Proportional valves with embedded electronics

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This article describes electro hydraulic proportional cartridge valves that control pressure or flow in an open or closed loop system. The valves are controlled from a dry round solenoid coil fitted over the tube. The solenoids have the electronics embedded into the coil. Unlike conventional controls the valve is set using an infrared interface between the electronics and a handheld programming device. The programmer is used for setting all of the parameters of the electronic control. One can also monitor the operating point, i.e. command and actual values of the amplifier in a simple and safe manner. The article describes the components of the proportional control and some selected circuits.

1 Introduction

Cartridge valves are still considered to be simple valves for mobile machines. However many cartridges are suitable for both mobile and industrial applications. And can work successfully in systems with pressures up to 350 bars. Cartridge valves today not only provide simple hydraulic functions but can also be used as electro hydraulic proportional valves to control flow and pressure. Simple analog amplifiers controlling proportional valves are difficult to set and do not always give good repeatability. Digital amplifiers are easier and clearer to use but if the digital amplifiers are plug mounted they come with a display which is hard to read or no display at all when trying to set the parameters. In addition the electrical connection between amplifier and coil can be unsafe.

SUN is offering new digital amplifiers which are embedded into the coil and can be adjusted via infrared interface for programming and monitoring. One must distinguish between the infrared interface for programming and monitoring and the electrical interface for power supply and command signals. Command signals are still provided through an electrical cable with 4-20 mA or 0-10 Volt so a dirty or masked infrared link doesn't jeopardize the operation of the valve. The infrared interface is used only to program the amplifier from a hand held device or from a laptop PC. Later the infrared link can also be used to monitor command signals and the actual current through the coil.

The integration of coil and amplifier avoids unnecessary contact points between amplifier and coil that often cause problems in different designs.

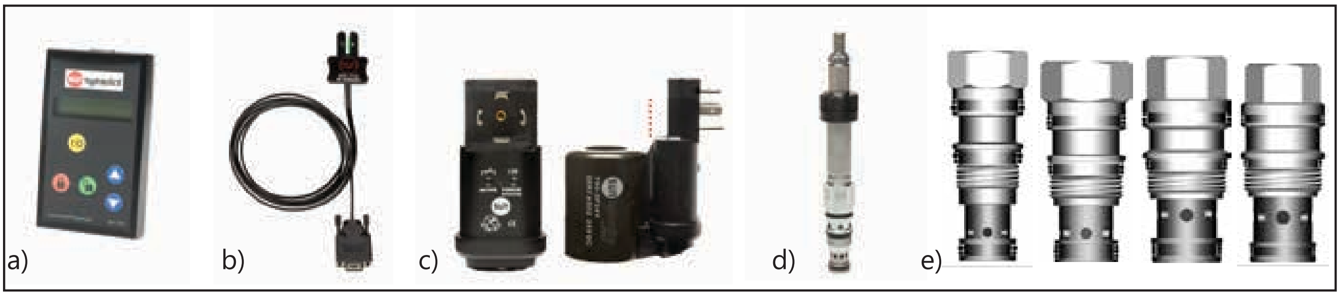

Figure 1. *The components of the proportional control and there follows is a brief description of those components: a: Hand held device for programming, b: cable with infrared interface, c: solenoid with embedded electronics, d: proportional direct acting flow control and proportional pressure control pilot valves, e: main stages that can be controlled by a proportional pressure control valve from top left down to the right: T-11A (40 l/min), T-2A (80 l/min), T-17A (160 l/min) T-19A (320 l/min).*

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2 Components of the proportional control

2.1 Hand held device for programming

The hand held device is powered from a battery and is basically a terminal (*Figure 1 a*). It has a digital display and only 5 buttons. Two of these buttons have arrows pointing upwards and downwards which can be used to select 8 different adjustable parameters and 4 actual values.

The adjustable parameters can be changed after unlocking with the green button. The adjustable parameters are: dither frequency, ramp time for rising and falling command values, the mode that determines whether an enable signal is required and others. Furthermore one can assign minimum and maximum command signals to minimum and maximum output currents. Command signals below minimum command are seen as zero while command signals above maximum command are seen as maximum command. This method of programming is easier than using gain factors as frequently used with analog amplifiers.

The four parameters that cannot be programmed from the hand held device but only displayed are: command signal (voltage between 0 and 10 V, or current 4-20 mA), the actual current through the coil and the actual supply voltage and the status signal.

2.2. Cable with infrared interface

The handheld device or a laptop computer communicates with the embedded electronics via cable (*Figure 1.b*). On one side that cable has a serial or USB interface while on the amplifier side it has two infrared interfaces: one for reading and one for writing. The cable is about 2 meters long so that programming and monitoring is possible from a safe distance. The cable can be put on the coil with embedded electronics without the danger of causing unwanted movements and the connection does not interrupt the hydraulic operation of the machine

2.3. Coil with embedded electronics

The third module is the coil with embedded electronics (*Figure 1.c*). Two diodes clearly indicate whether

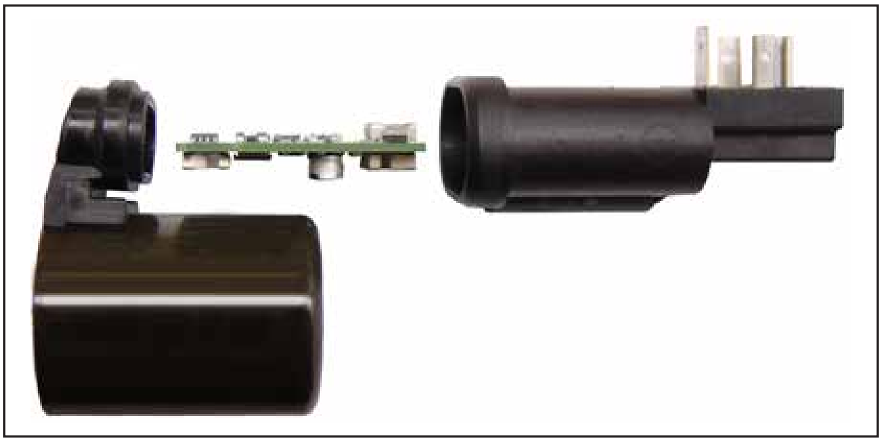


Figure 2. *Components of the coil with embedded electronics*

current is flowing through the coil (ACTIVE) and whether there is power supply to the amplifier (POWER/STATUS). This means one can easily check the basic functions of the device. A more detailed inspection and programming can be done with the hand held device.

The heat-sealed housing of the amplifier is connected with the coil and the housing has two windows for the infrared interface. The cable with the infrared interface can easily slide onto these windows. As soon as the amplifier is powered up the handheld device shows the current parameters of the amplifier. The device also shows the current through the coil, command signals, supply voltage and status information. This means that the information is always available without opening or touching electrical contacts which could cause dangerous movements of the actuator.

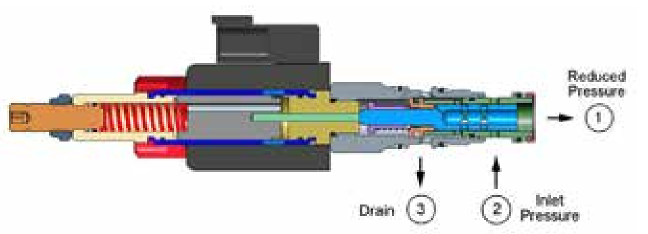
The clear digital display of the status and of all of parameters makes troubleshooting much easier. With analog amplifiers the setting is often not clear so for example if the setting for maximum current is too low the valve may not fully open or if a ramp time is so long the valve might appear to be malfunctioning.

Figure 1 shows the version of the coil with connector DIN 43650 A. Three pins are used for power supply (plus and minus) and for the command signal (0-10V or 4-20mA). Depending on the version the customer orders the fourth pin is either reference for the command signal- which is preferred- or a 5 Volt output, or an enable signal. The pin assignment therefore could be a compromise with DIN connectors. The Deutsch connector DT 04-6P has 6 pins and always provides reference for the command signal, enable input, and 5 Volt output to generate a command signal with a potentiometer as in a joystick.

The big advantage of the embedded electronics is the IP rating. Since amplifier and coil are encapsulated in a single housing they are well protected against moisture. With a Deutsch connector DT 04-6P the amplifier has IP 69K rating. With a DIN connector the IP rating depends on the connector.

Figure 2 shows the components of the amplifier. The amplifier card is built into housing with either the DIN or Deutsch connector. This housing is welded with ultrasound and filled with a polyurethane compound. Using the modular concept the valve manufacturer can combine different coils (12 V or 24 V) with different amplifier cards (proportional amplifier, coil safer or ramping amplifier) and different housings (DIN or Deutsch connector). The encapsulated and potted amplifier is also well protected against mechanical stress, heat and moisture.

The proportional amplifier is the most common amplifier used to control proportional valves. The amplifier uses pulse width modulation to control the current through



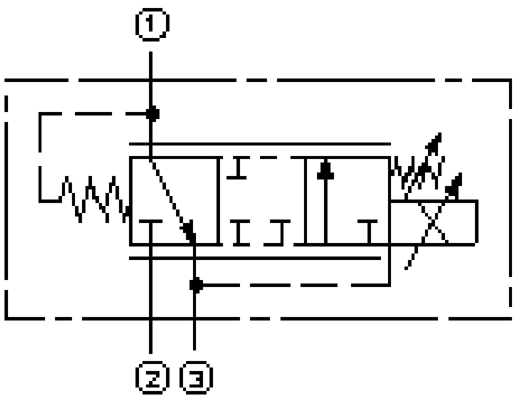


Figure 3. *Direct acting proportional 3 way pressure control valve with additional manual adjustment (a) in symbol (b)*

the coil so that it is proportional to the command signal. The current in the coil is proportional to the force on the valve's spool or poppet. The relationship between command signal and current can easily be given with four parameters (see above).

A simpler ramping amplifier can also be offered as an alternative. This will switches between two output signals if the command signal exceeds or falls below 9 V.

A third version is a coil saver to control on/off valves. This amplifier initially sends a high current through the coil so that the valve operates safely and overcomes flow forces at high pressure differentials. After a few hundred milliseconds the amplifier reduces the current. Once the valve is fully open a lower force is sufficient to keep the valve in that position. With less current there is less heat generated and the coil can be energized for a longer period of time. Unlike other common coil savers this one not only reduces the voltage but it reduces the controlled coil current with pulse width modulation. With the hand held device the user can set the initial current, the period of time until that current falls to a lower level and the final holding current. The holding current needs to be chosen carefully as if it is too low high then unexpected flows could cause the directional valve to close. The coil saver can extend the operating range and the life of directional valves.

3 Direct acting flow control and pressure control valves, pilot valves

The same proportional solenoid is used on many different types of valves:

- Direct acting flow control valves up to 28 l/min.
- Direct acting pressure control valves up to 20 l/min and 85 bar.
- Pilot pressure relief valves up to 350 bar and 2 l/min.

The pilot pressure relief valve can also be used with many different main stages. The combinations are pilot operated pressure valves:

- Proportional pressure relief valves in 4 frame sizes for up to 760 l/min nominal flow.
- Ventable proportional pressure relief valves in 4 frame sizes up to 480 l/min.
- Proportional sequence valves in 4 frame sizes for up to 480 l/min.
- Proportional (2-way) pressure reducing valves in 4 frame sizes for up to 320 l/min.
- Proportional (3 way) pressure control valves in 4 frame sizes for up to 320 l/min.
- Proportional pressure control valves with separate drain port in 4 frame sizes for up to 320 l/min.

3.1 Pressure control

Direct acting pressure control valves are available for pressures up to 85 bar and a nominal flow of 20 l/min. *Figure 3* shows the hydraulic symbol

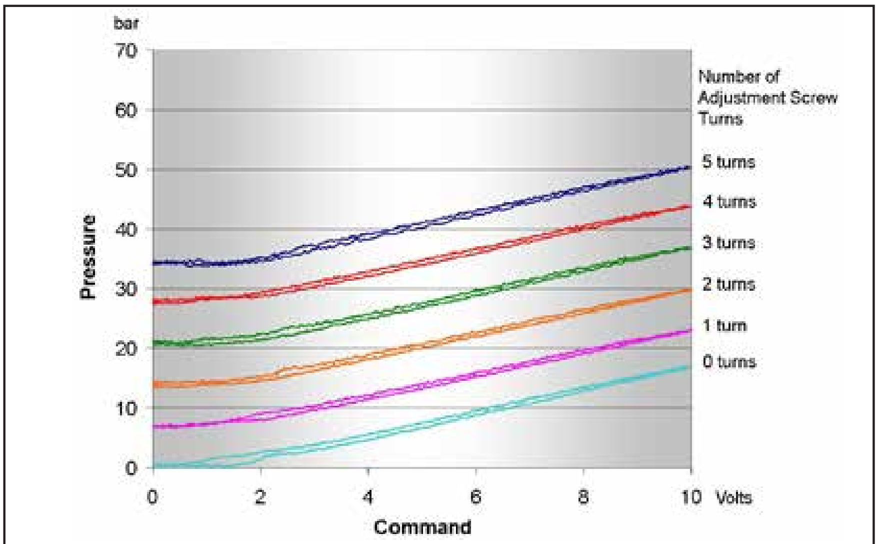


Figure 4. *Performance curves of the direct acting proportional pressure control valve shown in figure 3. Pressure rise against increasing command signals at different settings of the manual adjustment.*

and a cross section of a typical valve. Flow direction is from port 2 to port 1 which is from the nose end to the side port. The controlled pressure at port one operating on the effective area and the solenoid force are balanced. The effective area for the controlled pressure is the small diameter of the piston's shaft (shown blue in *figure 4*). The stepped piston is sealed on two diameters with a clearance of just a few microns. Manufacturing the sleeve and the piston within the required tolerance for roundness is difficult but the design has two advantages for the user:

- The effective diameter for the flow can be large regardless of the effective diameter for the pressure balance so the design allows for high flows and high pressures.
- The second advantage is a much better damping because of the ring chamber between the stepped diameters that communicates through a damping orifice with port 1. Other valves have damping chambers that see drain or tank pressure which is less effective.

The proportional valve can control pressures between two and eighteen bar. The manual adjustment can shift that range to higher pressures with the spring force of the manual adjustment being additive to the solenoid force. This means for example boosting the pressure range to say 32 and 48 bar with good resolution (*see figure 4*). The manual adjustment can also be useful in emergency situations, when pressures must be controlled accurately during loss of electrical power.

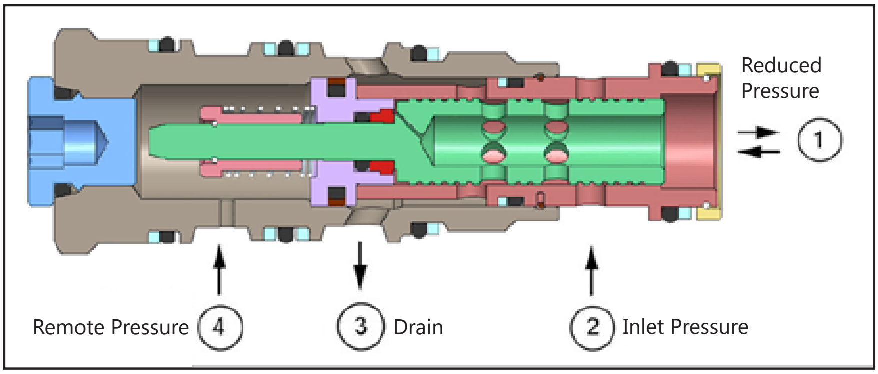


Figure 5. *Proportional pilot pressure relief valve*

For high flows and high pressures, pilot operated pressure control valves are used. The proportional pilot pressure relief valves in combination with a main stage can provide proportional pressure control valves in four frame sizes for flows from 60 to 320 l/min (*see figure 1*).

In some applications one needs different proportional pressure control valves Container vehicles for example have mechanical brakes on the hydrostatic drive that are released hydraulically. The driver uses a joystick to operate the valve for a smooth acceleration of the vehicle. It is important that the pressure control valve does not open until there is at least about 7 bar pilot pressure from the joystick and that the valve doesn't open too quickly. Another feature of this pressure control valve is that it is normally open which is a safety feature required in some applications. The valve is normally open between controlled pressure port and tank and therefore normally closed for the supply pressure. The valve can be pilot operated with a hydraulic joystick (that is a pilot pressure control valve) or with a pilot pressure relief valve.

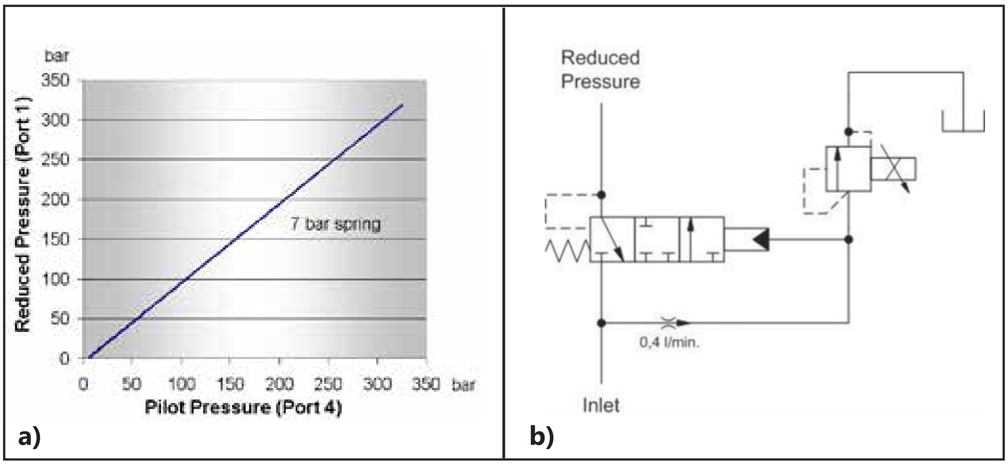


Figure 6. *controlled (reduced) pressure vs. pilot pressure of the pressure control valve – a and. circuit with the normally closed pressure control valve –b*

Figure 6. shows a circuit with the normally closed pressure control

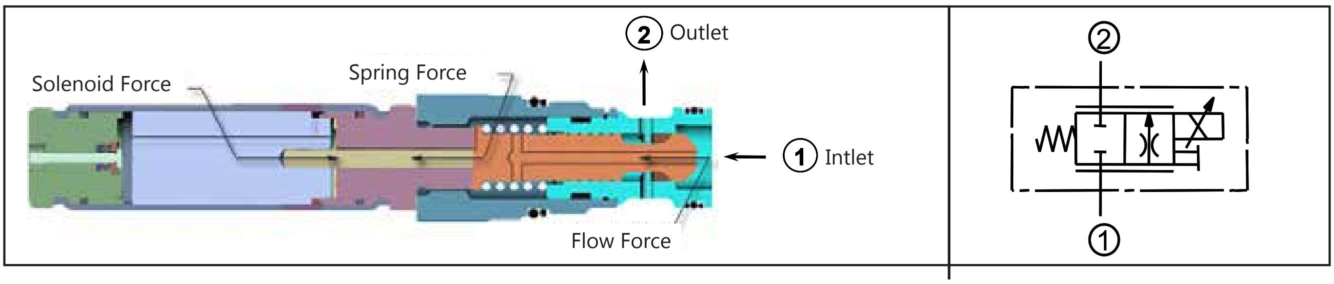


Figure 7. *Cross section of a normally closed proportional flow control valve.*

valve shown in *Figure 5*, using a pressure compensated flow control valve and proportional pilot relief valve. This circuit gives a pressure control valve with good damping because the valve itself is well dampened and because the pilot pressure uses the supply pressure as source and not the controlled pressure. In this circuit, the normally closed pressure control valve also helps avoiding pressure overshoots when a directional valve connects the pressure valve to supply pressure.

3.2 Flow control

The same proportional solenoids are used for pressure and flow control valves. The force of the solenoid valve is sufficient for a direct acting flow control valves with flows up to 28 l/min. *Figure 7* shows the cross section of a direct acting, normally closed flow control valve.

With this type of valve the solenoid pushes against the poppet directly. In order to keep the leakage of the valve down to a minimum, the poppet and sleeve have sufficient positive overlap. The disadvantage with this is that the valve does not open before the electric current reaches about 30% of the nominal value. The parameter for minimum current on the amplifier can be used to overlap that dead band.

If oil flows through the valve from port 1 to port 2 (nose to side) there are flow forces that tend to close the valve. Those flow forces become stronger with increasing pressure differentials and tend to close the valve. To a degree the flow forces pressure compensate the flow control valve but the flow does not increase following the square root of the pressure differential. *Figure 8* shows how well proportional flow control valves are pressure compensated. The graphs show the performance curves of 3 normally closed flow control valves with a nominal flow of 7, 14 and 28 l/min, each one at different command settings. Initially the flow rises with increasing pressure differential but eventually at high pressure differentials the flow forces become so strong that the valves overcompensates and the flow passing through the valve falls with increasing pressure differential.

To further improve the performance of a proportional flow control one can keep the pressure drop across the flow control constant using a two way pressure compensator as show in the *figure 9*. The curves show the proportional valve's performance in combination with a 12 bar pressure compensator. This means that the flow control valve sees about 12 bar pressure differential regardless of the total pressure drop. The flow could be higher with pressure compensators that have a higher setting. In designing the hydraulic circuit it is important to look at the total pressure drop across the two way pressure compensator

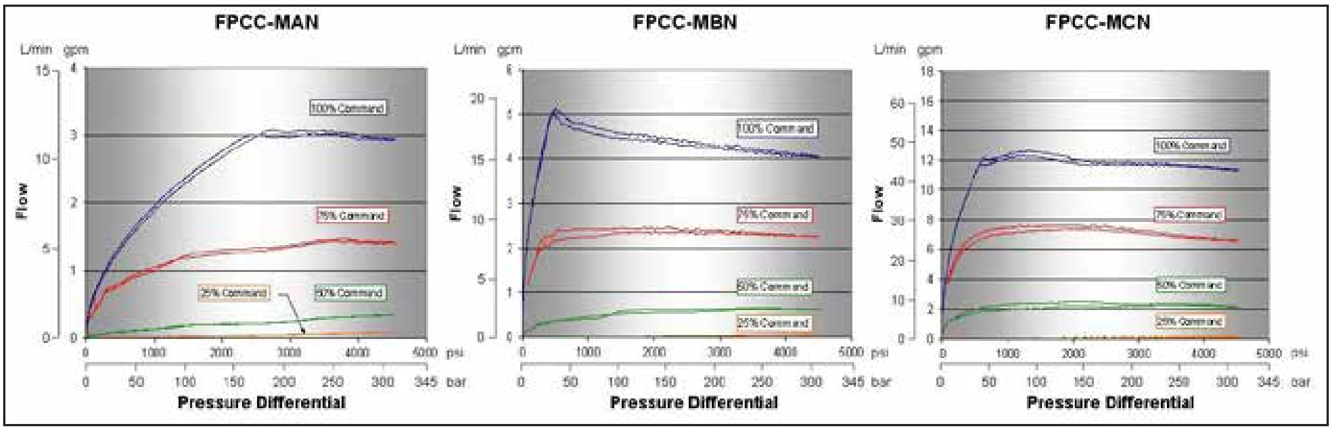


Figure 8. *Flow vs. pressure differential for 3 different normally closed proportional flow control valves. Curves shown for different command signals*

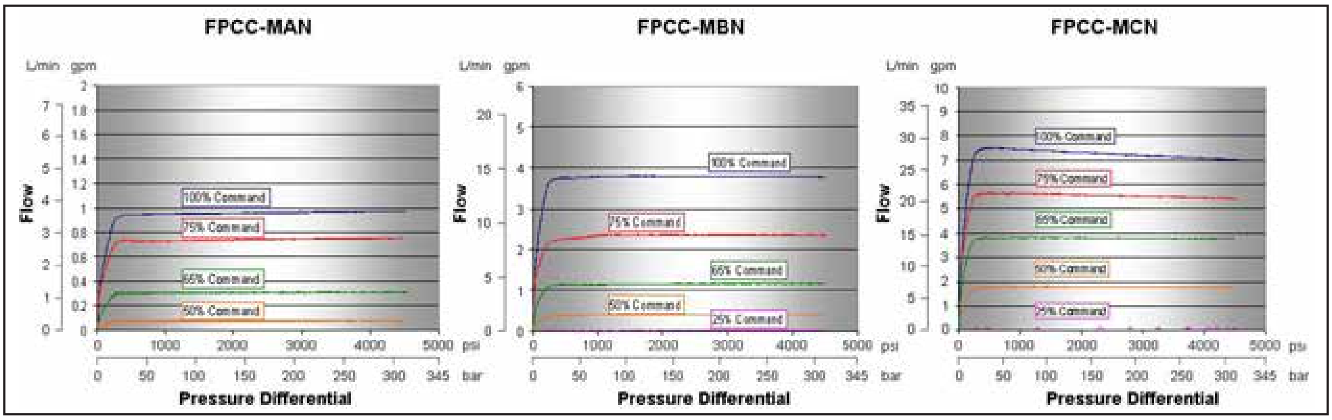


Figure 9. *Flow vs. pressure differential for 3 different normally closed proportional flow control valves. The curves shown are for different command signals. The pressure differential across the valve is kept constant at about 12 bar using a 2 way pressure compensator. The curves show the total pressure drop across pressure compensator and flow control valve.*

and the flow control valve. At high flows in valves where the pressure compensators are too small or have springs for low pressure differentials they will tend to close due to flow forces resulting in higher total pressure losses. This means that the pressure compensator must be dimensioned correctly.

4 Summary

Proportional valves with ultrasonically welded housings that include the coil and the amplifier have less open electric contact points and the operation of the valve becomes more reliable. This article has described how embedded electronics is used in proportional pressure control and flow control valves.

The solenoid valves with embedded electronics shown in this article also have an infrared interface to program the amplifier and monitor the valve's operation. Programming can be done with a hand held device that can be used without any extensive training. The programming device can also be used to monitor the setting, the electrical power supply, command signals and the actual current through the coil.

Monitoring is possible without opening or even touching electrical contacts so the operation of the hydraulic drive remains safe, avoiding unwanted movements.

Proporcionalni ventili z vgrajeno elektroniko

Razširjeni povzetek

Prispevek obravnava elektrohidravlične proporcionalne ventile za vgradnjo (z navojem), ki krmilijo tlak oziroma tok v odprtih in zaprtih krmilnih zankah. Ventili so krmiljeni z elektromagnetno tuljavo, ki ima vgrajeno elektroniko. V primerjavi z drugimi konvencionalnimi izvedbami ima ventil infrardeči vmesnik med elektroniko in ročno programirno napravo, ki jo programer uporablja za postavljanje parametrov elektronskega krmilja. Programer lahko enostavno in varno nadzoruje delovne točke oziroma ukaze in dejanske vrednosti ojačevalnika. V prispevku so predstavljene komponente proporcionalnega krmilja ter nekatera izbrana krmilna vezja.

Ventili z navojem za vgradnjo so še vedno obravnavani kot enostavni ventili za mobilno hidravliko. Nekateri ventili pa so primerni tako za mobilno kot industrijsko uporabo in lahko uspešno delujejo v sistemih pri tlaku do 350 bar. Ventili z navojem danes nimajo samo enostavne hidravlične funkcije, ampak se lahko uporabljajo tudi kot proporcionalni ventili za krmiljenje tlaka in toka. Slabosti analognih in tudi digitalnih ojačevalnikov je SUN izboljšal z novim digitalnim ojačevalnikom, ki je vgrajen v okrov tuljave in ga je mogoče programirati in nadzorovati preko ročne programirne naprave.

Razlikovati je treba med infrardečim vmesnikom za programiranje in nadzor ter električnim vmesnikom za oskrbo z energijo in ukaznimi signali. Ukazni signali so še vedno vodeni z električnim kablom s 4–20 mA oziroma 0–10 V, tako da umazanija in infrardeča povezava ne vplivata na delovanje ventila. Infrardeči vmesnik se uporablja le za programiranje ojačevalnika z ročno programirno napravo ali s prenosnim računalnikom. Povezava med tuljavo in ojačevalnikom preprečuje nepotrebne stične točke med ojačevalnikom in tuljavo, ki bi lahko povzročale probleme v različnih konstrukcijah.

Komponente proporcionalnega krmilja ventila so (*slika 1*):

- Ročna enota za programiranje z napajalno baterijo je v osnovi terminal, ki ima digitalni prikazovalnik in samo pet tipk. Dve imata puščice za premikanje navzgor oziroma navzdol in se lahko uporabita za izbiro 8 različnih nastavljivih parametrov in štiri dejanske vrednosti. Nastavljivi parametri so na primer: frekvenca nihanja, strmina vrednosti za dviganje in padanje ukazne vrednosti, način, ki določi, če je nek signal zahtevan ali ne, ter drugi parametri. Določi se lahko vrednost minimalnega in maksimalnega ukaznega signala k minimalni in maksimalni izhodni napetosti. Lahko se na primer določi, da so ukazni signali pod vrednostjo minimum enaki nič in signali nad vrednostjo maksimum enaki maksimalni izhodni napetosti. S programirno napravo ni mogoče spreminjati ukaznih signalov, lahko se le prikažejo (napetosti med 0 in 10 V oziroma tok od 4 do 20 mA), dejanske trenutne napetosti v tuljavi, dejanske napajalne napetosti ter signala stanja.
- Kabel z infrardečim vmesnikom ima na eni strani serijski ali USB-vmesnik, na strani ojačevalnika pa sta dva infrardeča vmesnika, eden za branje in drugi za pisanje. Kabel je dolg okrog 2 m. V tuljavo z vgrajeno elektroniko ga je mogoče vstaviti brez nevarnosti, da bi se povzročili nezaželeni premiki, vstavljanje ne prekine delovanja hidravlike na stroju.
- Tuljava z vgrajeno elektroniko je tretja komponenta in je sestavljena iz tuljave, elektronike ter okrova s priključki (*slika 2*). Dve diodi na okrovu jasno pokažeta stanje osnovnih funkcij (stanje, napajanje), več podrobnih informacij pa se ugotavlja preko ročne programirne enote. Prednost vgrajene elektronike je zaščita proti vlagi. S konektorjem DT 04-6P je zaščita IP 69K. Okrov je varjen z ultrazvokom in napolnjen s poliuretanom.

Ker je sistem modularen, je mogoče kombinirati različne tuljave (12 V ali 24 V) z različnimi ojačevalniki ter različnimi okrovi s priključki. Vgrajen ojačevalnik je varovan tudi proti mehanskim sunkom, toploti in vlagi. V programu je tudi verzija z varčevanjem tuljave pri krmiljenju vklopno-izklopnih ventilov. Ojačevalnik najprej pošlje velik tok skozi tuljavo, tako da ventil deluje varno in zanesljivo in premaguje tokovne sile in velike razlike tlakov. Po nekaj sto milisekundah ojačevalnik zmanjša tok. Ko je ventil popolnoma odprt, zadošča že majhna sila, da drži ventil v danem položaju. Varčevalnik tuljave podaljša življenjsko dobo potnih ventilov.

Ista proporcionalna tuljava se lahko uporabi pri različnih izvedbah ventilov, tako za neposredno delujoč krmilnik toka do 28 l/min, neposredno delujoč krmilnik tlaka do 20 l/min ter 85 bar ali pa za predkrmilne – pilotne tlačne – varnostne ventile za toke 2 l/min in tlake do 350 bar. Sam pilotni tlačni varnostni ventil se lahko uporabi z več različnimi glavnimi enotami, kot na primer proporcionalni tlačni varnostni ventil, proporcionalni ventil z razbremenitvijo, proporcionalni zaporednostni ventil, proporcionalni zmanjševalnik – reducirni ventil, trismerni proporcionalni regulator tlaka in podobno.

Na *sliki 3* je prikazan neposredno delujoč tlačni ventil za tlake do 85 bar in nominalni tok 20 l/min. Fluid teče v smeri od priključka 2 k priključku 1. Tlak olja, ki deluje na čelno stran ventila, je v ravnotežju s silo v tuljavi. Značilne krivulje poteka tlaka pri neposrednem proporcionalnem krmilniku tlaka so prikazane na *sliki 4*. Tlak narašča glede na povečanje krmilnega signala pri različnih ročnih nastavitvah. Proporcionalni ventil lahko regulira tlake med dva in 18 bar. Ročna prilagoditev z nastavitvijo sile vzmeti potisne to območje višje, tako da je še tudi pri tlaku 32 in 48 resolucija dovolj dobra. Ročna nastavitev je uporabna tudi pri izpadu električnega napajanja.

Za večje toke in višje tlake se uporabljajo tlačni ventili s predkrmilnimi – pilotnimi ventili. Tako lahko proporcionalni varnostni s pilotnim ventilom v glavni stopnji pa pretoke med 60 do 320 l/min.

Na *sliki 6* je prikazano krmilno vezje, kjer normalno zaprt regulator tlaka (*slika 5 a*) uporablja tlačno kompenziran krmilnik toka in proporcionalni pilotni razbremenilni ventil. Krmilje daje regulator tlaka z dobrim dušenjem, ker je ventil sam dobro dušen in pilotni tlak uporablja napajalni tlak kot vir in ne krmiljeni tlak. V tem krmilju normalno zaprt regulator tlaka pomaga pri izogibanju prenihanja tlaka, ko direktni ventil poveže tlak ventila z napajalnim tlakom.

Za regulacijo toka se uporabljajo iste proporcionalne tuljave. Neposredno delujoči proporcionalni tokovni ventili so primerni za tokove do 28 l/min (*slika 7*). Pri teh ventilih proporcionalna tuljava deluje neposredno na krmilni element oziroma magnetna sila je v ravnotežju s silo vzmeti, deformacija vzmeti je premo sorazmerna s tokom skozi ventil. Lekaža je minimalna zaradi dovolj velikega prekritja krmilnega elementa ter puše. Slabost je le v tem, da ventil ne odpre pretoka, dokler elektromagnetna sila ne doseže 30 odstotkov nominalne vrednosti.

Ko teče olja v smeri od priključka 1 do priključka 2 (s čelne strani k stranskemu priključku) nastopijo sile, ki imajo tendenco zapiranja ventila, to je še posebno opazno pri veliki tlačni razliki. Diagrami na *sliki 8* kako dobro proporcionalni krmilnik toka kompenzira razliko tlakov. Diagrami kažejo poteke krivulj treh normalno zaprtih krmilnikov toka z nominalnim tokom 7, 14 in 28 l/min pri različnih ukaznih vrednostih. V začetku tok narašča z večanjem tlačne razlike, vendar pri zelo visokih tlačnih razlikah so tokovne sile tako velike, da je ventil prekompenziran in tok skozi ventil prične padati tlačno razliko.

Z uporabo dvosmernega kompenzatorja tlaka je mogoče karakteristiko proporcionalnih krmilnikov toka bistveno izboljšati (*slika 9*). Prikazani rezultati meritev kažejo da je, ob uporabi 12 bar kompenzatorja, tok skozi ventil enak tudi pri večjih razlikah tlakov. Pomembno je, da je kompenzator ustreznih dimenzij, kar zahteva natančno dimenzioniranje.

Povzeti je mogoče, da so ventili zanesljivi in da je vgrajena elektronika primerna rešitev za krmiljenje proporcionalnih tlačnih in tokovnih ventilov. Prednosti ventilov so v enostavnem programiranju in povezavi z ročno programirno napravo.

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