DEVELOPMENTS IN HIGH PERFORMANCE PROPORTIONAL VALVES WITH CANOPEN FIELDBUS INTERFACE

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Abstract

Fieldbus systems were established some time ago in the industry, but proportional valves with fieldbus interfaces have not been available in the past.
Fieldbus systems were developed to replace analogue techniques, where various industry standards exists. The counterpart to these industry standards are open fieldbus systems. In addition to the fieldbus standards, device profiles for proportional valves are required. These are currently under development by a group of hydraulics manufacturers.
With the introduction of a proportional valve with CANopen interface, MOOG makes a further step into a new era of valve design. The resulting proportional valve includes features that haven't been possible to date. A detailed knowledge of the fieldbus and the device profile is not essential for a hydraulics expert, because of the availability of set-up, diagnostics and configuration tools.
Future development will include other fieldbus systems and will integrate axis control functionality into the proportional valve.

1 Introduction

The fieldbus technology belongs to the key technologies of the automation industry. InterBus-S, Profibus-DP, DeviceNet and CANopen are some well-known representatives of those systems. Fieldbus systems are characterised by the use of a network which interconnects several devices at the machine level.

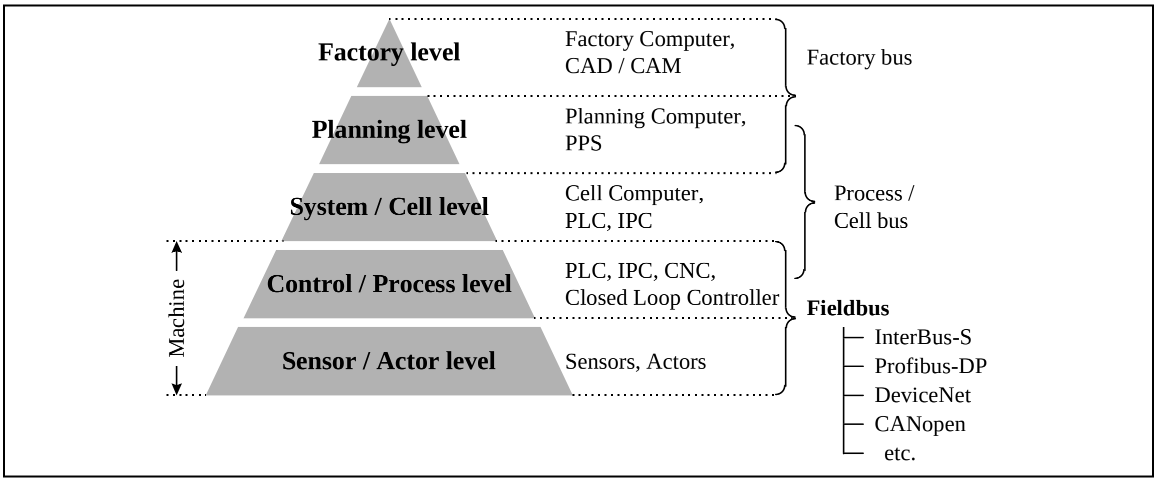

Figure 1: The fieldbus in the layer model of the automation technology

Although fieldbus systems were established some time ago in the field of electrical drive technology, the hydraulic drives have been slow to follow this trend. In particular, industrial proportional valves with fieldbus interfaces have not been available in the past.

There are various reasons for this delay:

Firstly, it is an economical question. The additional expenditures for the integrated fieldbus interface will be only invested, if considerable benefits can be obtained.

Secondly, the acceptance of fieldbuses within hydraulic systems is restricted because of the special nature of the hydraulics market. The use of electronics and related technologies is not as self-evident as it is in many other industrial fields.

Furthermore, the high dynamics of servo hydraulics demands for high speed fieldbus-systems and high processing power, which is difficult to realise if costs are critical.

Because of limited space in the electronics housing and the extremely harsh environment to which proportional valves are exposed, the integration of the required electronics is demanding. As a consequence of the fieldbus implementation, the technology inside the valve is going to change from analogue to digital micro-controller based electronics, which itself represents a considerable changeover.

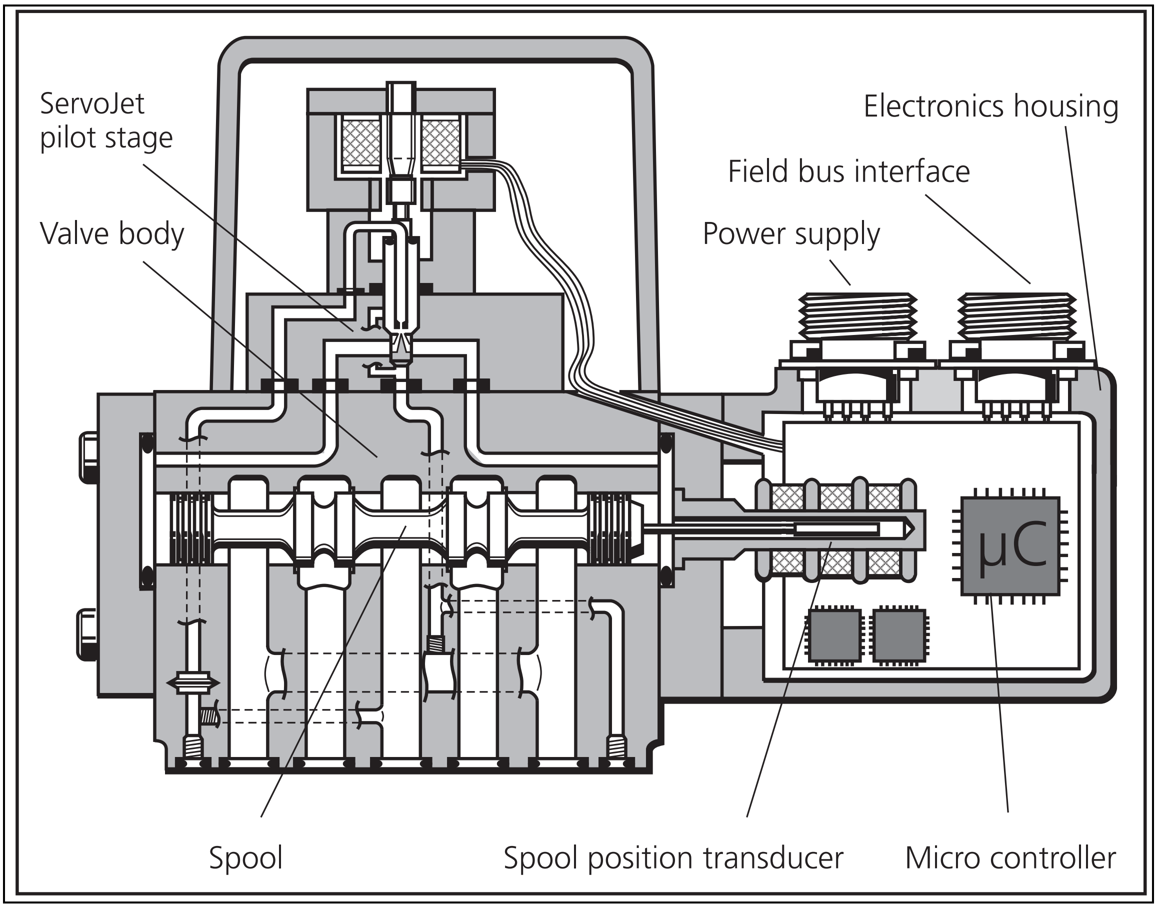

Figure 2: Principle of a proportional valve with fieldbus interface
and integrated digital electronics

2 Fieldbus Systems vs. Analogue Techniques

Fieldbus systems were developed to replace analogue techniques, where some industry standards exists (e.g. ±10V, 4…20mA). The counterpart to these industry standards are open fieldbus systems, which are clearly specified or standardised in terms of physical details (cables, connectors) and data exchange mechanisms (protocols). This ensures compatibility and device inter-operability, independent of the device manufacturer.

The parallel wiring of analogue techniques will be replaced by a serial wiring scheme, reducing the installation and documentation costs. It also enhances flexibility, because the system can be easily changed or extended.

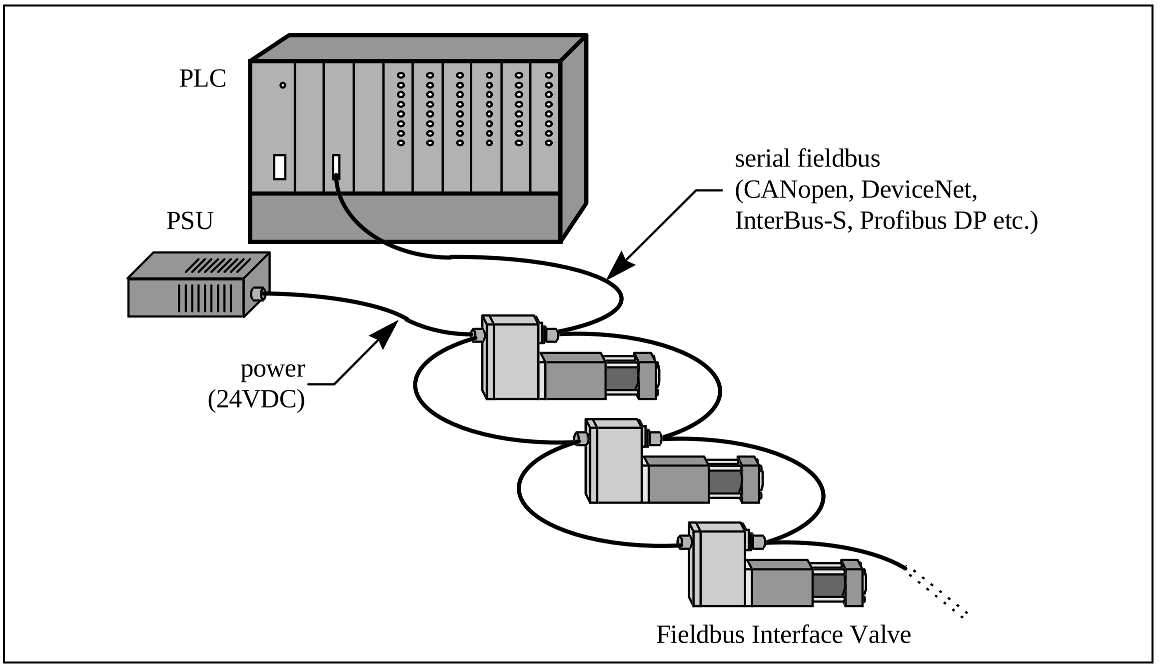

Figure 3: Serial wiring scheme for fieldbus interface valves

A network requires digital data transmission and a protocol to interpret the transmitted information. Therefore, a fieldbus system appears to be more complex in comparison to analogue systems. On the other hand, the user-friendliness is enhanced by several configuration and diagnostics tools which are available for fieldbus systems.

To improve the safety and reliability of fieldbus systems, emergency and diagnostic mechanisms are implemented, which also simplifies the maintenance. Transparency of device status and process values within the network allows improved process control, which is necessary for high and steady quality of the products.

Electromagnetic interference and transmission losses are a serious problem for analogue systems. Fieldbus systems provide error correction mechanisms in order to significantly increase immunity to interference. Furthermore, the digital data transmission improves the accuracy and the reproducibility of the process, even though the resolution is limited due to quantization.

Decentralisation of the application is another aspect of fieldbus systems. In a decentralised system, the tasks of a sub-system are assigned to local devices, whereby the complexity and the required processing power of the main control device can be significantly reduced.

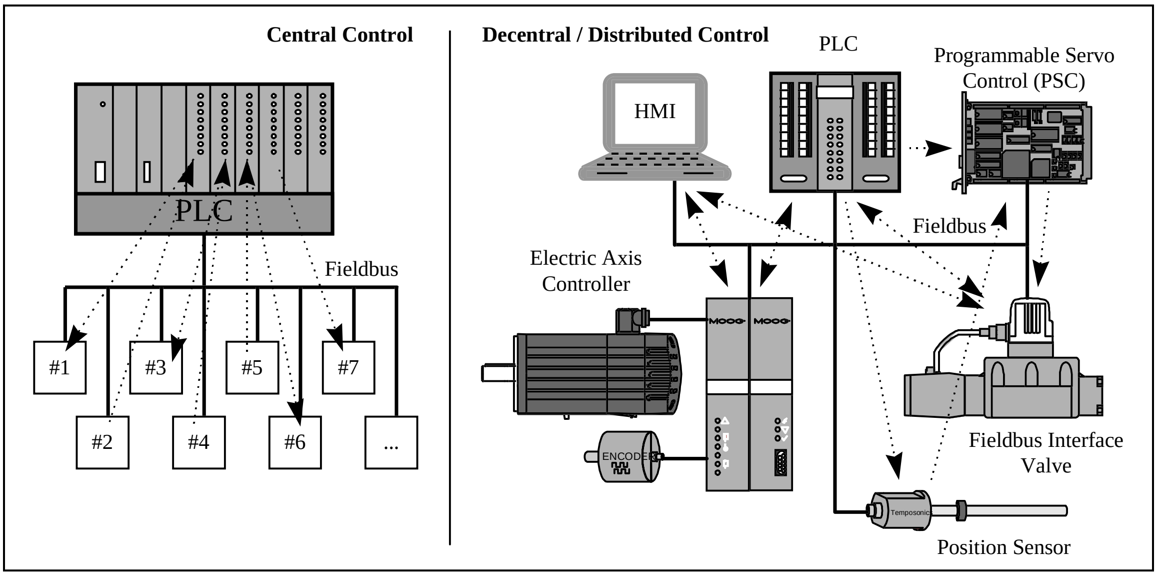

Figure 4: Central vs. decentralised systems

A decentralised system completely changes the architecture and the control concept of the machine. Nevertheless, such a system can be centrally operated, so that the full functionality of all controlled devices appears to be located on the main control device.
A potential drawback of fieldbus systems is the limited transfer rate, which could affect the performance of devices with high dynamic requirements.

2.1 Fieldbus Systems in Hydraulics

A fieldbus selection usually is based on the requirements and demands of a specific industrial sector, machine or a customer. To introduce the fieldbus technology successfully in the hydraulics market, a highly specialised field, it is advisable to support open, standardised or internationally accepted fieldbus systems. Thereby it is ensured, that a wide range of compatible components are available, which can be easily adapted to hydraulic motion control systems.
Digital and analogue I/O's, sensors, human machine interfaces (HMI), external controllers (PLC, IPC…) etc. are readily available, even though they were not originally designed for hydraulic applications.

2.2 Device-Profiles

In addition to the fieldbus standard, which mainly describes the data exchange mechanisms, a specification of available functions and parameters for each specific device is required. The so-called device profile is a standardised specification of the device functionality and applies to all devices of the same family (e.g. proportional valves). A device profile is a provision that is required for compatibility and inter-operability within a system. A device-profile for hydraulic drives or hydraulic proportional valves does not exist so far.
A framework for such a profile is currently under development by a group of hydraulics manufacturers. This group meet at the VDMA, the German Machinery and Plant Manufacturer's Association. The aim of this framework is to serve as a guideline for bus

specific implementations, and has been distributed to several bus system organisations for approval. MOOG is an active member in this VDMA group and supports the standardisation process, because we see this as the key to a breakthrough of fieldbus technology in hydraulic systems.

3 Fieldbus Interface for High Performance Proportional Valves

The analogue interface of a proportional valve is easy to handle, and it does not affect the performance of a valve, if an adequate wiring is carried out. However, the time discrete transmission of demand values in a fieldbus system can affect the closed loop performance. Therefore, a careful system design is required to obtain the full benefits of fieldbus integration without degrading performance:

- The fieldbus interface provides overall access to the valve, so that it can easily be configured, monitored and maintained. The valve parameters can be visualised and modified via a PC or by any other Human Machine Interface (HMI).
- Due to configurable functions and tuneable valve characteristics, the functionality and performance can be optimised for various control applications.

3.1 Fieldbus Performance Requirements

The main restriction of fieldbus systems, the limited transfer rate, becomes relevant if the fieldbus is used to close a control loop: to ensure similar performance compared to the standard analogue interfaces of conventional proportional valves, high transfer rates and real time capability must be guaranteed. Although fieldbus systems are designed for highly efficient data-exchange, they have restrictions should short cycle times be required. To reach an equivalent performance to analogue valve applications, a cycle time in the region of 1ms is recommended. The cycle time selected depends on the application, pressure or flow control, as well as the overall system dynamics.
In fact, the high dynamics of hydraulic motion control systems demands for higher efficient fieldbus systems. But even with faster fieldbus systems available in the future, their standardisation and acceptance will take time.

4 Proportional Valve with CANopen Fieldbus Interface

With the availability of highly integrated and high-performance micro controllers at an affordable price, the concept of an industrial proportional valve with fieldbus interface can become reality. With the introduction of a proportional valve with CANopen interface, MOOG makes a further step into a new era of valve design.

4.1 Controller Area Network (CAN)

CAN was originally developed for automotive applications. Major advantages of CAN are the high efficiency and the high data transmission security. Further features of CAN include:

- Two wire serial bus with line-topology.
- Up to 64 modules per network.

- Up to 1Mbit/s transfer rate.
- Secure data transmission (Hamming Distance 6).
- Multi-master capability.
- Hot-plugable.

Each device connected to the bus is permitted to transmit data via broadcast messages, and each device itself decides whether the message received is relevant for its own application. A message is addressed by its Communication Object Identifier (COB-ID) and contains zero to 8 data-bytes. Secure data transmission is ensured with bit-stuffing and a CRC-field (**C**yclic **R**edundancy **C**heck).

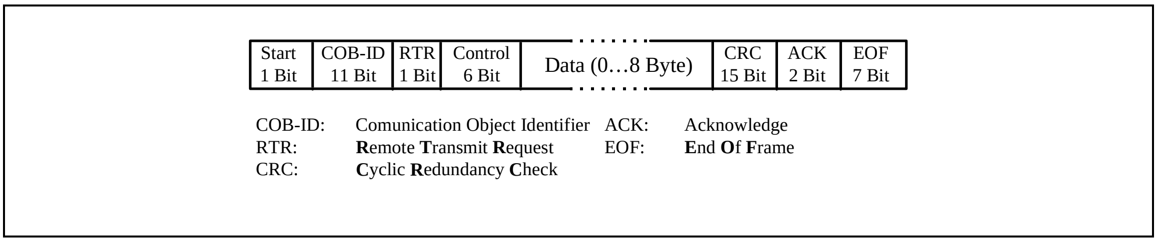

Figure 5: CAN data frame (specification 2.0 A)

4.2 CAN and CANopen in the OSI Reference Model

The CAN bus describes the first two layers of the 7-layer OSI Reference Model (**O**pen **S**ystem **I**nterconnection) as follows:

- Physical Layer (electrical and mechanical definitions: e.g. connectors, cables, coding etc.)
- Data Link Layer (**M**edium **A**ccess **C**ontrol [MAC], error detection and correction mechanisms)

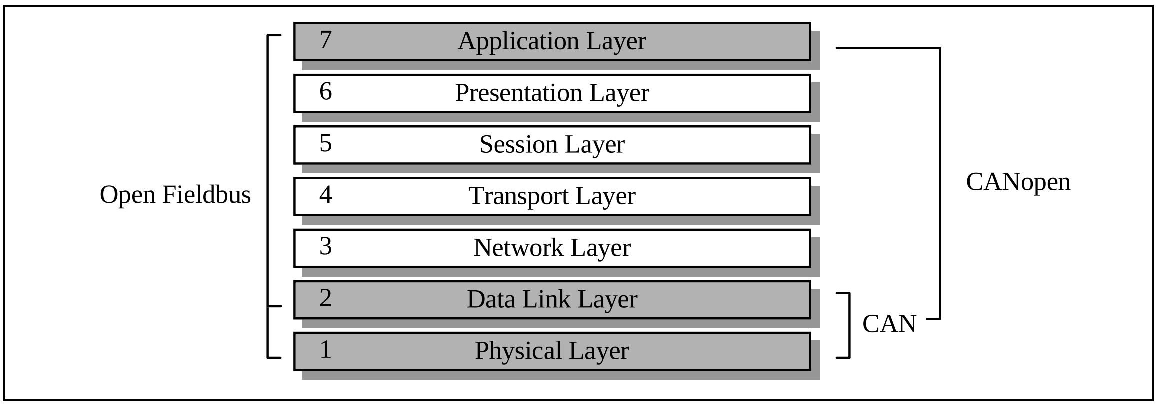

Figure 6: CAN and CANopen in the OSI Reference Model

Both layers are supported by integrated CAN controllers, so that a CAN node is relatively easy to implement. The cost of these controllers is low due to high production volumes.

It is these lower costs and high efficiency of the CAN bus, that makes it suitable for industrial applications. However, the lack of the CAN bus is, that it doesn't meet the requirements of an open system.
To achieve this, layer 7 of the OSI model must be defined, which is called the Application-Layer. The Application Layer describes the protocols and methods, that are required for the inter-operability in an open system.
CANopen enhances the simple CAN bus to an open system by means of a standardised Application Layer. The CANopen standard specifies the data exchange mechanisms and protocols, so that inter-operability between CANopen conforming devices is guaranteed.

4.3 Open Fieldbus Standard CANopen

CANopen is a draft standard, which is maintained and distributed by the **C**an **i**n **A**utomation user group (CiA).
CANopen provides high flexibility, so that a device can be adapted to specific communication requirements, even to allow communication with devices which are not conform to the CANopen protocol. CANopen also provides a ‘plug and play’ feature, where all basic settings are predefined.
The main elements of CANopen are the **S**ervice **D**ata **O**bject (SDO) for down- and upload of configuration data and the **P**rocess **D**ata **O**bject (PDO) for highly efficient process data transmission.

4.3.1.1 Down- and Upload of Configuration Data via the SDO

All configuration tasks are handled via SDOs (**S**ervice **D**ata **O**bject). This is a logical communication channel to a specific configuration device, which could be a laptop or the PLC controller. Each data exchange requires a minimum of two CAN messages, one for the request for the down- or upload and the second for the confirmation of receipt.

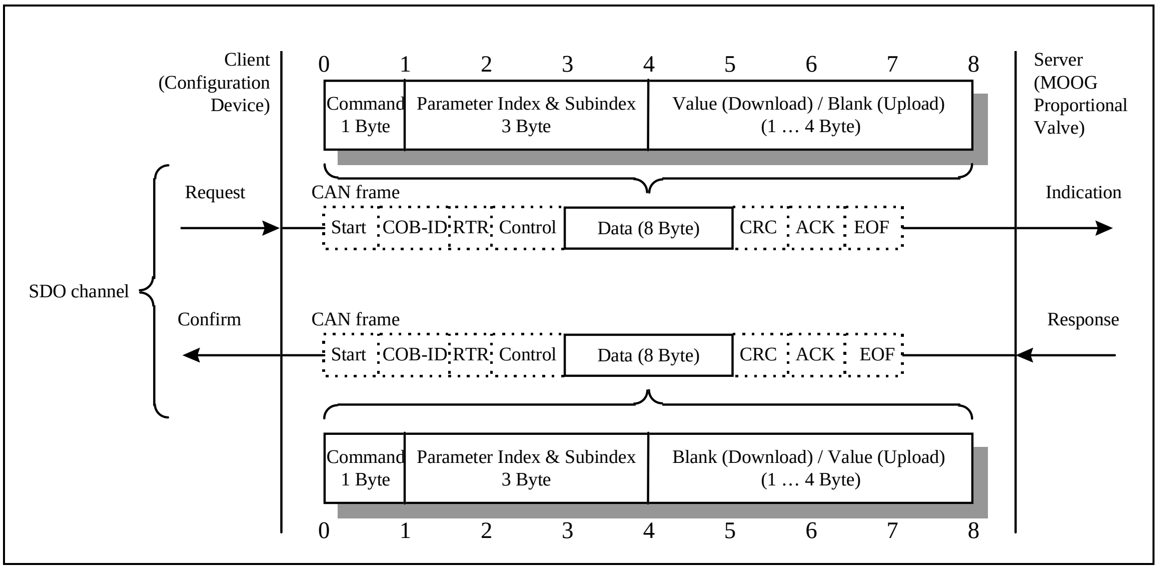

Figure 7: Protocol for an expedited up-/download of configuration data

The standard method is the so-called expedited up- or download, which allows transfer of data with a maximum length of 4 bytes. More data can be transmitted with an segmented up- or download, where the data is distributed into separate CAN message frames.

4.3.1.2 Process Data Transmission via the PDO

The process data is transmitted via PDOs (**P**rocess **D**ata **O**bjects), which are highly efficient because of no protocol overhead. This means, that the data field of the PDO does not contain any data description, just the process data. The PDO content itself is described in communication and mapping parameters, which are stored in the device. There are two types of PDOs, the Receive PDOs (RPDO) and the Transmit PDOs (TPDO), distinguished by the direction of the data flow.

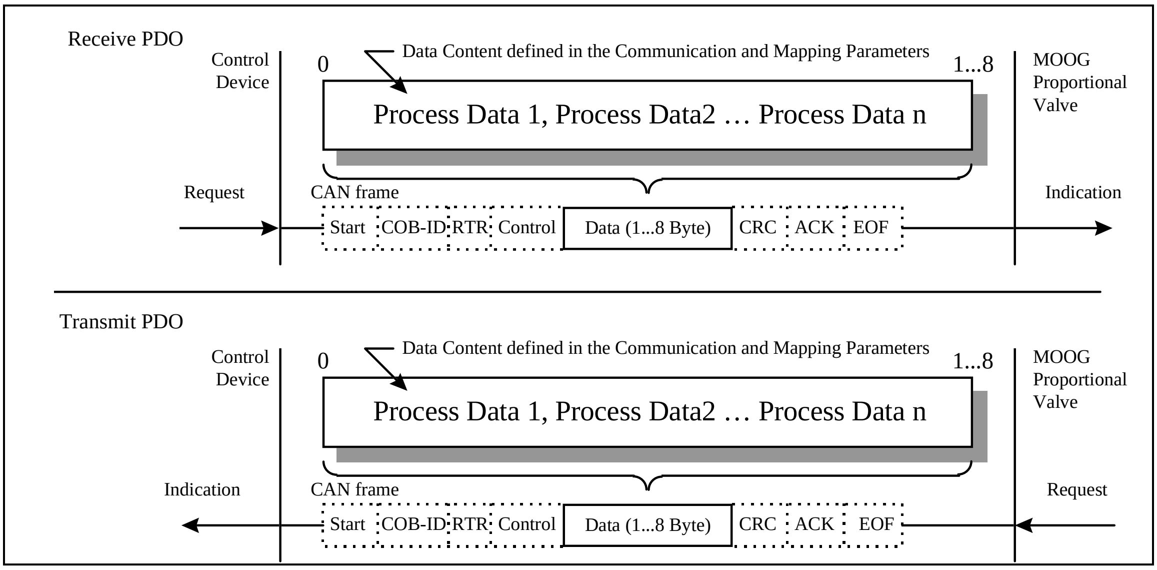

Figure 8: Process data transmission, the protocol data is not included in the real time communication

To enable a deterministic time behaviour, CANopen provides a synchronisation mechanism for the PDO transmissions. This is implemented by an Synchronisation Object (SYNC), which is a high priority message used to trigger the process data transmission and reception.

4.4 Valve Functionality

The valve functionality is based on a proposal, that is currently under development by VDMA. The resulting proportional valve includes features, that haven't been possible to date.
The current release includes demand signal conditioning, ramp generators and tuning capabilities (Figure 9):

- Linearisation of flow characteristics.
- Four quadrant ramp generator.

- Cylinder area compensation of the actuator.
- Adjustable deadband compensation.
- Demand signal limiting.
- Tuneable loop closure for the spool position.

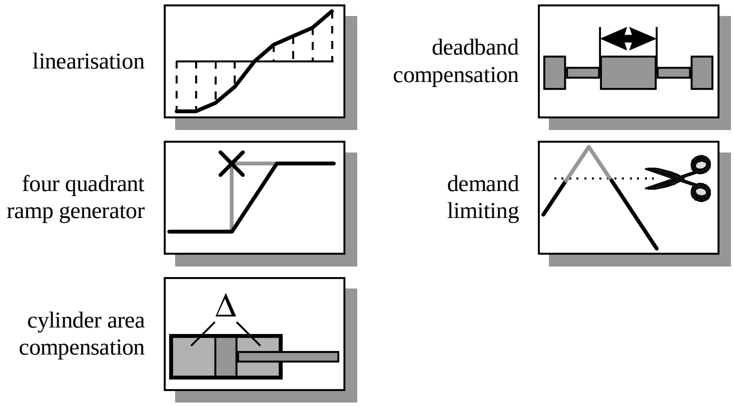

Figure 9: Demand signal conditioning

Valve status, parameter settings and process values are completely transparent via the fieldbus:

- The status-word parameter provides overall information about the valve status.
- All parameters and process values are fully accessible via the bus.
- Unauthorised access to sensitive parameters is prevented by password protection.
- The error of the spool position controller is monitored and signalled if it exceeds the limit.

Simplified maintenance is ensured by efficient diagnostics mechanisms:

- Errors are signalled via emergency messages.
- Occurred errors are listed in a chronological error list.
- The reason of a malfunction is described by an error code.
- The valve can be identified by the manufacturer's name, device type and serial number, which are stored in the device.

The demand value represents the flow rate of the fluid and is transmitted with a resolution of 16 bits. It is also possible to read the actual value, which corresponds to the spool position of the valve.

4.5 Loop Closure via the CANopen fieldbus

Reception of the demand value and the transmission of the actual value is handled via the highly efficient PDO. Loop closure via the bus is possible due to the high transfer rate of the CAN bus (up to 1 Mbit/s). For high performance motion or pressure controls in hydraulic applications, a cycle time in the range between 0.5 to 2ms is advisable. Figure 10 shows the maximum number of motion control axes in closed loop applications, whereby a position sensor with 4 byte input data and the MOOG fieldbus interface valve with 2 byte output data is assumed for each axis.

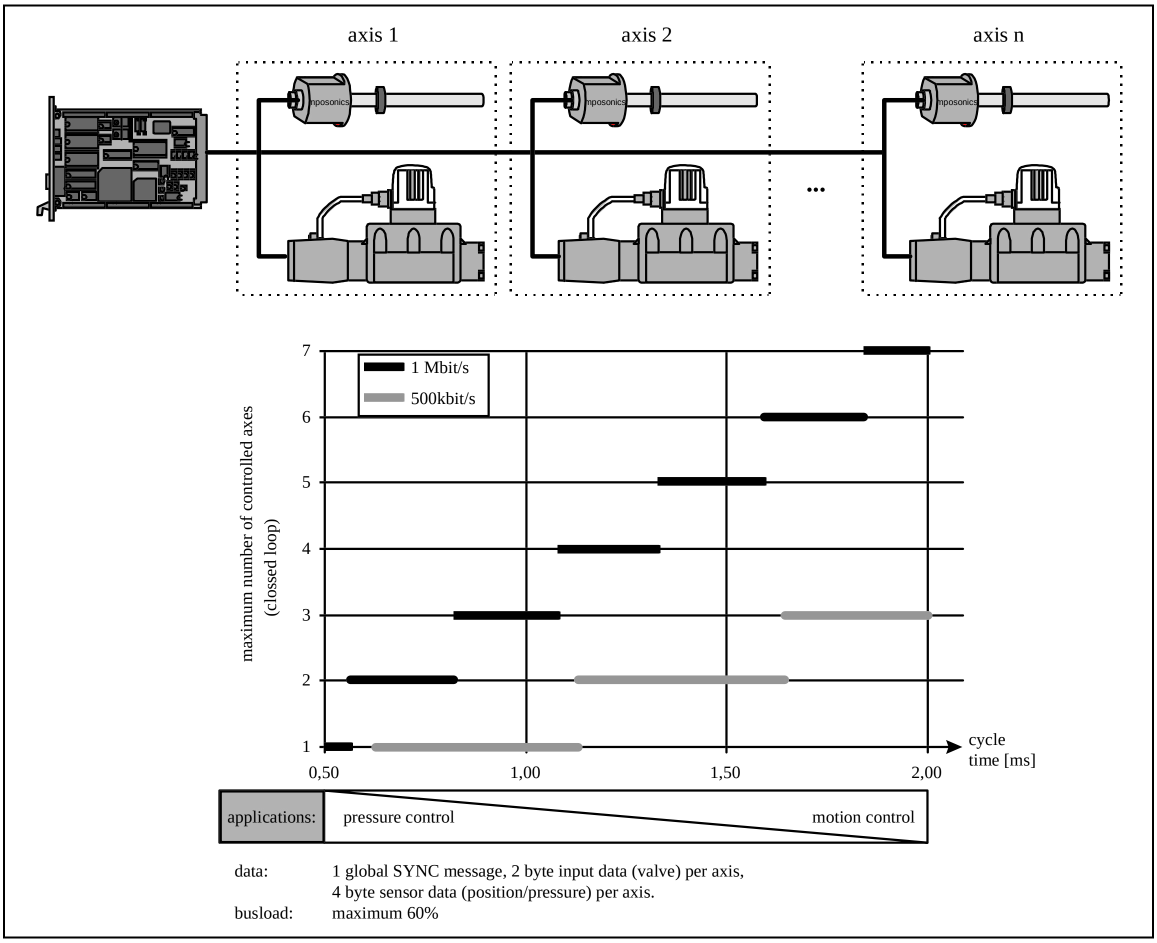

Figure 10: Maximum number of controlled axes (closed loop applications)

The required cycle time affects the maximum number of devices within a network, which are simultaneously within a loop. However, it should be remarked that more devices can be handled by one CAN network, when only a limited number of loops are closed at a time. This applies especially to machines, where a machine cycle is divided up into separated processing phases, so that the loop closure for some devices can be temporarily interrupted.

Possible applications for this proportional valve are small systems, such as production-cells and small or mid-size machines. In lower performance applications, where no loop closure is required, the system is expandable to 64 devices, which is the maximum allowable extension of a CAN-bus system.

5 Set-up, Diagnostics and Configuration Tools

Set-up, diagnostics and configuration tools serve as a human machine interface, therefore a detailed knowledge of the fieldbus and device profile functionality is not essential. This enables the hydraulics expert to concentrate on the application.

Such tools can typically be obtained from third party suppliers, but aren't currently available for hydraulics. To allow customers to configure the valve with CANopen interface, MOOG developed a PC-based graphical user interface (GUI). Figure 11 shows the graphical front end, where in this example the ramp configuration page is selected.

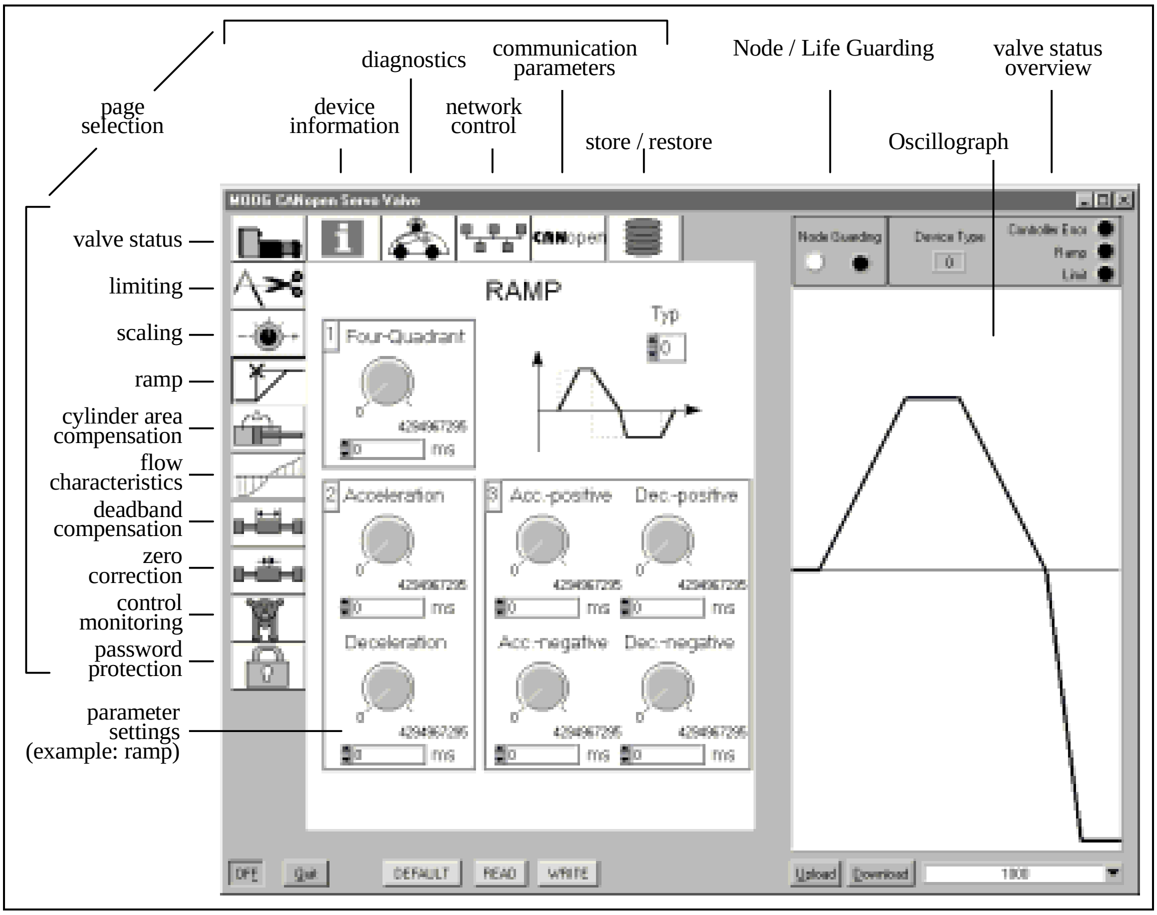

Figure 11: Graphical User Interface for the MOOG CANopen Valve

6 Outlook

In addition to the fieldbus technology, incorporation of digital electronics in the valve provide a platform for further innovations in future. The built-in micro-controller enables supplementary functions, which are conventionally processed by external control systems. The fieldbus is a prerequisite to configure and access these built-in functions, since the valve is completely capsulated.

The incorporation of functions into the valve electronics has considerable advantages:

- The costs and the wiring for the external electronics could be saved.
- The motion and pressure control tasks would be processed decentrally by a highly specialised device, thereby simplifying the planning and the set-up of an application.
- The bus load would be significantly reduced by closing the control loop locally. This could be easily achieved by using pressure control valves with integrated pressure transducer, which is an exceptional speciality of MOOG (e.g. P/Q proportional valves).

As a consequence, the basic proportional valve will migrate to an ‘intelligent’ device, which is going to take over the complete control for one axis. The result would be an 'Axis Control Valve', which includes the functionality of up-to-date external electronics, e.g. the MOOG **P**rogrammable **S**ervo **C**ontrol (PSC)

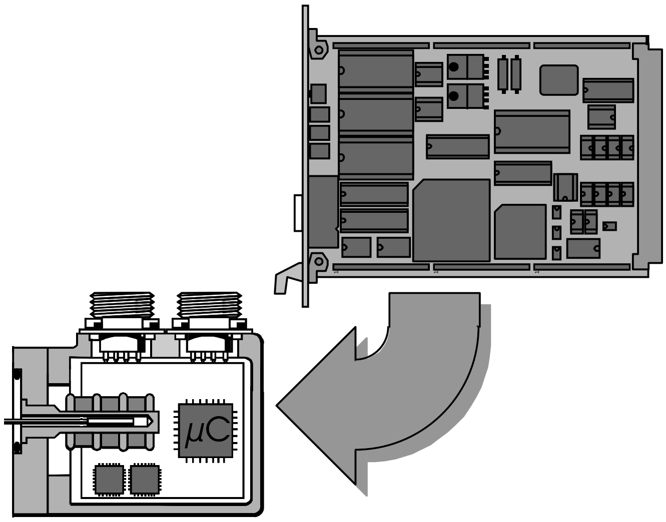

Figure 12: Built-in axis controller in an 'Axis Control Valve'

MOOG is in progress to develop the next generation of 'intelligent' proportional valves, so that the 'Axis Control Valve' is more than just a vision.

7 Summary

MOOG's prototype marks the beginning of a new generation of high performance proportional valves. Production units of CANopen fieldbus interface valves will be available in the near future. Their introduction is justified by the given advantages of the fieldbus interface:

- Freely configurable functions enhances the functionality and the flexibility.
- Adjustable valve characteristics allows best performance in hydraulic control applications.
- The wiring costs can be reduced because of less planning and installation expenditures.
- The immunity against electromagnetic interference is significantly increased.
- The improved diagnostics simplifies the maintenance.
- Tuning and configuration is simplified due to an external Graphical User Interface (GUI).
- The fieldbus enables distributed control systems.

The development will continue to support further fieldbus systems, which are:

- Profibus-DP
- InterBus-S
- DeviceNet

After the fieldbus integration, the incorporation of axis control functionality into the proportional valve will be the next step. This will require an entirely new approach in system design and implementation.

The future of hydraulics will change. MOOG will therefore introduce new and innovative products. The developments of fieldbus systems in hydraulic applications is not only a question of competition, but more a result of the demands of today's state-of-the-art machines.