WEST

Application Note: AN-101

POS-123-U
POS-123-P
POS-123-U-SSI
POS-323-P
POS-124-U-PDP
POS-124-U-PFN
POS-124-U-ETC
UHC-126-U-PDP
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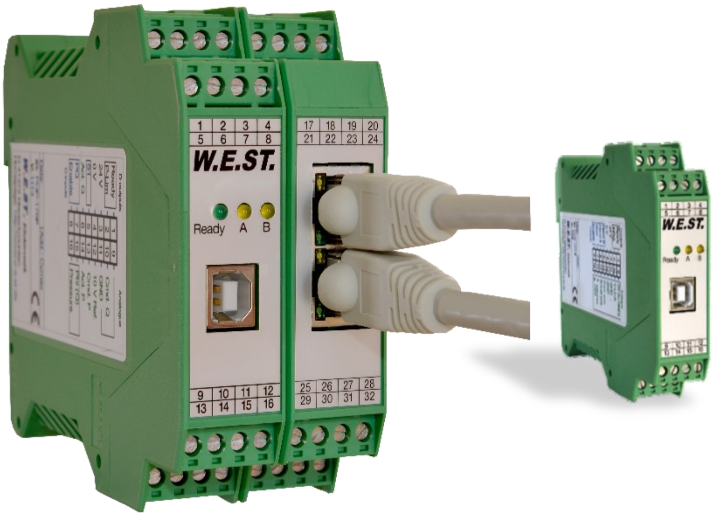
and synchronization controls

Positioning controls: Requirements for the hydraulic design



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Content

1 The hydraulic axis

Position control is one of the most common applications with proportional valves. Positioning accuracies from a few mm to 1 µm are possible. This "Application Note" is about a general description of which component properties have an impact on accuracy.

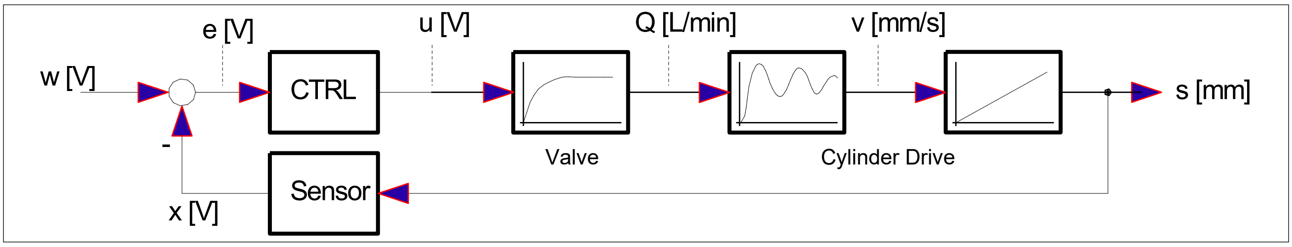
1.1 Advantages of the electro-hydraulic positioning control with cylinder drives

In general, it can be stated that the hydraulic cylinder drive is an easy to control system. Only applications in which the cylinder eigenfrequency is very low are critical[1].
The advantages are:

- linear motion
- very robust
- high forces with compact dimensions
- easy to control[2]
- no complex control loops
- easy to optimize, results can be calculated in advance

1.1.1 Basic structure of the position control loop

The controller calculates the difference (e) between the setpoint (w) and the actual value (x), amplifies the signal and outputs the manipulated variable (u). The valve converts the control signal (u) into a volume flow (Q). The cylinder converts this volume flow (Q) into a speed (v). Since the cylinder drive is a control loop without compensation, the output signal is a constantly changing position (s). The speed is proportional to the volume flow. The sensor converts the position (s) into an analog voltage or a digital SSI - signal.



picture 1

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[1] At frequencies below 10 Hz, the dynamic behavior should be taken into account when designing and selecting the controller. At less than 5 Hz, extended control technology to improve the damping is recommended in many cases. At less than 3 Hz, the hydraulics are difficult to control. A simulation of the system could be necessary here.

[2] This applies to limited requirements regarding the behavior and accuracy of the drive.

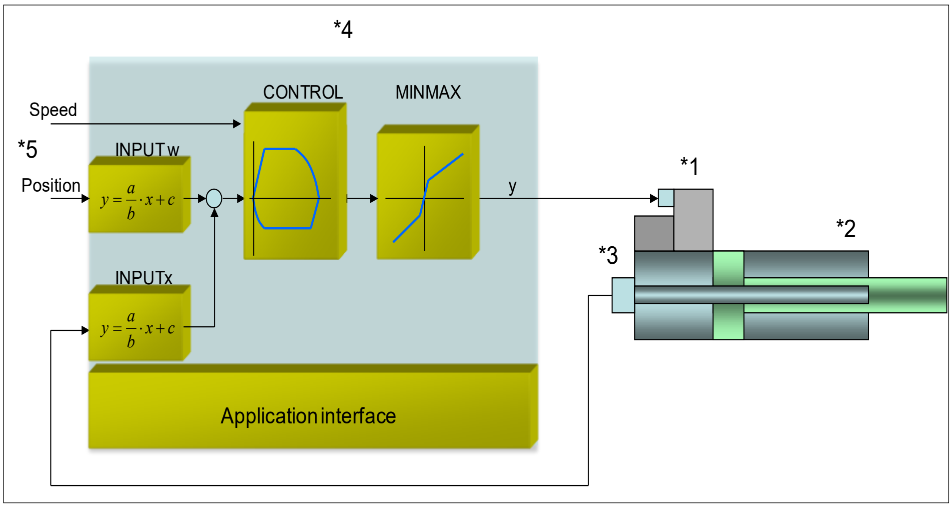
1.1.2 Which control structure is necessary for the position control loop?

Based on the classic PID controller, only the P component is required for the hydraulic positioning control. As a result of the integrating behavior of the cylinder, an integrator in the controller is not necessary, as there would be a clear oscillation. Hydraulic drives also have very low damping. The D component in the controller has a destabilizing effect in most cases[3].
Additional measures such as a PT1 controller and a standstill integrator for fine positioning can improve the control behavior.

In very critical cases, acceleration feedback is recommended. This acceleration feedback can stabilize the system and enable significantly higher gains. In this case, however, it must be ensured that the valve natural frequency is at least three times higher than the cylinder natural frequency.

1.1.3 Structural setup

(*1)	Proportional valve (or control valve): The valve type essentially determines the accuracy. With control valves, it is advantageous to use valves with integrated electronics.
(*2)	Hydraulic cylinder
(*3)	Integrated position measuring system with analog or digital SSI interface (alternatively with an external measuring system)
(*4)	Control module POS-* / UHC-*
(*5)	Interface for machine control with analog and digital signals



picture 2

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[3] A D component can only be used advantageously if the proportional valve has a significantly lower natural frequency than the cylinder drive

1.1.4 Requirements

During the specification of the system, the requirements should be defined as precisely as possible (and not exaggerated). The main points are:

- the positioning accuracy
- the dynamic behavior (not to be confused with the speed, since acceleration, deceleration and the tendency to oscillate must also be taken into account here)
- the speed, the reproducibility / constancy of the speed
- the static and dynamic load stiffness

1.1.5 How is the positioning accuracy affected?

In many cases, better positioning accuracy is achieved with a higher quality valve. For the positioning accuracy, hysteresis and responsiveness are more important than e.g. the natural frequency of the valve. The most important aspects:

1. The quality of the proportional valve (sensitivity / hysteresis). In other words, how well (and with what resolution) the electrical signal is converted into a volume flow. An incorrectly (over) dimensioned hydraulic system significantly influences accuracy.
2. A good system design. The hydraulic system, from the pressure supply, the hydraulic circuit technology to the selection of components, should be tailored to the requirements. This should always be seen in connection with point 1.
3. The faster the theoretical maximum speed, the poorer the positioning accuracy. See point 1 (signal resolution = speed resolution).
4. Signal resolution of the sensor. From a range of 1: 5000 of the nominal length, digital sensors must be used. Up to approx. 1: 1000, analog sensors are sufficient. The range between 1: 1000 and 1: 5000 depends on the electrical signal quality and whether the repeat accuracy[4] or the absolute accuracy is decisive. Basically, you cannot position better than you can measure.
5. The dynamic behavior of the system (natural frequency of the cylinder and the valve as well as the dynamics of the controller). This can only be analyzed with the help of calculations / simulations.
6. Signal resolution of the control module. This influence is usually only relevant if the accuracy requirements are very high (example: vmax = 500 mm / s, following error = 50 mm / s, maximum possible accuracy of our solutions: 0.002 mm; the typical position error in a In comparison, the hysteresis of 0.1% of the valve is already 0.05 mm)[5].

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[4] Repeatability places lower demands on the drive than absolute accuracy. Even with analog sensors, very high positioning accuracies can be achieved as repeatability.

[5] The drift compensation / fine positioning function must be used to compensate for position errors that are caused by an incorrect zero point setting or by external forces.

1.1.6 Dynamics

A closer look at point five of the previous list (the dynamic behavior).

1. Basically, the natural frequency of the entire system should be as high as possible. The higher the natural frequency, the higher the dynamics and the better the accuracy of the positioning drive. The dynamic behavior is described by the possible loop gain V0.

   $$V_{0krit} = 2 \cdot d \cdot \omega_{0z}$$

   Attention: The damping (d) also plays a decisive role in hydraulic drives. If no data is known, an attenuation of 0.1 should be assumed. From the product of the natural angular frequency and the damping, the theoretical maximum loop gain "*V0krit*" (stability limit).

   $V_0 = 0{,}05 \dots 0{,}1 \cdot \omega_{0z}$ *This calculation can be used as the basis for a first robust setting.*

2. The natural frequency and the damping of the drive determine the controlled behavior. One of the most important features of a good actuator is that the proportional valve is placed as close as possible to the cylinder. A large dead volume reduces both the natural frequency and the damping. Hoses between the cylinder and valve should only be used when no other solution is really possible.

3. The influence of a high natural valve frequency is generally overestimated (with single-loop control circuits). Due to the low damping of hydraulic drives, the natural frequency should be 50% to 100% of the cylinder's natural frequency. If the valve natural frequency is higher, the system behavior can be damped using a PT1 controller[6].

4. The cycle time of the electronic controller should be in the order of 1 ms. From 3 ms on, a significant deterioration of the system behavior can often be observed. This must be taken into account when using a PLC as a control module. The conversion times for the input and output modules and the delays due to communication, e.g. via a field bus, must also be added.

1.1.7 The load stiffness

The load stiffness is a measure of a position error with an external force that wants to push the cylinder out of position. The load stiffness is increased by the highest possible loop gain and the highest possible pressure gain. The static load stiffness can also be improved by simple control measures. Dynamic load stiffness or an improvement in dynamic load stiffness, respectively, imposes very high demands on the control behavior of the hydraulic system as well as on the controller.

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[6] A fast valve while using a PT1 filter is preferable to the slower valve. The dynamics of the valve depend on the operating point and vary with the amplitude. In contrast, the PT1 filter always has the same dynamic behavior regardless of the amplitude.

1. **Static load stiffness**: The drive is pushed out of position by a force and must control against this force. The loop gain, the maximum speed and the pressure gain can be used to calculate how large this position error can be with a given force. This can be compensated by a standstill integrator (drift compensation / fine positioning) so that the load stiffness becomes extremely high.
2. **Dynamic load stiffness**: An external force builds up while driving (usually at creep speed) (e.g. machining a workpiece). This force reduces the speed[7], which is then increased again via the controller (in NC mode). The drive runs with a higher following error, but at a constant speed. The dynamic load stiffness depends on the overall dynamic behavior, i.e. how quickly the system can react to the speed deviation. Special controllers, through which the hydraulic system can be linearized, increase the dynamic load stiffness[8].

1.2 The hydraulic system design

Only the most important points from a control engineering point of view are presented here. Many mistakes are made in the selection of the valve, especially in combination with differential cylinders. A pressure and speed calculation for retraction and extension should definitely be carried out.

1. The theoretical speed should not be higher than twice the desired speed, otherwise the system behavior deteriorates considerably.

2. The dynamics of the drive (natural frequencies) should at least be roughly calculated.
   a. In principle, the dead volume (lines between cylinder and valve) should be kept as small as possible.
   b. Furthermore, no hoses should be used between the valve and the cylinder.
   c. Stroke ratios have a considerable influence on the dynamic behavior depending on the operating point.

3. 3. On the basis of points 2 and 3, important settings for the control module can be determined.

1.2.1 Why should a hydraulic positioning drive be calculated in advance?

With a little experience, you can optimize a position-controlled drive relatively quickly and achieve useful results. In this case, however, nobody knows whether the drive is at its performance limit, what is still possible or whether there are negative influences that limit the accuracy.

A calculation of the drive is the reference, so to speak, of what the real drive should be able to do. If the setting differs significantly from the calculated values, important influencing points are usually not taken into account or wrong components were selected.

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[7] The speed reduction also reduces the speed gain and thus the loop gain.

[8] The MR controller linearizes the hydraulic axis and thus enables theoretically infinitely high load rigidity. Deviations only occur during dynamic processes (force build-up / force reduction).

1.3 Example application

Task:

1. A simple positioning drive should be equipped with a control valve[9] (CETOP 3).
2. Cylinder: Servocop 40/28 with 300 mm stroke, coupled mass 40 kg
3. Maximum speed: 500 mm/s
4. Pressure supply: 80… 100 bar
5. Maximum force: …. N
6. Positioning accuracy: better than ± 0,1 mm
7. Control module: UHC-126-U-PFN with fieldbus interface and SSI Sensor

This drive is a fast auxiliary drive. The accuracy of 0.1 mm means that the sensor should have a signal resolution of significantly better than 0.1 mm. This is not a problem with common sensors.

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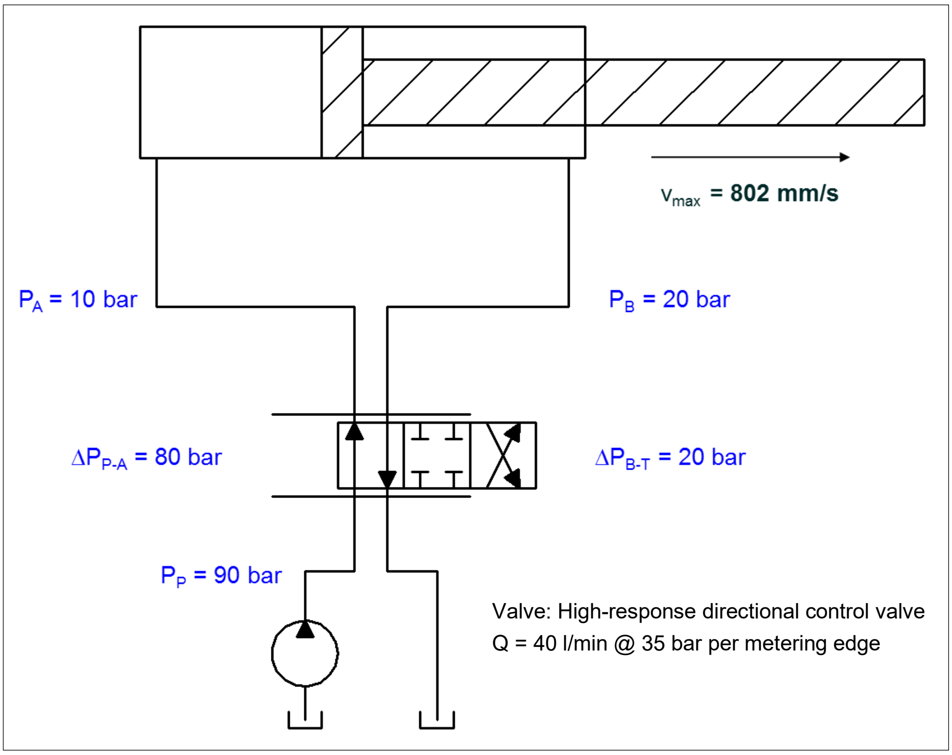
[9] The calculations are based on the use of a linear zero lapped control valve. To a large extent, the control valves of the various manufacturers behave similar. The differences only become noticeable when the requirements are very high.

1.3.1 Pressure and speed calculation

The first and most important step concerns the calculation of the pressures and speeds for the extension and retraction.

Note: *The results of the exemplary calculation are explained below. To carry out the calculation, we can provide an Excel-based calculation sheet on request.*

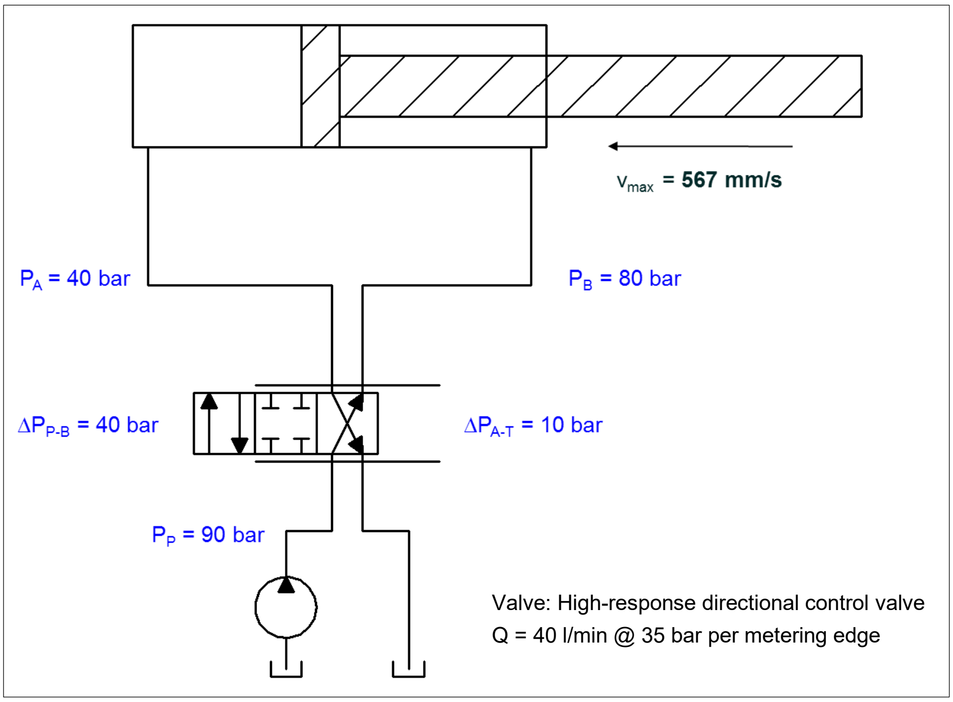
1.3.1.1 Extending



picture 3

When extending, we are dealing with relatively large pressure drops across the control edges. The speed is higher than when retracting (by a factor of 1.41 for a 2: 1 cylinder). The pressures in the cylinder chambers are relatively low. Particular attention should be paid to the pressure PA, as cavitation can occur when braking large masses.

1.3.1.2 Retracting



picture 4

When retracting, the pressures in both chambers are not critical. As a result of the higher pressures, the natural frequency increases when retracting compared to extending. This difference is usually relatively small, so this can be ignored.

1.3.2 Solution and calculation of the axis with control valves

1. The calculations show that a control valve with 40 L/min nominal volume flow is appropriate.
2. The natural frequency of the entire system is 32 Hz
3. The maximum loop gain (stability limit) is 40 s^{-1}
4. It follows that the braking distance should be approx. 16 mm (D: A, D: B parameters), which corresponds to a control gain of 19.
5. The calculated accuracy (no load) is 0.03 mm.

How should the controller be parameterized?

1. The loop gain is set to 20 s^{-1} for robust parameterization.
2. Alternatively, a braking distance of approx. 32 mm (D: A, D: B parameters) is set for stroke - dependent deceleration, which corresponds to a control gain of 9.5.
3. The calculated accuracy (no load) is now 0.06 mm.

2 Optimization

Based on the calculated data and the parameterization, the axis should move satisfactorily.

2.1 Optimization options

First of all it is necessary to define what should be optimized. Is the positioning not precise enough, is the stroke time too long or are there instabilities?

2.1.1 The positioning is not precise enough

Here you have to differentiate again how the error is noticeable.

- Is the error constant after each positioning process (same sign)? This means that the axis is e.g. always to the left of the target position. In this case the cause is usually an excessive zero offset of the valve.
  Measure 1: If the axis is stationary, the value U can be read in the monitor and the OFSSET parameter must be parameterized with the negative value of U..
  Measure 2: Fine positioning must be activated and the error is automatically compensated. Disadvantage: Depending on the direction, the target position is overrun.

- It is also possible that the axis always stops before reaching the target position. In this case, there are external frictional forces that prevent more precise positioning.
  Measure: Fine positioning must be activated and the error is automatically compensated. Depending on the setting of the fine positioning, this may take longer. To do this, the DC: I parameter must be adapted to the system behavior.

- There is no direct cause for the insufficient positioning accuracy. This must be taken into account together with the next point.

- Does the valve have a positive overlap? The positive overlap means that the positioning accuracy is significantly reduced. In this case, the overlap compensation must be set as precisely as possible.

2.1.2 The axis is positioning too slowly

The braking distance is too long or the loop gain is too low. The parameters D: A, D: B or V0: A, V0: B must be changed until there are noticeable improvements. **CAUTION**: Braking distances that are too short or loop gain settings that are too high lead to instabilities. Alternatively, the control characteristics of our modules can be changed using the CTRL command (LIN / SQRT1).
Another reason could be that the maximum speed is limited by the pump volume flow It is important to ensure that the supply pressure does not drop during the movement.

2.1.3 System is unstable and oscillates around the target position.

There are various points here that can lead to this behavior:

1. The gain is too high or the braking distance is too small. Reducing the braking distances means *: higher gain and thus higher accuracy, increasing means: lower gain and accuracy, which then leads to more stable behavior.

2. A high static friction with a high gain also leads to an oscillation. If the static friction cannot be reduced, the gain must be lowered. However, this then leads to less precise positioning.

3. With overlapped valves, the overlap compensation is set too high (overcompensated). In this case the compensation must be reduced.

3 Imprint

W.E.St. Elektronik GmbH

Gewerbering 31
41372 Niederkrüchten

Tel.: +49 (0)2163 577355-0
Fax.: +49 (0)2163 577355 -11

Homepage: www.w-e-st.de
EMAIL: contact@w-e-st.de

Date: 18.07.2023

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