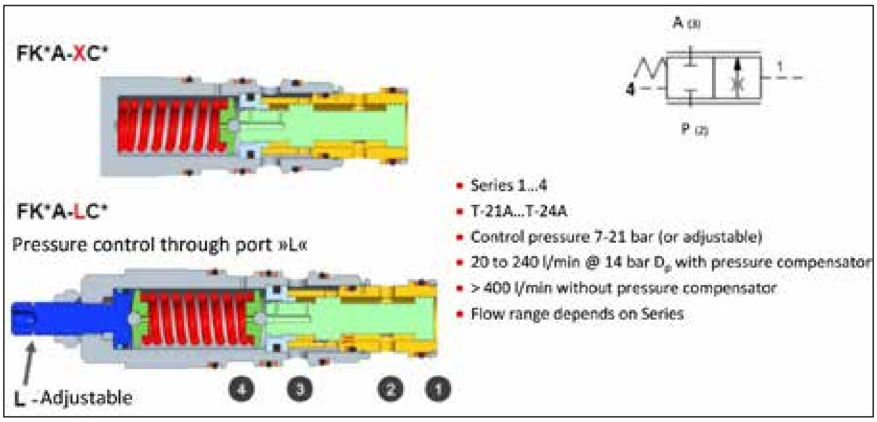

Figure 10. *Adjustable, proportional 2/2 valve*

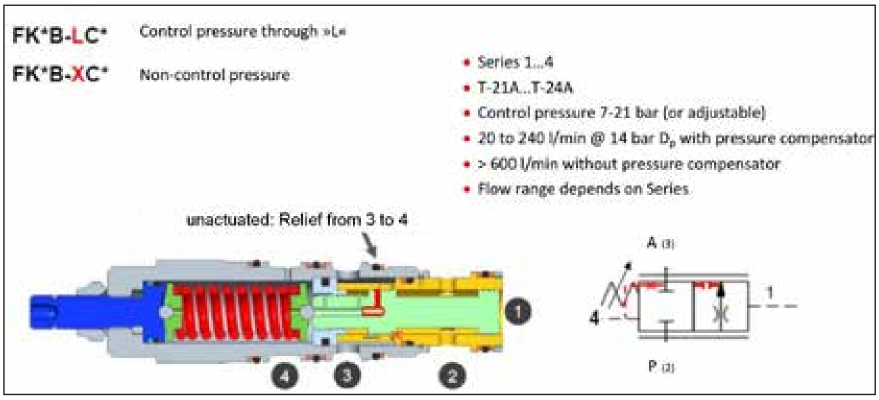

Figure 11. *Adjustable, proportional 2/2 valve with a vent*

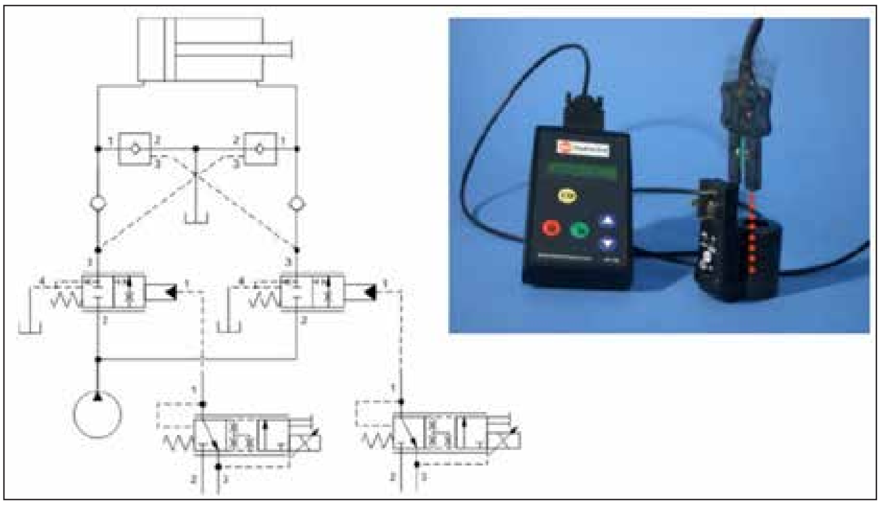

Figure 12. *Adjustable proportional 2/2 way directional valves with a vent to control the cylinder*

Summary

The article describes the advantages of directional and proportional valves as screw-in cartridges. Cross sections show the function of 3/4, 3/3 and 2/2 way valves. Circuits show typical applications of a variable displacement pump that makes several actuators very efficient. A circuit with a bidirectional pressure compensator helps avoid overshoots in velocity controls when the supply pressure changes rapidly. A circuit is shown for a displacement pump on several consumers in parallel with a supply pressure just high enough to move all actuators. The supply pressure follows the highest load pressure without the feedback of a load sensing signal. The pump supply and the proportional valves are driven by a controller that calculates the required flow based on command signals to proportional valves.

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Krmiljenje majhnih in velikih pretokov z ventili v izvedbi krmilnih vložkov za vgradnjo v blok

Razširjeni povzetek

Članek opisuje prednosti konvencionalnih in proporcionalnih potnih ventilov v izvedbi krmilnih vložkov za vgradnjo v blok. V industriji se v odprtih in zaprtih tokokrogih najpogosteje uporabljajo ventili v velikosti od Cetop ISO 3 do Cetop ISO 10. Nekateri potni ventili imajo zaprto regulacijsko zanko, ki zagotavlja kontrolo položaja krmilnega bata. Ti so zelo natančni in se lahko uporabljajo tudi v industriji, kjer se zahteva visoko ciklično in trajno obratovanje. Pri mobilnih hidravličnih napravah se veliko uporabljata t. i. »sendvič« način vgradnje ventilov kot tudi gradnja ventilov v krmilne bloke. Pogosto so krmilni bati potnih ventilov nameščeni direktno v izvrtine ulitih blokov.

Ventili v izvedbi krmilnih vložkov za vgradnjo v blok se pogosto ne uporabljajo za velike pretoke. Slabost teh ventilov je nesimetrična zgradba, tj. krmilni bat lahko vstavimo v pušo ventila samo z ene strani. Prednost takih ventilov za vgradnjo v blok pa je v manjši porabi vgradnega prostora. Tako je krmilje z ventili v izvedbi krmilnih vložkov kompaktnejše in lažje od industrijske izvedbe krmiljenja s standardnimi Cetopovimi krmilnimi ventili.

V prispevku so prikazani funkcionalni prerezi 4/3-, 3/3- in 2/2-potnih ventilov. Predstavljena hidravlična vezja prikazujejo tipične primere uporabe omenjenih ventilov, pri katerih črpalka s spremenljivo iztisnino napaja več porabnikov pri dobrem skupnem izkoristku. Hidravlično vezje z dvosmerno tlačno tehtnico preprečuje nenadne prekoračitve hitrosti izvršilne sestavine, ko se sistemski tlak sunkovito spreminja. Prikazano je tudi hidravlično vezje s črpalko s spremenljivo iztisnino in več vzporedno vezanih porabnikov. Vezje je zasnovano tako, da zagotavlja čim nižji sistemski tlak, tj. tlak, ki je dovolj visok za pomik vseh obremenjenih izvršilnih sestavin. Trenutno nastavljen sistemski tlak je tako visok, kot je trenutno najvišji tlak pri posamezni izvršilni sestavini. Črpalka s spremenljivo iztisnino in proporcionalni potni ventili so krmiljeni preko krmilnika, ki na osnovi krmilnega signala proporcionalnih ventilov preračuna potrebni pretok.

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