The advantages of new proportional and servo valves with integrated digital electronics

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ABSTRACT

The paper presents a new generation of proportional and servo valves with integrated digital electronics. The micro controller allows with its free programmable signal processing options a significant improvement of the dynamic and static performance of the valves. Selected examples demonstrate this improvements. In addition to the performance the valves could be changed from simple hydraulic components to intelligent axis control devices, which are state of the art and are able to compete against electric drive systems. These additional features like self diagnosis, remote access, comfortable control parameter tuning and free programmable characteristics are demonstrated in selected application examples like a wind turbine or an injection molding machine.

NOMENCLATURE

p	pressure	bar
Q	flow	l/min
f	frequency	Hz

1 INTRODUCTION

The performance and comfort of electrohydraulic valves could be improved by the use of digital electronics instead of analogue electronics. The performance is mainly characterized by an improved bandwidth, reduced step response time, threshold and hysteresis. The digital electronics also allows the easy implementation of features like self-diagnosis, remote access or integrated axis control. That means that the new generation of valves changes from a pure component to an intelligent high performance subsystem, which is well accepted by the industry. Application examples will be shown in the following.

2 PERFORMANCE OF ELECTROHYDRAULIC VALVES

Servo and proportional valves are typically actuated by proportional solenoids, linear force motors or torque motors. These different drive systems are often characterized by a nearly linear dynamic open loop behavior. The static characteristic is more or less non linear and depends on the design of the drive system. These non linearties are progressive or digressive force or torque curves versus stroke or non linear hydraulic gains of the pilot stages in pilot operated valves. There is also a power limitation of the electric current driver by the limited or regulated supply voltage of the amplifier.

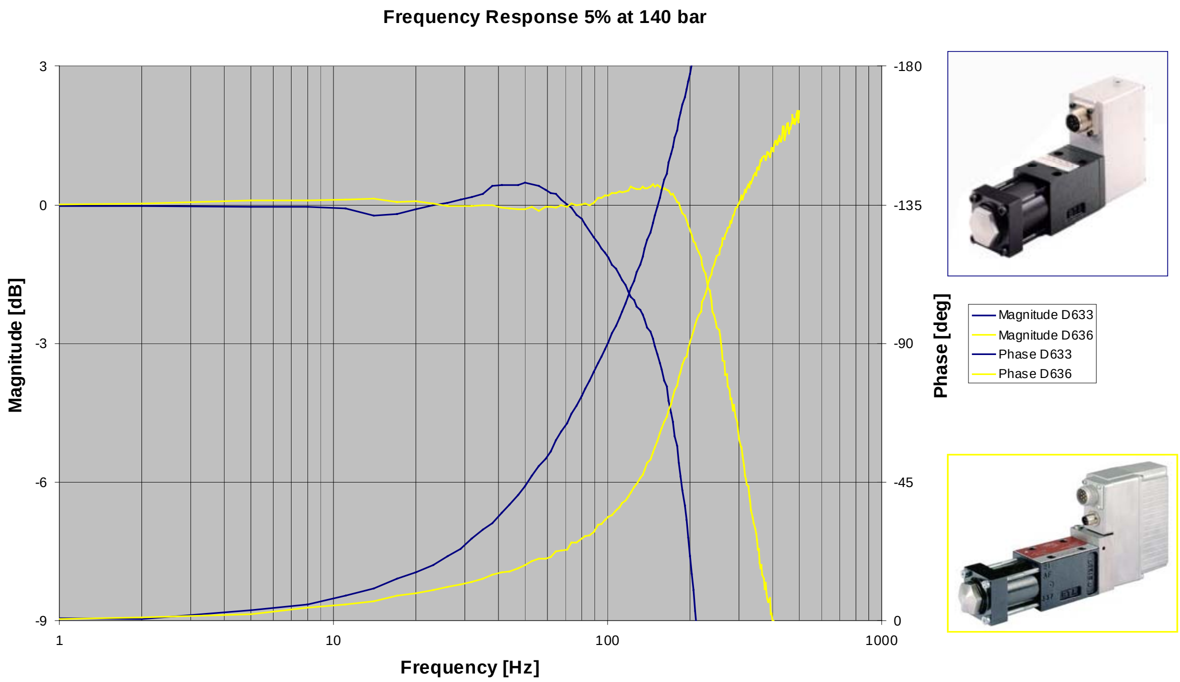

Figure 1: Frequency responses of a direct operated valves

In analogue valves these characteristics are often not compensated or adapted by dual gain curves of the feedback of the static and dynamic values. The micro controller with its free programmable signal characteristic allows a tailor made adaptation of the non linearity. The effects are higher loop gains of the feedback values which increase the bandwidth and he accuracy of the valves. ***Figure 1*** shows an example of these effects. Both frequency response plots are measured under the same conditions, which means the same mechanical hardware and the same hydraulic values. The yellow curves of the digital valve indicate that the bandwidth is nearly the double of the analogue valve, which is plotted in blue lines. Similar results are shown in ***Figure 2*** for pilot operated valves. The improvement of the performance is for pilot operated valves limited due to the flow limitation of the pilot stage.

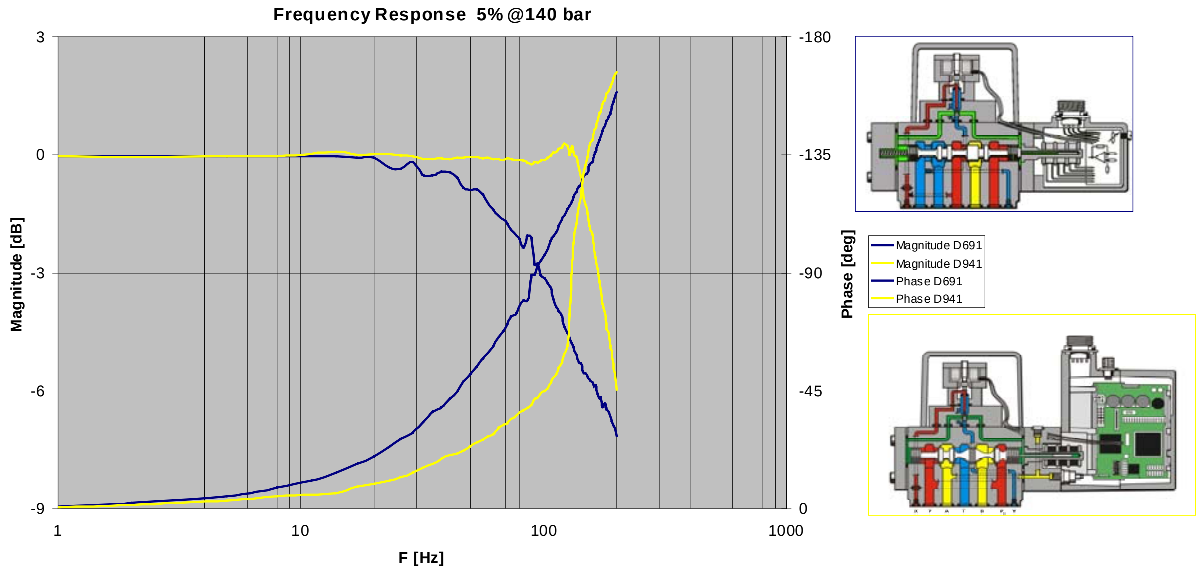

Figure 2: Frequency responses of a pilot operated valves

In some applications the gain of the inner valve control loops could be increased by factor 10 in relation to the analogue valves. Direct operated valves accede by adjustment of these high loop gains a sensitivity, which is only known from pilot operated servo valves.

3 FEATURES

The use of a microcontroller allows the implementation of additional features. That means that only the performance of the valve is improved. There are also benefits regarding the reliability, remote access and comfortable adjustment of the controller feedback parameters.

3.1 SELF DIAGNOSIS

Any component in a system could fail and damage the system or the machine or in worst case injure or kill people. It is nearly impossible to monitor components, sub systems or systems by the host system, because a lot of internal data has to be known and to be transferred online. In the most cases the designer of the system or the machine doesn't have the knowledge about the internal processes of a component or a device, because he uses this device (for example the valve) as a black box system. A logical consequence is to delegate this monitoring and self diagnosis function down to the device itself. The device or component becomes more intelligent and handles its behavior on failure situations by itself.

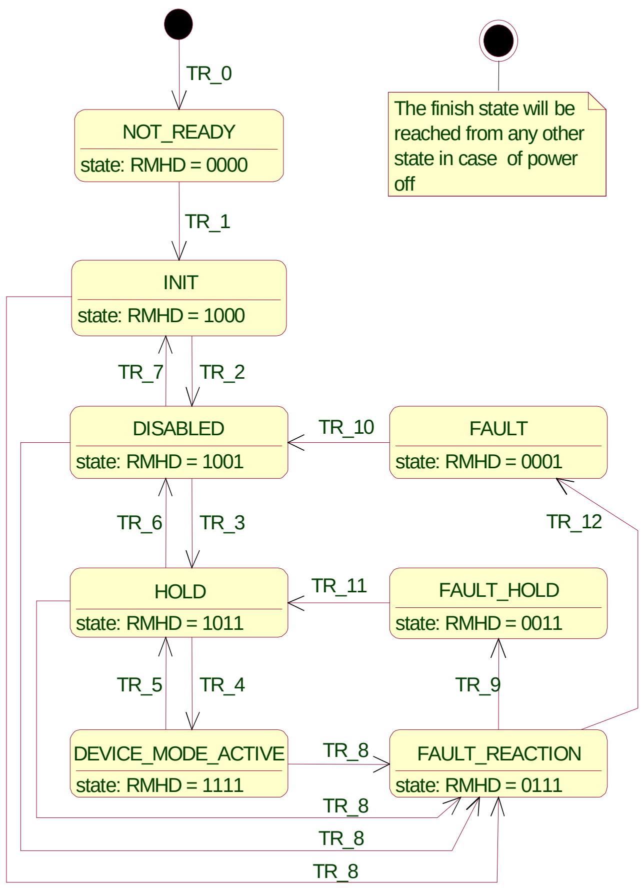

Figure 3: State machine of the hydraulic device

Figure 3 shows the state machine of the device and fault reactions of the valve. The user has different options to adjust the an individual fault reaction on any possible failure situation. These fault reaction options are:

- Disabled
- Hold

- No Reaction
- Error Message

All control loops are monitored and could create a fault reaction. Additional values like temperature or supply voltage are monitored and could also create one of the shown fault reactions. ***Figure 4*** shows how the different states or fault reactions effect the control loops of the valve.

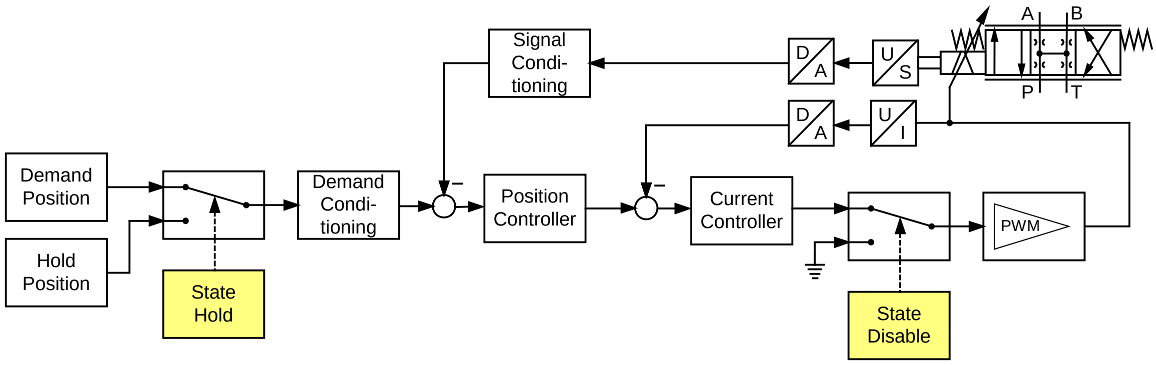

Figure 4: Function of the different States of the Device State Machine

3.2 REMOTE ACCESS

All parameters of the device are programmed and implemented according to the standardized device profiles on the different field buses /Can408/. That means that all adjustment and tunings of the hydraulic valve device will be done via standardized objects and could be adjusted via remote access. A connection to the host can be used to tune or adjust valve parameters over a distance of a couple of thousand kilometers.

3.3 AXIS CONTROL

Typical control values for hydraulic axis are position, velocity, pressure/force, flow/open loop velocity. The structure of the controller is well known from a lot of publications /Mur02/. Modern axis are very often controlled in different functions, which means different control values and loops and have to be able to do a transition from one control mode to an other by theirself. A well known and representative example is the injection axis of an injection molding machine. During the injection phase of the material the axis is in a closed velocity control loop. Then the mold is filled the axis changes immediately from velocity control to pressure control. This capability of transition from one control mode to another triggered by external or internal events is minimum feature of axis control units to be accepted in modern control architectures.

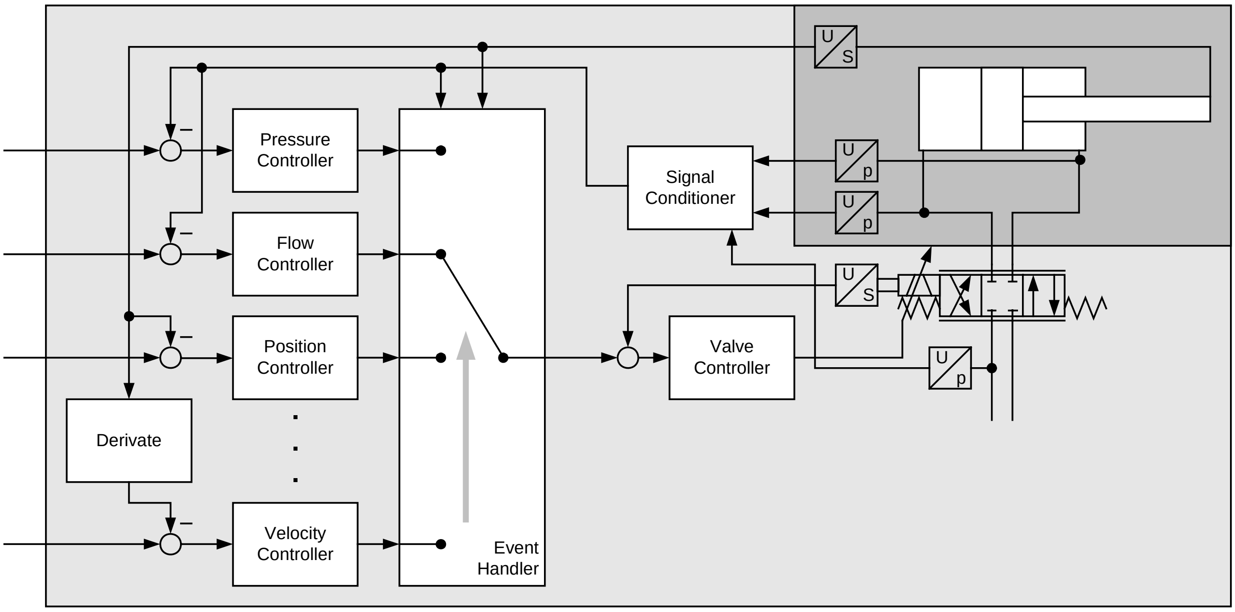

Figure 5: Transition of different Control Modes by Event Handler

3.3.1 Position Control

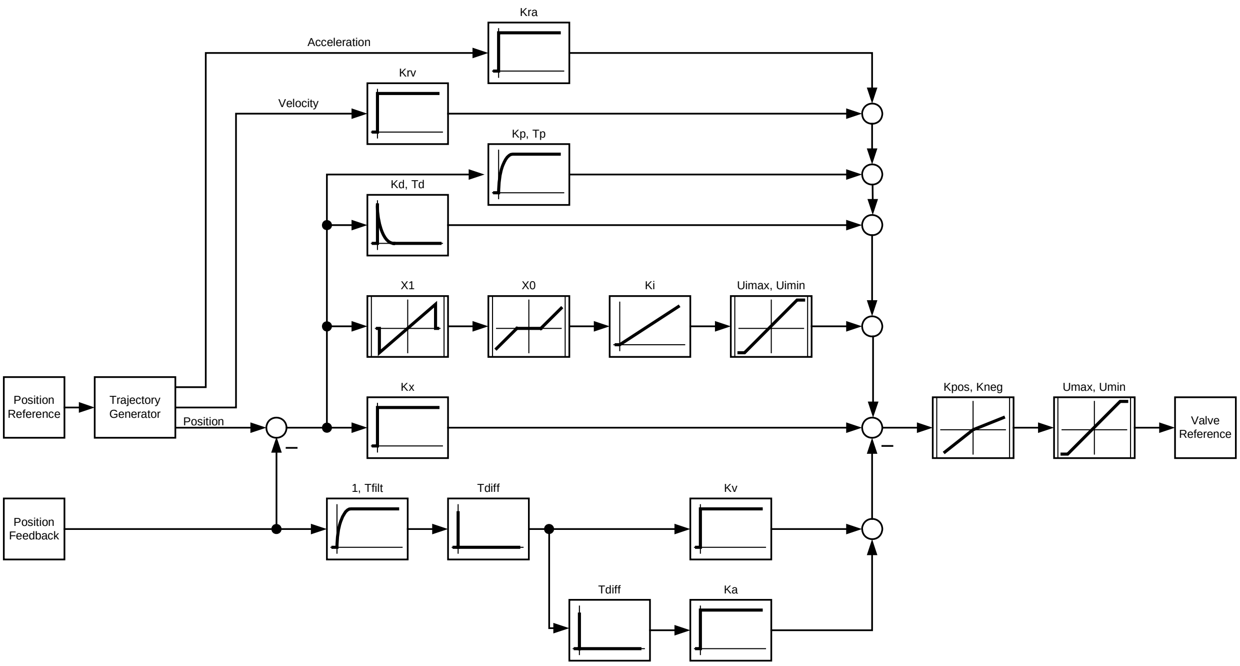

Figure 6: Controller structure of the position feedback loop

The design of the position feedback in ***Figure 6*** loop allows a parameter adjustment for the most dynamic situations in the practice:

- Axis with high natural frequency and valve with low bandwidth
- Axis with low natural frequency and valve with high bandwidth
- Frequency of axis and valve in the same domain.

Depending on the dynamic characteristic of the axis and the ratio of the valve bandwidth to the resonance frequency of the axis different feedback paths of *Figure 6* are used or deactivated by adjustment of zero gain. Example: To adjust a state loop controller for a low frequent axis, only the Gains Kx, Kv and Ka are tuned to values > 0.

3.3.2 Velocity Control

The structure of the velocity control loop for the hydraulic axis is well known from the literature /Mur02/ and shown in ***Figure 7***. The block diagram is shown here to explain the application example of the injection molding machine later on.

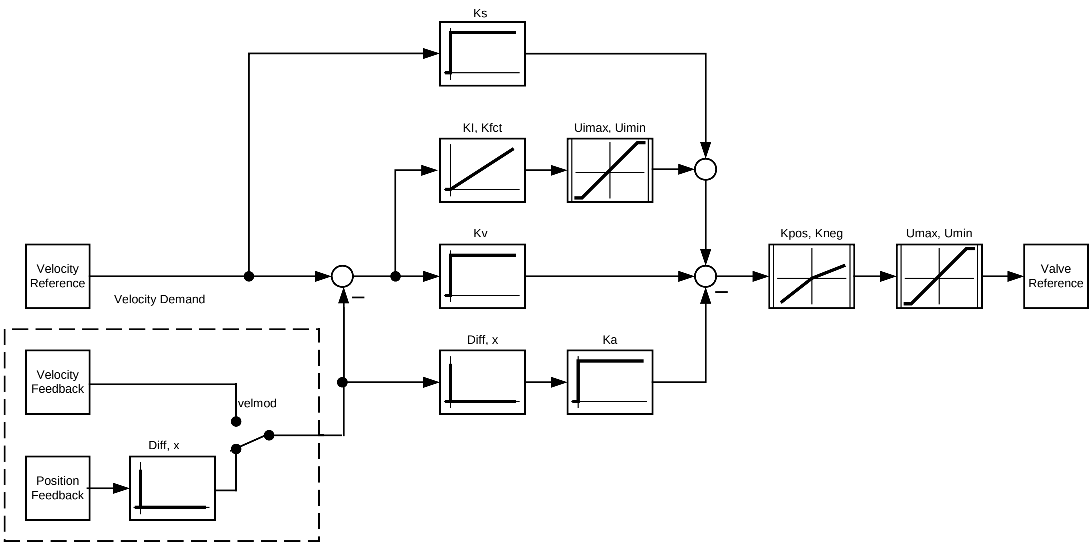

Figure 7: Controller structure of the velocity feedback loop

3.3.3 Flow Control

The hydraulic flow is given by equation 1:

$$Q = Q(y) \cdot \sqrt{2 \cdot \frac{p_S - p_L}{\rho}} \qquad (1)$$

and the load pressure defined in equation 2:

$$p_L = p_A - \frac{p_B}{\alpha} \qquad (2)$$

To compensate changes in the flow by changes of supply and load pressure, the command value of the valve has to multiplied by the factor k of equation 3:

$$k = \sqrt{\frac{p_{bez}}{p_S - p_L}} \qquad (3)$$

The implementation of this feature allows a hydraulic flow through the valve, which is independent from variances of the supply or load pressure. The pressure independent flow control is known from the literature /Boe95/ and is often used in open loop velocity control applications like ejectors of injection molding machines. ***Figure 8*** shows the block diagram of the pressure compensation algorithm.

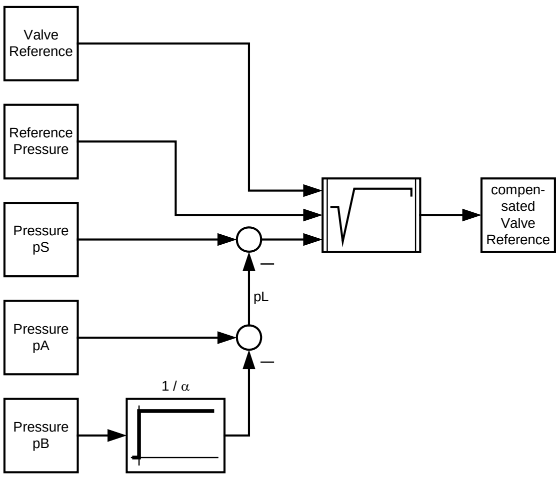

Figure 8: Controller structure of the flow/velocity loop

3.3.4 Pressure / Force Control

The structure of the pressure controller feedback is known from lot of publications /Boe03/ and will not be discussed more detailed here. The parameters have to be adjusted due to the characteristic of the hydraulic system. That means, that the controller tuning very often has to be done by people, who are not experienced in this subject.

Figure 9 shows the adjustment of a complete pressure controller by tuning of only one parameter.

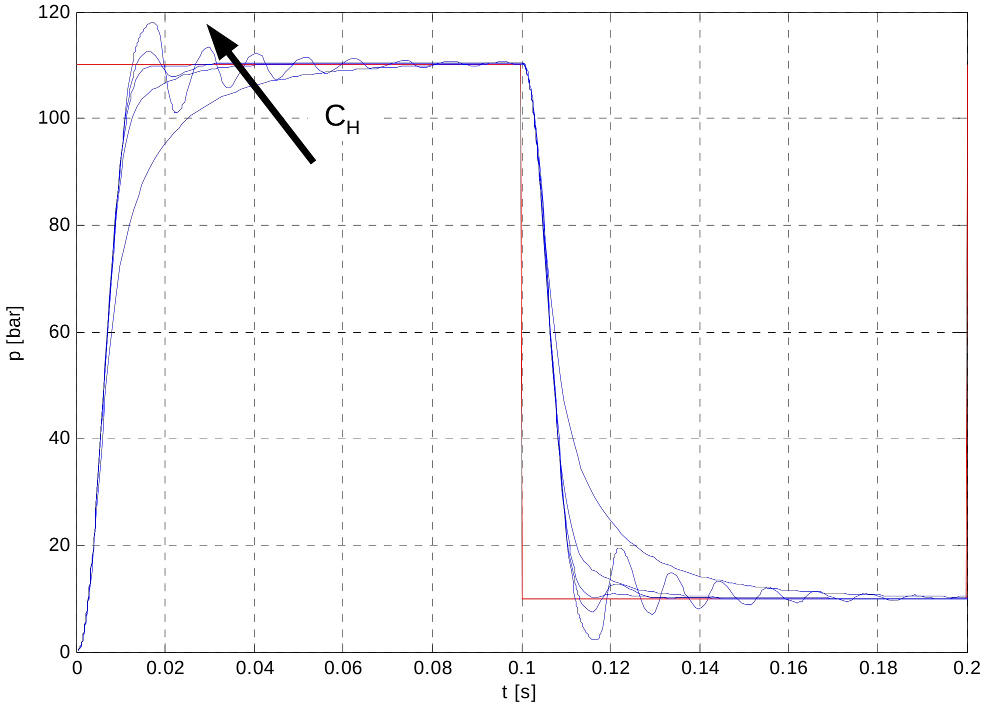

Figure 9: Adjustment of the pressure controller by tuning of one Parameter

4 APPLICATION EXAMPLES

The new generation of hydraulic valves with integrated digital electronics has been introduced in a couple of applications. The following examples indicate how these different applications profit from the advantages of this new valve generation.

4.1 WIND TURBINE

The trend in the wind turbine market indicates that the size of the machines will decrease in the future. The actual installed machines have a nominal power output of 2 or 3 MW. The next generation, which is actually being developed will have a nominal power of 5MW and more. The new machines are often installed in off shore wind parks, which means that there are very high requirements regarding the reliability of the machines, their systems and components. The hydraulic pitch control is used in a lot of applications, because the high power density of the hydraulic axis requires less room than the electric version. The energy for fail safe movements of the pitch axis can also be easier stored in a hydraulic system than in an electric system. ***Figure 10*** shows an example of a hydraulic pitch control system.

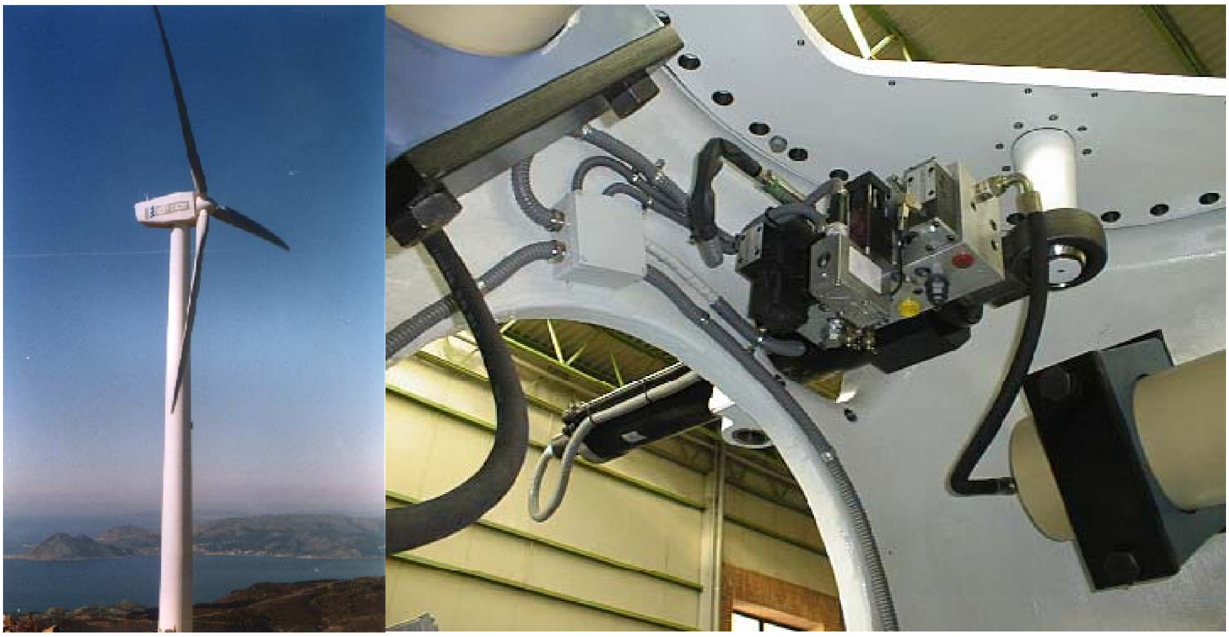

Figure 10: Pitch Control of a Wind Turbine

The pitch control systems are located in the rotor of the machine, which means that power and signals have to be connected from the hub to the rotating system. The connection of hydraulic power can be done easily and the signals are preferred to be transferred in a digital manner. ***Figure 11*** shows the block diagram of an implemented solution. The proportional valves with integrated digital electronics execute different tasks:

- All functions of the valve control loops
- Axis control (position control)
- Synchronization (parallel control of the different axis)
- Self monitoring of the inner valve control loops and the axis control loops.
- Communication with the host (PLC)

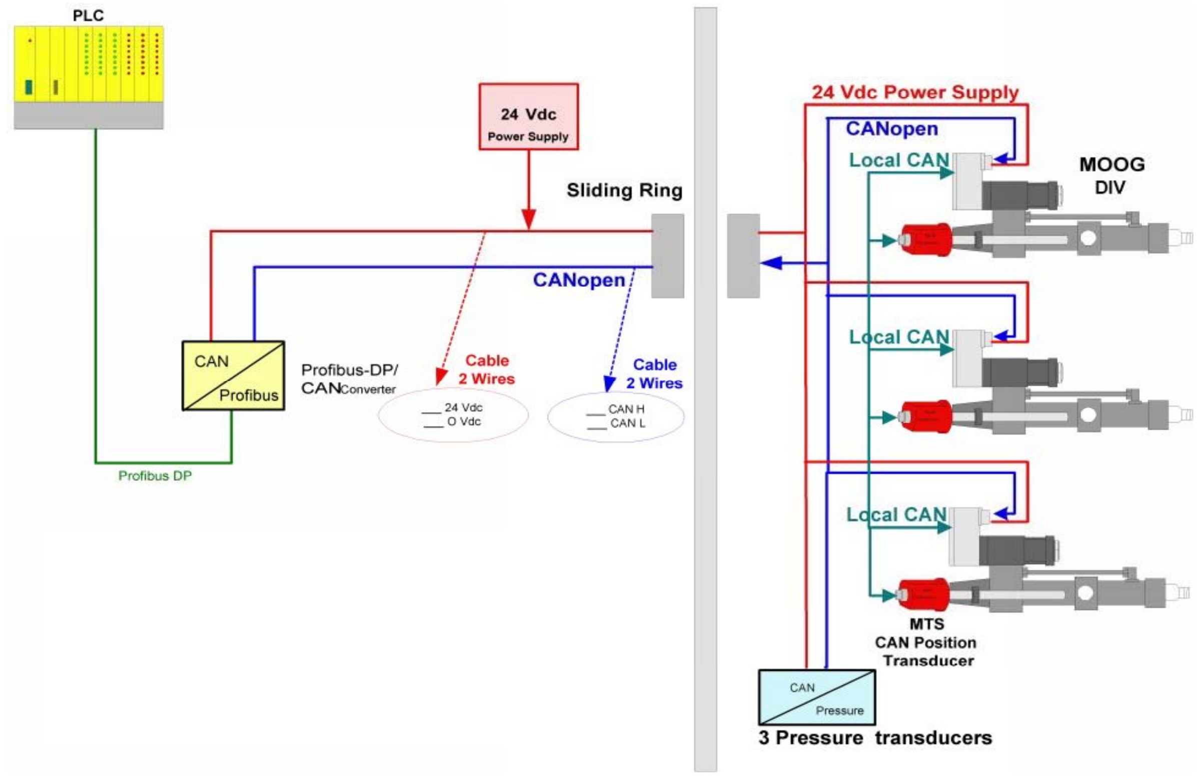

Figure 11: Block Diagram of the Pitch Control

An other important feature that diagnosis of the pitch control axis could be done by remote access via the PLC. The number of service trips could be reduced and the time effort of an potential service or maintenance trip is decreased, because a failed component or system is identified before the service people travel to the machine.

4.2 INJECTION MOLDING MACHINE

The most critical axis of an injection molding machine is the injection axis. The flow of the material into the mold is controlled by the velocity of this axis. After filling the mold the control mode changes immediately from velocity to pressure control. This transition and the following phase of pressure control define the important phase of the machine cycle. The quality of the produced parts is mainly depending on the performance of the pressure control loop and the transition from velocity to pressure control.

High injection speed and very precise pressure control are very often mutually exclusive requirements, because the size of the injection valve is optimized to the speed of the injection phase, which effects normally to high a flow gain for the pressure control loop.

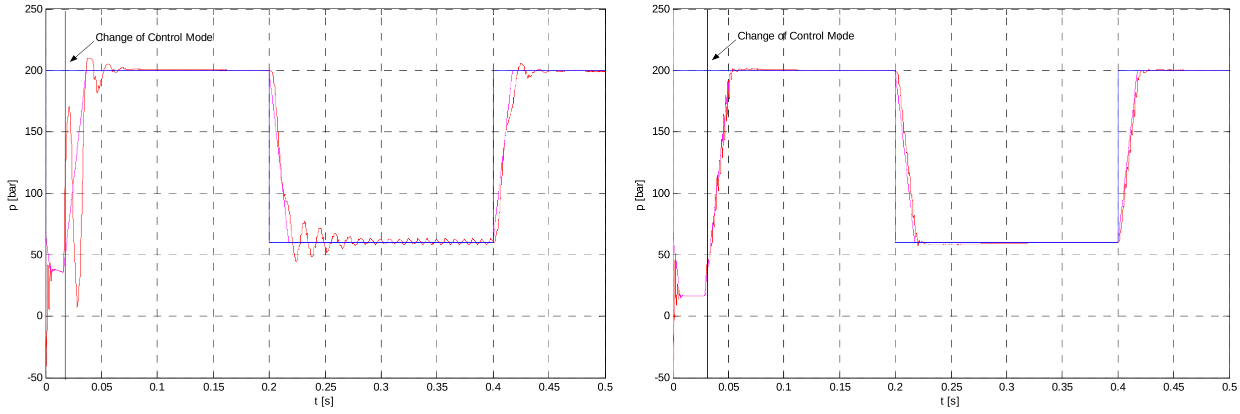

Figure 12: Pressure Control in

Figure 12 shows an example of the pressure control of a high speed injection molding machine. The left diagram indicates that the flow gain of the valve is too high selected or the gain of the controller feedback has to be reduced. The right diagram of *Figure 12* shows, the effect of a digital compensation of the valve characteristic.

CONCLUSION

The use of digital electronics to control proportional and servo valves effects an essential improvement of the dynamic and static performance of theses devices. The improved performance is combined together with a lot of other features, which lift hydraulic components up to intelligent state of the art systems.

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