Proportional Leak-Free Pressure Control Valve

Christian Stauch, Frank Schulz, and Dr.-Ing. Michael Reik

HYDAC Fluidtechnik GmbH, Justus-von-Liebig-Straße, D-66280 Sulzbach/Saar, Germany
E-Mail: christian.stauch@hydac.com

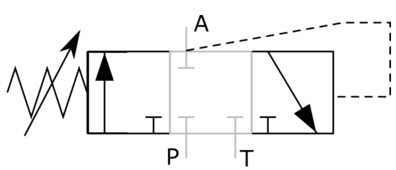
Pressure control valves combine both a reducing and a relieving function. Such valves typically are spool type valves which principally suffer from leakage flow. Additionally, in case of an electrical failure, usual proportional pressure reducing and relieving valves fully open either the supply port connection or the tank port connection. In some applications like clamping functions in machine tools, this is a clear disadvantage. For fail safe operation in machine tools, it is desired to hold the set pressure in case of failure. The article introduces a new kind of proportional pressure reducing and relieving valve, which is leak-free due to seat valve technology. Furthermore, the valve is able to keep the set pressure in case of power-off and is therefore well-qualified for clamping applications.

Keywords: control valve, independent metering, leak-free pressure control
Target audience: machine tool, industry hydraulics, test stand

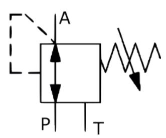
1 Introduction

Pressure control valves, also referred to as pressure reducing/relieving valves, are commonly used in fluid power systems in order to regulate a pressure at a certain point in the system(e.g. such as an actuator). Such valves exist in wide range of varieties. In order to illustrate the generic function of a pressure control valve, the simplest type is used in the following subsection (cf. Figure 1).

1.1 Function of a pressure control valve



(a) Functional symbol



(b) Simplified symbol

Figure 1: Symbols for a pressure control with manually adjustable set pressure.

A pressure control valve, typically having 3 ports, combines both a pressure reducing function and a pressure relieving function. When either increasing the load pressure or maintaining a constant set pressure with a flow rate consumption at the working port A, then the valve is in reducing mode. In this case it causes a pressure drop from the supply port P to the working port A such that the pressure at the working port A reaches the desired value. If the flow direction is reverse or the working port pressure is to be decreased, then the valve changes to pressure relieving mode. In this case, the flow path from the working port A to the relief port T is used. The valve causes a pressure drop between these two ports such that again the desired pressure value in the working port A is achieved. The quality of the regulation in terms of precision and dynamics heavily depends on the construction type of the valve. Obviously, there is a great variety in the requirements for pressure control valves as there are plenty of different applications for such valves.

1.2 Types of pressure control valves

A common way to classify pressure control valves is to differentiate by looking not at the control properties but at the underlying construction principles of the valve. Some relevant distinguishing properties are listed and discussed in the following:

- Set point adjustment
  The set pressure of a control valve can be adjusted either **manually** (e.g. by manipulating the preload force of a spring) or **electro-proportionally** (e.g. by using electromagnetic actuation). Whereas the electro-proportional set point adjustment offers clear advantages in terms of flexibility and adaptability, the classical manual adjustment still has its raison d'être in applications that are either very cost-sensitive or have special safety requirements.

- Pressure feedback
  In valves with **direct feedback**, the control pressure at the working port A causes a feedback force acting on the control element, typically being a spool. By contrast, some types of valves rely on an **indirect or electronic feedback** using a pressure signal from a sensor in order to control the spool. Typically, a direct hydraulic-mechanical feedback is much more dynamic than an electronical feedback which also depends on the dynamics of both the sensor and the actuator. However, an exception to this is given by high-response and servo valves that also can be used for pressure control with an underlying highly dynamical position control for the main spool. An intermediate type of feedback is the combination of a direct force feedback for high dynamic control with an additional low-dynamic outer electronic control loop for steady-state precision.

- Main control element
  Most pressure control valves are **spool-type** valves having a main spool whose position defines the flow areas of the flow paths in the valve. However, there are a few **poppet-type** pressure control valves in the market which have the advantage of leak-freeness in the closed position.

- Mounting type
  As nearly all kinds of valves, pressure control valves exist both as **cartridge** (slip-in or screw-in) valves and as flange- or **plate mounted** valves. Cartridge valves are used mainly, but not exclusively, in mobile applications, e.g. for clutch controls whereas sub-plate mounted pressure control valves are to be found in industrial applications almost exclusively.

The resulting variety of valve types including some examples is illustrated in Figure 2. This classification is by no means claimed to be complete or canonical in any sense. Further categories such as pilot operated/direct operated could be added easily.

Having a closer look to the proportional valve branch in Figure 2, a gap becomes obvious: so far, there is no proportional seat-type pressure control valve in the market, at least to the best of the authors' knowledge. The focus of this article therefore is the presentation of a novel market-ready leak-free proportional pressure control valve.

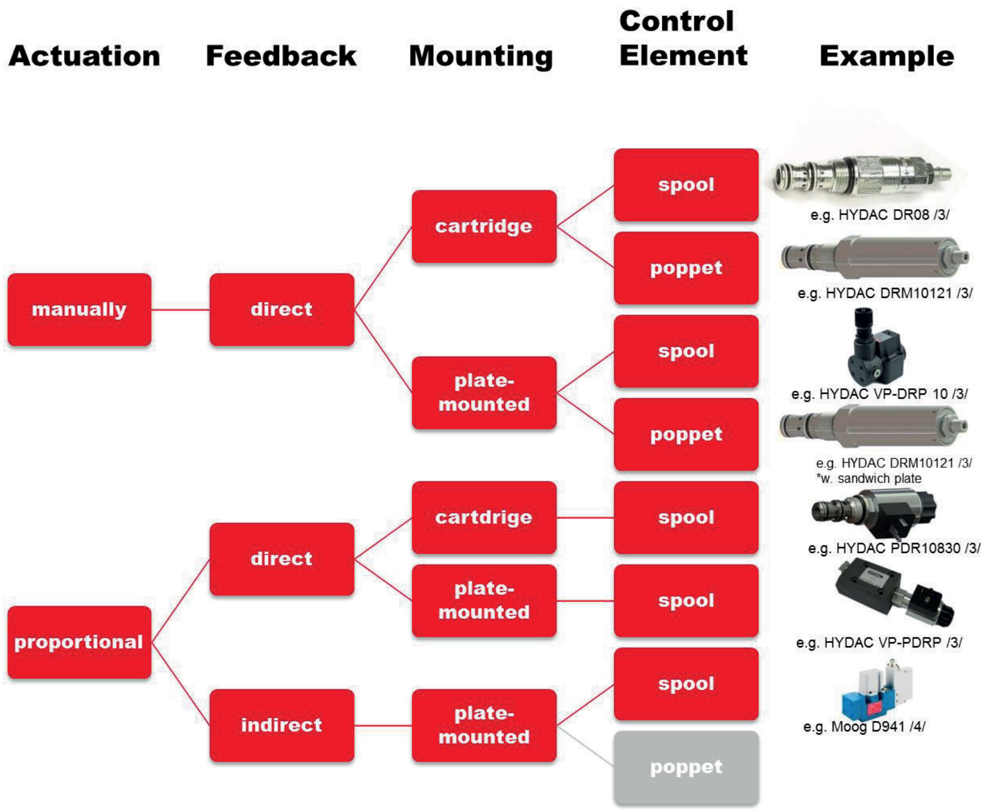


Figure 2: Different types of pressure control valves.

2 The leak-free proportional pressure control valve P3RSEE 6

The main motivation for designing the P3RSEE 6 was to close the gap shown in Figure 2, i.e. to have a poppet-type proportional pressure control valve. The origin of this principle lies in the research area of digital hydraulics /1/, where two 2/2 poppet-type on/off valves are used in combination with a pressure sensor and PWM valve control in order to regulate the pressure between the two valves. However, the PWM principle requires very fast switching valves which are not available at marketable costs. A principle using poppet valves similar to the pressure control valve presented here was successfully implemented by Plöckinger et al. for the position control of a hydraulic membrane actuator /2/.

The novel pressure control valve P3RSEE6 (cf. Figure 1 Figure 4) combines the advantages of closed loop pressure control, independent metering, and poppet-type valve elements in one highly integrated subplate-mounted size 6 valve with on-board electronics (OBE).

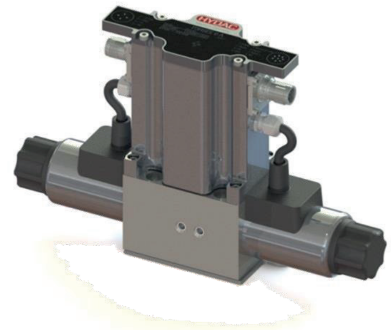


Figure 3: Pressure Control Valve P3R.

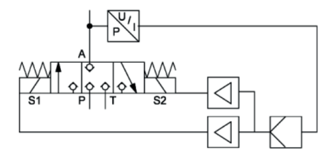


Figure 4: Functional circuit symbol.

2.1 Functional principle

The valve involves a housing with a standard mounting interface, an integrated on-board digital electronics (OBE) and two poppet valve elements which can be activated independently from each other. One valve element connects the supply port P to the working port A, the other element connects the working Port A to the relief port T. The use of seat-type valve technology avoids undesired leakage cross flow from both supply port P and working port A to the tank port T. A pressure transducer detecting the working port pressure is integrated in the valve housing. The pressure signal is fed to the digital OBE, where a pressure control algorithm determines the opening of the poppet elements. The desired set pressure is also fed to the OBE via an analogue input signal. Additionally, the OBE involves the underlying current control for the valve coils.

2.2 Features

First of all, the availability of an integrated pressure transducer and an OBE allows for closed loop pressure control which brings about several advantages: Most obviously, with closed loop control, the hysteresis can be reduced to the limits given by the pressure transducer which is below 1% of the measurement scale. In Figure 5, the pressure-current-curve shows the quasi-static characteristic of the valve. Another benefit of closed loop control is the linearity of this characteristic curve. The major advantage however is the flow compensation due to the closed loop control. Figure 6 shows the pressure-flow characteristic of the valve in relieving mode. The influence of the flow rate on the set pressure is reduced significantly as compared to open loop pressure control valves.

The combination of poppet-type elements and independent metering principles allows realising zero overlap control behaviour while at the same time having zero leakage in the “neutral position”. This brings about another advantageous load-holding feature of the valve: in case of an electrical failure, e.g. an undesired power-off or an emergency stop, both flow paths from supply port P to working port A and from port A to the relief port T are closed by the poppet elements. Besides, in another case of known failure where the hydraulic power is lost (i.e. the supply pressure breaks down) the valve allows to relief the pressure from the working port A to T in a fully controlled manner.

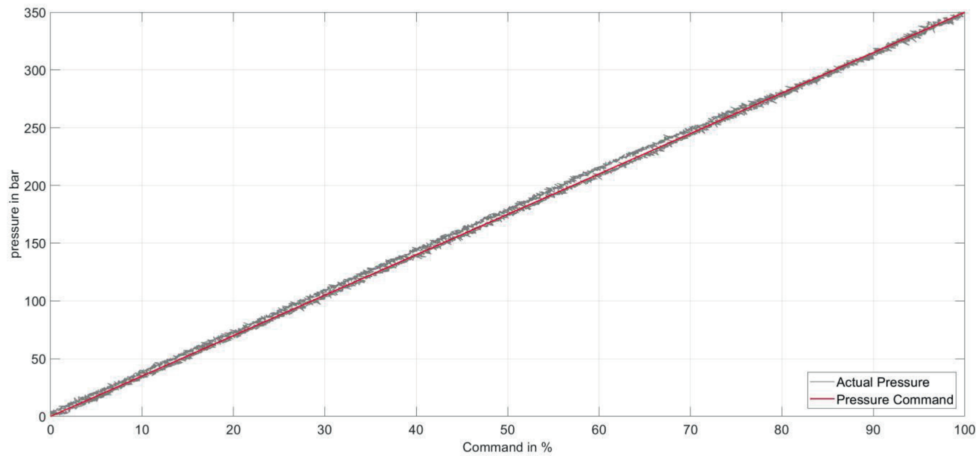


Figure 5: Pressure control characteristic.

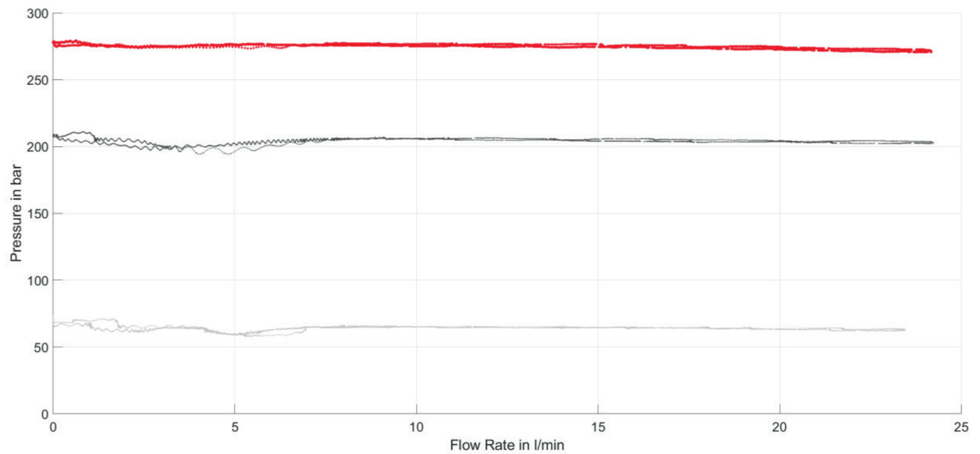


Figure 6: Pressure-flow-characteristic.

The sales-ready version of the valve has an analogue monitoring output, where the actual pressure determined by the pressure transducer can be forwarded to any higher level control system which allows for a more sophisticated process control and monitoring; a fact from which predictive maintenance systems also might benefit. Further development of the valve involves the complementation of digital communication interfaces (cf. Section 4).

2.3 Technical Specification

The pressure control valve P3RSEE 6 has a CETOP 03 standard interface in accordance to ISO4401. The nominal flow is 25 l/min and the maximum pressure range is 350 bar. The dynamics of the valve depends on the operating conditions, the load dynamics attached and the controller parameters. Typical step response times are in the range of 50-300 ms. The pressure drop per metering edge is in the range of 5 bar at 8 l/min flow rate.

2.4 Case study

A technology demonstrator is used to illustrate the main features of the pressure control valve (cf. Figure 7). This demonstrator includes an accumulator charging circuit with a compact power unit being connected to the supply port P of the valve. The relief port is connected to the tank of the power unit. A pressure gauge and a pressure transducer are mounted at the working port A with an overall trapped oil volume of 25 ml. The set pressure is repeatedly ramped up and down between 0 and 100 bar using ramp times of 1 s and holding times of 1 s, i.e. the overall cycle time is 4 s. The hysteresis set points of the charging logics are chosen such that the power unit starts charging at a supply pressure of 101 bar and stops when the pressure has reached 115 bar. Within one accumulator charging cycle, the valve is able to perform 225 load pressure cycles. Taking into account the accumulator dimensioning, the overall amount of oil consumed within these 225 cycles can be estimated to 50 ml. Approximately 80% of this amount are used for repeatedly compressing the trapped oil at the working port A. This experiment emphasises the valve's ability for pressure control at almost zero leakage level and load holding at zero leakage.

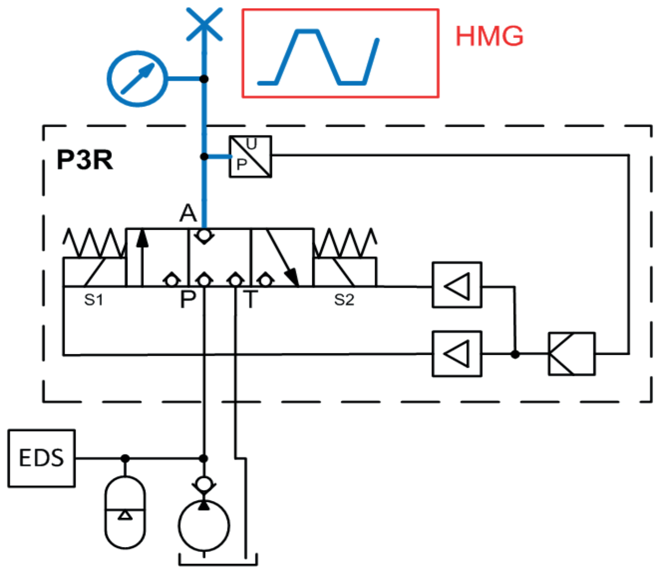


Figure 7: Circuit sketch of the technology demonstrator.

3 Application areas

The most obvious target application area is clamping in machine tools. Here, most of the features of the presented valve bring about added value for the application. The possibility to precisely control the clamping force dependent on machining processes and workpieces becomes more important in machining of lightweight workpieces and materials. The integrated pressure feedback enables a process monitoring and fine-tuning without the need to install additional sensors. The integrated load holding feature allows for increased functional safety. Modern clamping hydraulics often relies on accumulator charging circuits with variable speed drives. The avoidance of leakage in the clamping not only yields a significant benefit regarding the energy efficiency of the system but also reduces the fluid heating due to energy loss in the hydraulic system. This in turn might reduce the necessary expenses for cooling in the hydraulic system. Additionally, the decrease in leakage losses in an accumulator-based clamping hydraulics either allows for downsizing of the accumulator or the pump drive or requires less recharging cycles. Summing up, the pressure control valve P3RSEE 6 enables a change in the design of the clamping hydraulics that might bring significant benefits in efficiency, cost and service life.

Other target application areas can be found both inside and outside the field of machine tools. Presses with high numbers of working cycles will benefit from the increased energy efficiency due to the reduced leakage and leak-free load holding. The same holds true for variable counterbalancing functions in machine tools. Requirements that are very similar to those of clamping circuits can also be found in the field of hydraulic brakes.

In general, any pressure or force control application that is both sensitive to leakage or energy loss and requires precise control with intermediate dynamics is a possible target area for the presented pressure control valve. Other applications that might benefit are such where both proportional pressure control and leak-free load holding in case of power-off is needed.

4 Outlook: Further development and additional features

The pressure control valve P3RSEE 6 as presented in the Sections 1-3 is available for sales. Nonetheless, the valve is under constant development. The next development step will be the complementation of digital communication facilities.

In addition to new state-of-the-art communication interfaces, the control software itself is subject to further development. The implementation of adaptive control algorithms and auto-tuning capabilities is the main focus of current development in this area. Recent experiments have shown that the valve is qualified for online identification of plant parameters. A recursive identification algorithm that is fed with test signals and measurements that are available within the OBE yields a parameter α that gives a measure for the load capacity attached to the working port A (cf. Figure 8). In most of the relevant applications, this load capacity determines the plant dynamics. Therefore, future control algorithms can be tuned automatically in dependence of this parameter α which then will be identified on-line.

Further activities in development aim at increasing the physical dynamics of the valve in order to be applicable to systems that have higher requirements regarding the closed-loop dynamics as those mentioned in section 3.

5 Summary

The present article introduces a novel kind of proportional pressure control valve with on-board digital electronics relying on independent metering principles and poppet-type valve elements. This allows pressure control at very low leakages and low hysteresis as compared to conventional pressure control valves and load holding at zero leakage. The integrated pressure sensor may also be used for monitoring purposes at higher levels in the control hierarchy. These features may bring about significant advantages regarding energy efficiency, cost and service life in applications like clamping hydraulics and similar areas. The valve as presented is project ready. Further development efforts aim at including additional features like auto-tuning and increasing the valve dynamics.

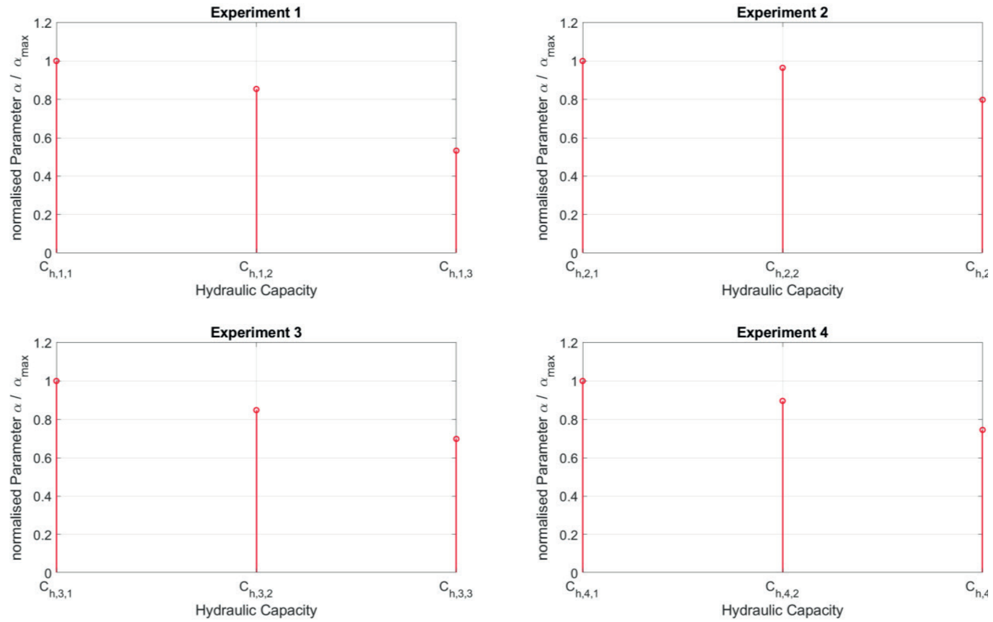


Figure 8: Relation between the identified parameter α and the load capacity C_L.

References

/1/ Linjama, M. *Digital fluid power: State of the art*. In 12th Scandinavian International Conference on Fluid Power, Tampere, Finland, May 2011.

/2/ Plöckinger A., Winkler B., Foschum P., Scheidl R.: *Digital Hydraulics for an Industrial Micro-Positioning System*, in: Hubertus Murrenhoff (Eds.): Proceedings of the 9th International Fluid Power Conference (9th IFK), 24th - 26th March 2014, Aachen, Germany, Volume 1, Page(s) 478-489, 2014

/3/ HYDAC International GmbH, *Compact Hydraulic. Product Catalogue*, https://www.hydac.com/fileadmin/pdb/pdf/PRO000000000000000000053000010011.pdf, visited on December 11, 2017.

/4/ Moog Inc., *Proportionalventile Baureihe D941*, http://www.moog.de/content/dam/moog/literature/ICD/d941seriesvalvesD.pdf, visited on December 11, 2017