Actual Trends in the Design and Development of Valves and Actuator Control

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Abstract

The development of motion control technology during the last years has been driven by different requirements from the application markets as increased dynamic performance, low energy consumption, higher power density or easy to use features. The publication shows how the leading companies react on these technical market requirements. This article responds also to the trend towards electric and hybrid motion control systems due to their low energy consumption.

KEYWORDS: market trends, energy consumption, power density, explosion proof devices

1. Trends in the application markets

The following chapters demonstrate how technical developments by the leading companies react on the different trends and requirements of the application markets.

1.1. Dynamic performance

The dynamic performance of servo hydraulic valves has been improved by different approaches during the last years. The introduction of digital electronics allows the easy implementation of nonlinear control loops which lead to inner loop gains of current and position control loops. In parallel there have been developments of new actuation systems for the valves like voice coil drives (Parker). While these concepts base mostly on a replacement of the standard actuator like the proportional solenoid, alternative solutions have been designed.

Figure 1 shows a new design concept. In the classic design of a servo valve the sleeve is fixed inside the valve body and the spool is moved directly by an actuator like a linear force motor or a voice coil drive (Figure 3). In this design spool and sleeve are moved, the spool by a classic actuator and the sleeve by a piezo actuator. The piezo allows only 10% of the stroke of the linear force motor, but that is suitable for a high bandwidth in the range of small magnitudes.

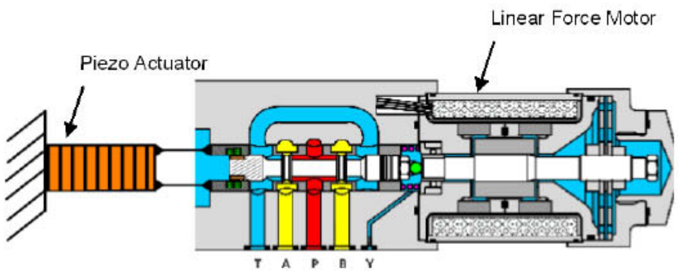

Figure 1: Concept for high dynamic servo valves (Moog)

The high dynamic performance of piezo actuators combined with the limited stroke of this actuator has been used in the design, shown in **Figure 2**. Here 4 piezo pilot valves are used in a hydraulic full bridge.

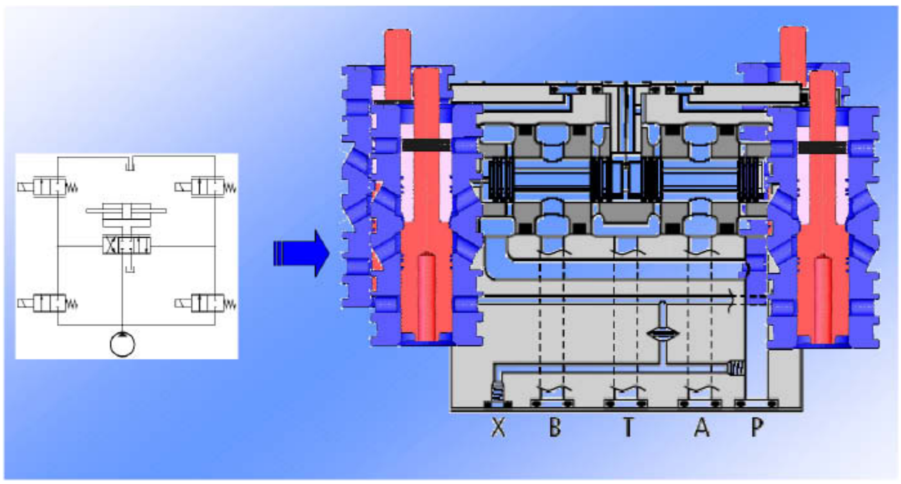

Figure 2: Concept for a pilot operated high dynamic servo valve (IFAS)

The dynamic performance of this university design study was very high. The acceptance in industrial praxis due to the relative high effort with 4 pilot valves and 4 electronic units and due to the high energy consumption was moderate.

1.2. Energy consumption

The increasing energy costs became a driver for new developments in motion control applications. Hydraulic drives are valve controlled in the meantime. The valve itself in form of a throttle is an equivalent for energy dissipation. This effects on the one hand in a transition from hydraulic drives to electric drives and on the other hand in two main streams in the development of hydraulic motion control technology:

- Reduction of energy losses inside the control valves
- Replacement of valve (throttle) control by direct energy control, e.g. in electro hydrostatic actuators

The following chapters explain in form of short examples how the industry reacts on these trends in valve controlled hydraulic motion control applications.

1.2.1. Extension of the functional limit of direct operated servo valves

Servo valves can be grouped into two classes:

- Pilot operated servo valves (i.e. nozzle flapper or jet pipe actuation)
- Direct operated servo valves (i.e. linear force motor, solenoid or voice coil actuation)

The first group allows due to the high dynamics of the torque motor actuator, the short strokes and the minimised moving masses a very high dynamic performance of the valves. This dynamic advantage is combined with high energy losses in the first stage of the valves, which amounts typically a few kW. Losses in the dimension of a few kW in relation to the controlled hydraulic power in representative dimensions of a few 100 kW or MW seems not significant, but the number of installed valves makes this dominant.

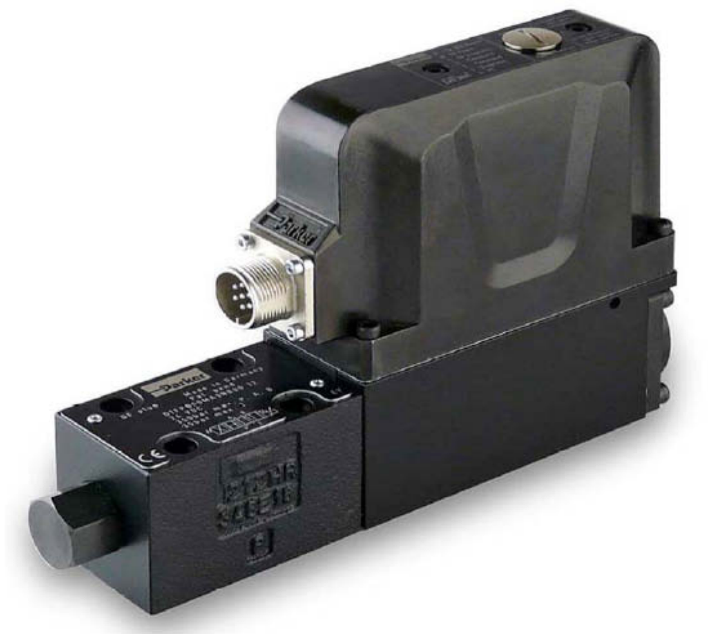

Figure 3: High dynamic direct operated servo valve with optimised actuator (Parker)

On the other hand there is a high motivation to extend the functional limits of direct operated valves combined with high dynamic performance. This is reflected by actual market trends to replace pilot operated valves by direct operated as much as possible.

The design of direct operated valves, which are also used as pilot valves for bigger valves, is characterised by the extension of the hydraulic functional limit and not by minimising the electric input power. **Figure 3** shows an example of such a high end valve based on a voice coil actuator to move the spool of the valve directly. The principle of the voice coil drive allows a series connection of several coils to sum the force of the single coils without losses in the dynamic. Such state of the art devices are characterised by dynamic performance like bandwidth or response time, which are typically known from nozzle flapper valves.

1.2.2. Reduction of power demand of the pilot operated valves

The use of direct operated valves is limited to certain hydraulic power levels. The power consumption of pilot operated valves can be reduced by an adapted design of the control areas of the valve, which means to increase the area of the control surface of the main spool according to the power demand of the special valve application.

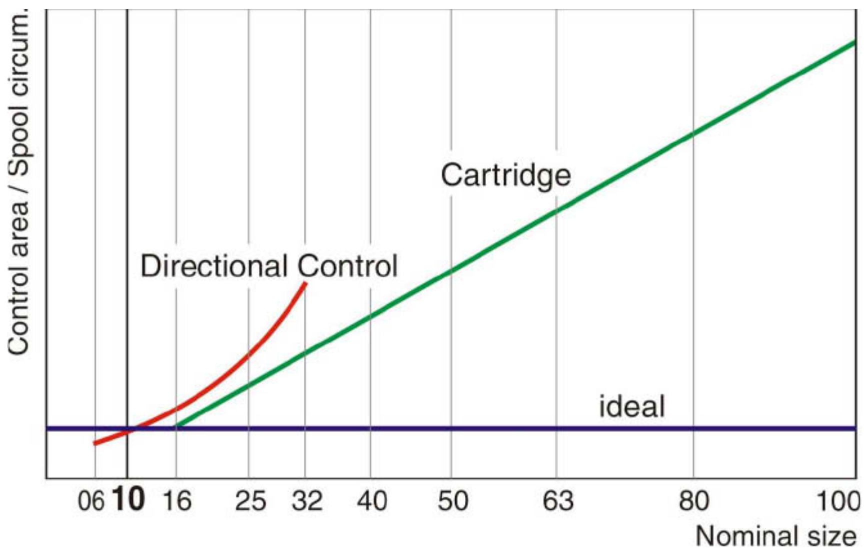

Figure 4: Dimensioning of the control area of pilot operated valves (Parker)

The curves in **Figure 4** demonstrate how a modern design approach for pilot operated valves can reduce the consumption of energy to operate the valve by reduction of the control area.

Figure 5: Servo cartridge valve with optimised control areas (Parker)

The picture in **Figure 5** shows an example of such a design with optimised control areas of the main stage spool.

1.2.3. Energy saving circuits for hydraulic cylinder drives

For unsymmetrical cylinders regenerative circuits are well known since a couple of years. In these circuits during movement outward typically the displaced oil from the ring chamber B of the cylinder is directed to the piston chamber A, while in parallel the valve controls the flow from port P (supply) to piston chamber A. **Figure 6** shows such a solution, integrated in the valve. By use of the integrated directional control valve and the check valve power savings between 10 and 1000 kW can be achieved.

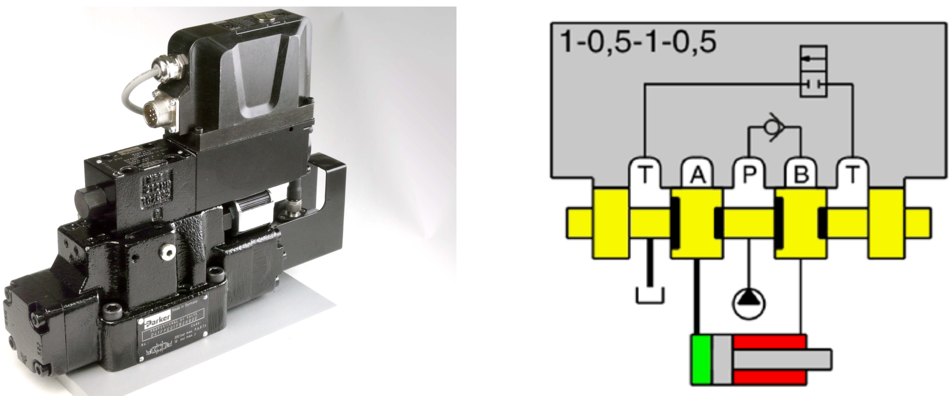

Figure 6: Servo proportional valve with integrated regenerative circuit (Parker)

Another approach without the integrated additional valves inside the servo proportional valve is shown in **Figure 7**. In this design the tank bridge is missing and 5^{th} port in the sub plate is used to connect the ring chamber port B to the second piston chamber port A2.

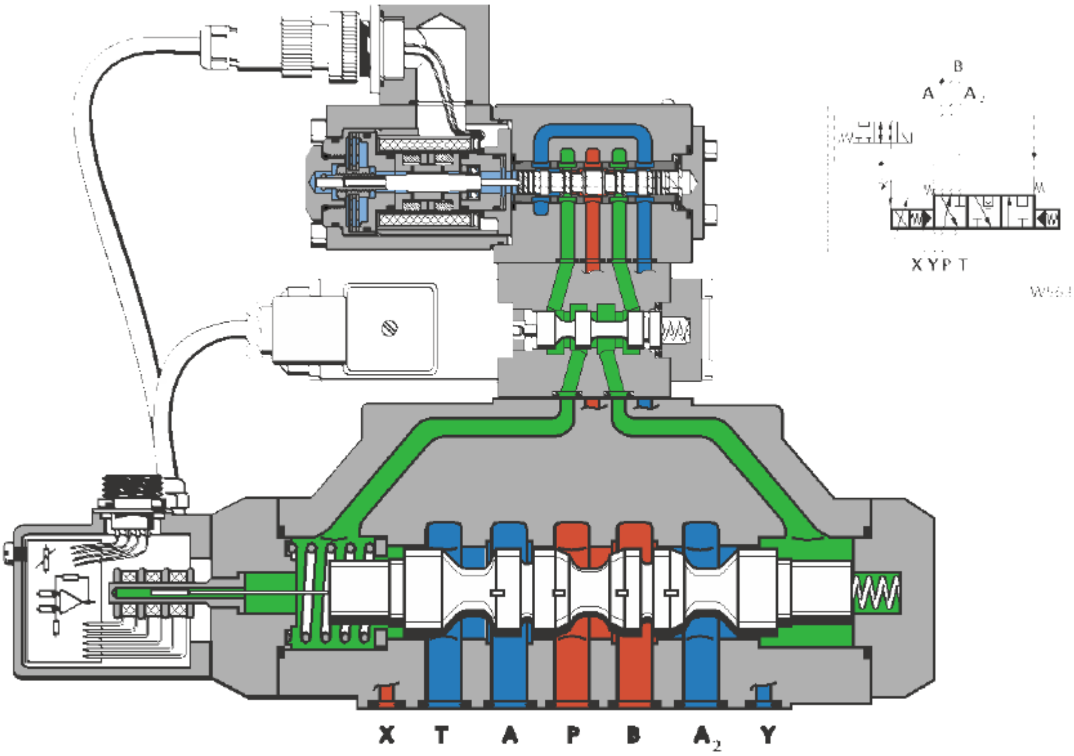

Figure 7: Servo proportional valve with integrated regenerative circuit (Moog)

1.3. Higher pressure

One trend in the design of production machines is to create smaller and compacter machines by higher force density. This leads to requirements of higher pressure in the hydraulic circuit. The actual industrial pressure standard is 350 bar and the trend is moving to 420 bar and in some applications also higher. In the moment 420 bar seems to be a suitable value and represents a lot of challenges for engineering:

- Lifetime and durability of pumps
- Availability and reliability of piping and connectors
- Availability of valves and other components

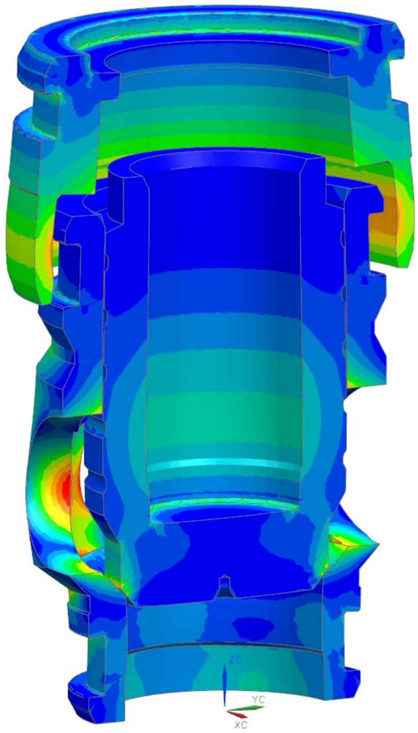

Figure 8: Finite element analysis of cartridge deformation and stress (Moog)

For valves the increase of the pressure level is a double challenge in form of cavitation tendency and deformation of steel components. A pressure level of 420 bar effects critical stress for steel material as shown in **Figure 8**. In parallel this pressure level effects critical deformations, so that the clearance between spool and sleeve must be adapted to avoid sticking of the spool while the leakage is increased.

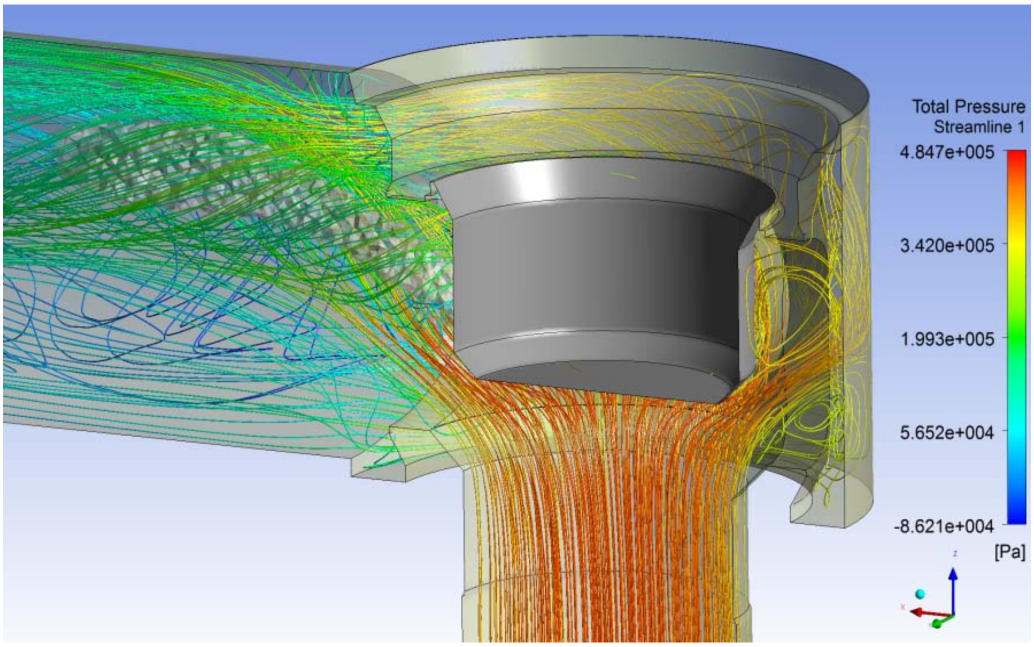

Figure 9: CFD analysis of 420 bar cartridge (Moog)

The use of CFD and FEA tools allows improved (decreased) pressure losses or improved flows on higher pressure level of 420 bar.

Applications like lifting, tensioning and testing demand for directional control (on/off) valves in higher pressure domains like 700 bar.

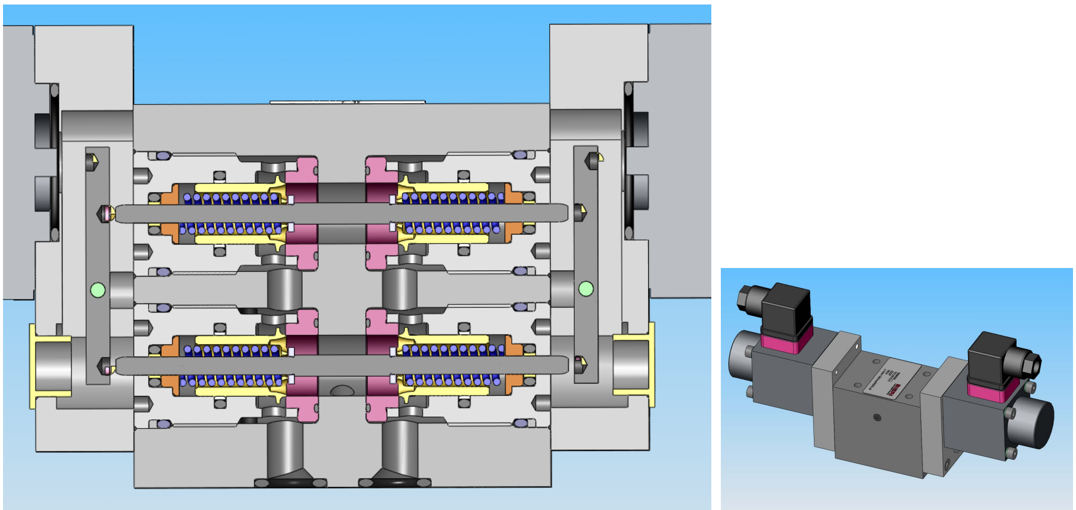

Figure 10: 4/3 seat valve for 700 bar (Hydac)

The seated valves in **Figure 10** are direct operated. Depending on the desired control function up to four valve cartridges are used. The poppets which are situated in the cartridge are pressed on the valve seat via springs or are opened via tappets. Hardened poppets and valve seats ensure long life. Pressure compensated poppets reduce the operating power.

1.4. Digital functions

There are developments in several places around the world to realise a proportional valve characteristic by use of on/off valves.

1.4.1. Realisation of proportional valve functionality with the help of on/off valves

A characteristic of so-called "digital hydraulics" deals with the realization of proportional functions with the help of on/off valves. Solutions as shown exemplarily on **Figure 11** are known from technical literature:

- The proportional valve function is realized using a great number of on/off valves
- In analogy to the principle of the "digital/analog converter" that is known in electronics, corresponding systems can be realised through differently weighted flow rates of valves

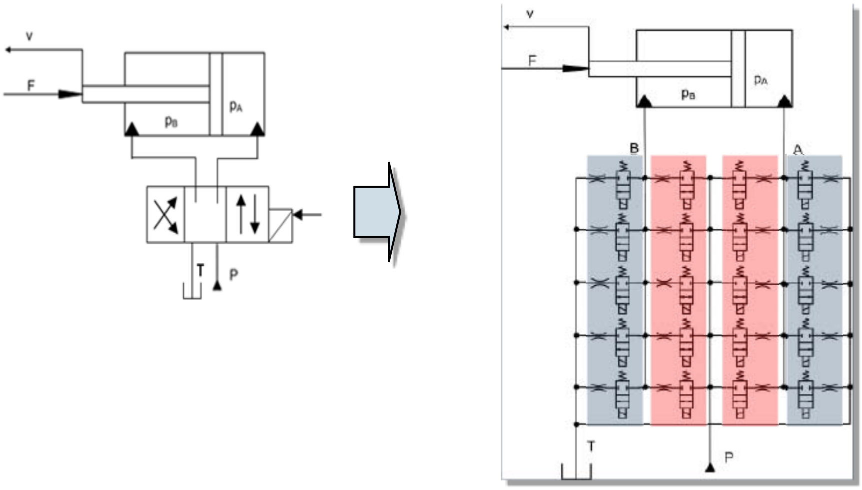

Figure 11: Realisation of a proportional valve function with the help of pulse code modulation (Bosch Rexroth)

This principle offers many advantages. Disadvantages, however, are the facts that

- a high resolution of flow requires an appropriate number of valves
- and this results in a relatively high investment in components and their connection and accordingly high installation space requirement

1.4.2. Ballistic control of on/off valves

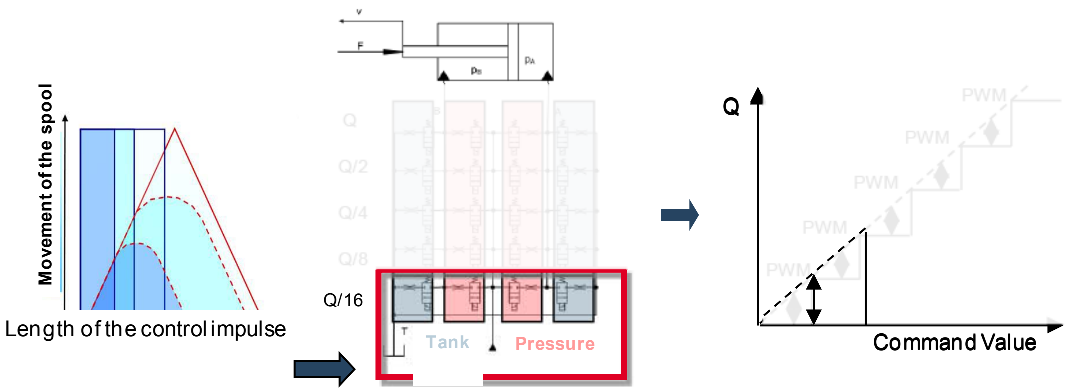

Figure 12: Ballistic control of on/off valves (Bosch Rexroth)

Another approach with regard to digital hydraulics was presented first at Hannover Fair 2011 as shown in **Figure 12**. With this approach, through the application of so-called ballistic control of on/off valves, a very high resolution is achieved, especially in the small signal range, with only one on/off valve per control land. This technology can offer advantages in terms of robustness, cost and energy consumption, in particular for applications that require a “rapid/creep speed functionality in conjunction with a distinct pressure-holding function”. Energy savings can be realized especially during the pressure-holding phase, because the operating principle of on/off valves with their inherent seat function generally rules out leakage oil losses and/or pilot oil losses.

1.5. Fieldbus interfaces

The field bus interface gets a dominant role for the integration of electrohydraulic actuators into the machine architecture. Actual standards of analogue interfaces are: ±10 V or 4…20 mA. Bus systems like Profibus or CAN are actually replaced by real time Ethernet interfaces, which are used for electric drive systems.

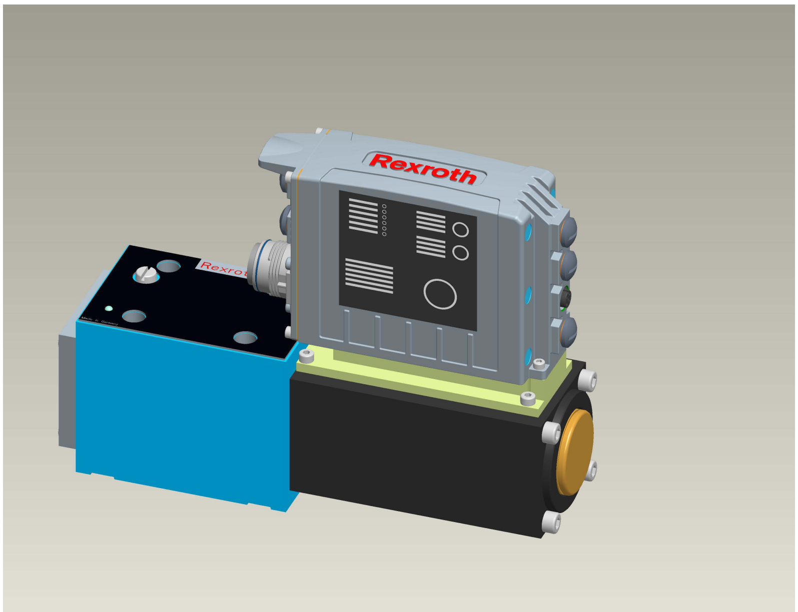

Figure 13: Servo proportional valve with „on board electronics“ and real time Ethernet interface (Bosch Rexroth)

Due to the electric systems valves with integrated real time Ethernet interfaces have been developed as the IA (Integrated Axis Control) shown in **Figure 13**. Such devices are characterised by features like:

- Multi-protocol ability like SERCOS III, VARAN and EtherCat.
- Same electronics for pumps and valves.
- Scalable electronics:
    - Replacement of analogue Interfaces. Implementation of the inner loops digitally
    - The use of integrated pressure transducers allows the implementation of pressure compensators
    - Implementation of integrated axis control loops like position and pressure/force
    - Motion control features like trajectories

These developments allow the integration of electro hydraulic actuators in central and decentral automation concepts.

1.6. User friendliness

The dynamic characteristic and performance like bandwidth, step response time, resolution and repeatability of servo valves can be really increased by using embedded digital electronics instead of analogue electronics. In parallel diagnosis and service features are available. Such devices contain typically a few hundred parameters to be tuned or read out by the operator. To allow a quick and easy use of the device the user interface gets a significant role for the handling of the control device.

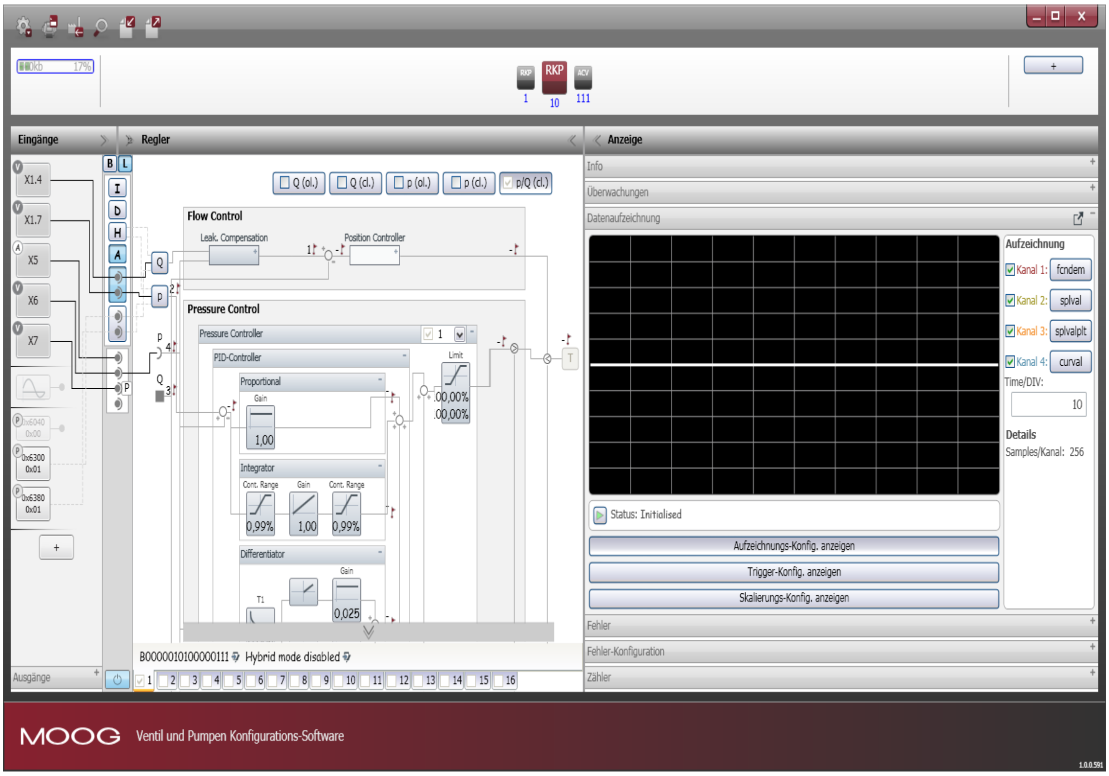

Figure 14: Screen shot of a valve configuration tool (Moog)

The investigations and the development of the digital control technology of the last years have been characterised by designs with focus on “easy to use” or user friendliness. The architecture of the controls and the control loops has not been changed or modified significantly meanwhile the surface and the architecture of the user interfaces has been improved significantly. **Figure 14** shows an example of such a user interface, in which the user graphically sees where he is and what he is doing. The control loops of the valve in form of current and position loops are shown as block diagrams and the actual behaviour of the valve in form of physical signals is shown in online oscilloscopes.

1.7. Special environment conditions

The use of integrated digital electronics inside of servo and servo proportional valves effects in increased dynamic performance, high repeatability and comfortable service and diagnosis interfaces. These features are now required in the growing markets of oil and gas production combined with explosion and flame proofed design. **Figure 15** shows a state of the art pilot operated and direct operated servo valve with integrated digital electronics and hot pluggable connector and according ATEX Temperature classes II 2G Ex d e IIC TX Gb T3 up to T6.

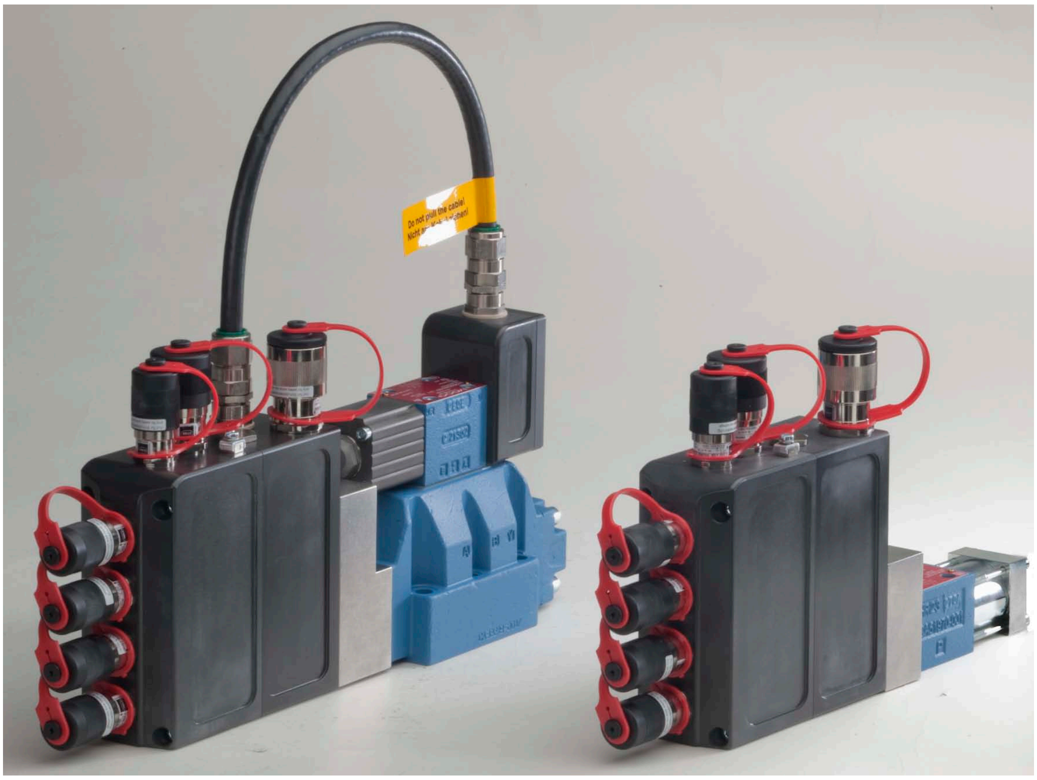

Figure 15: Explosion proof valves with integrated digital electronics (Moog)

The digital driver and control electronics are integrated in the valve. The valve electronics contain a microprocessor system, which executes all the important functions via the embedded valve software. The digital electronics enables the valve to be controlled across the full range of operation, with significantly reduced influence from temperature and drift. The built-in fieldbus interface (e.g. CANopen®, Profibus-DP® or EtherCAT®) enables operating parameters to be set, activates the valve and monitors its performance. In a safe private or virtually private network the user can communicate directly with the valve from anywhere in the world. Other representative applications for this technology are:

- Oil and gas exploration
- Gas turbines
- Power generation
- Wood processing
- Presses
- Maritime equipment

2. Outlook

In parallel to the actual development trends in the valve technology, described in the chapters above, there is a clear trend in the design of actuators to reduce the energy consumption of an electrohydraulic actuator by avoiding the throttle losses of the valve. In these electro hydrostatic actuator designs the cylinder is driven directly by the pump inside a hydrostatic transmission as shown in **Figure 16**.

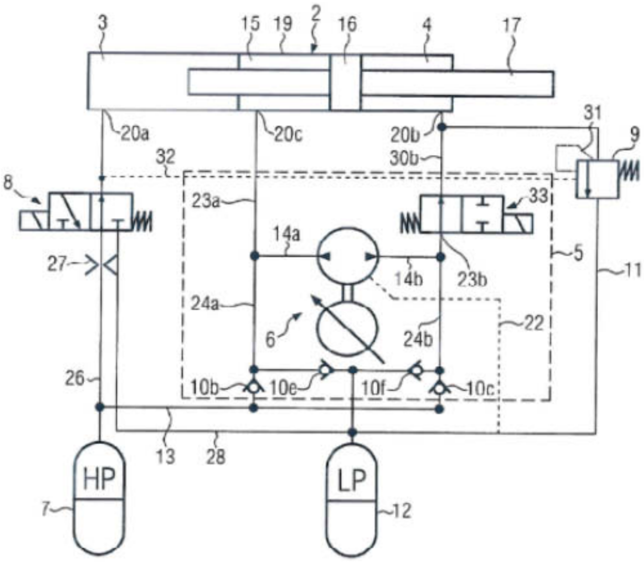

Figure 16: Circuit of electro hydrostatic actuator (Moog)

Such an actuator design is used in aircraft applications since a couple of years. It combines in a synergy the advantages of electromechanical and electrohydraulic systems:

- High reliability and durability of the hydraulic cylinder
- Low energy consumption by power only on demand
- Easy implementation of energy storage by a hydraulic accumulator

Figure 17: Electro hydrostatic actuator (Moog)

The picture in **Figure 17** shows such an implemented pitch actuator of a wind turbine with an integrated fail safe function. The reservoir could be integrated into the cylinder. The design is based on proofed basic components like motor, pump and valves, which have been adapted to the application requirements.

3. References

/1/ German patent 10 2010 053 811.6