IMPLEMENTATION OF EXTERNAL MATLAB CLOSED-LOOP CONTROLLERS WITHIN BECKHOFF SOFT-PLC CONTROLLER

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In the scope of the research, we have designed and implemented the closed-loop position control of the linear axis using a externally-developed controller imported into Beckhoff soft-PLC, which will, further on, allow us to use any position controller. Namely, in the industrial environment, the PID controller is most often used due to its simplicity and robustness. The goal of the research was to replace the PID controller with an external controller, which can also be non-linear, such as fuzzy logic. We have designed the controllers using the MATLAB-Simulink software, from which we have exported the model into TwinCAT 3 environment. We have compared the responses between external position controller and the embedded Beckhoff PID position controller, and then compared the operation of the PID and fuzzy logic controller. Due to high energy density of hydraulic systems and potential risks, the first research was made on small scale electromechanical axis.

Keywords:
Closed-loop control,
PID,
Beckhoff,
TwinCAT 3,
Matlab-Simulink

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1 Intruduction

Fluid power control systems often contain closed-loop position controllers, where the most common used in the industrial environment are proportional-integral-differential (PID) controllers, which meet a wide range of system control needs.

Proportional-integral-differential closed-loop controllers work on the basis of feedback loop principle and are very often used in industrial control systems. When using a PID controller, the error is calculated on the fly with the help of a feedback loop. The latter is calculated between the desired (set) value at the input and the actual value at the output of the system. The controller itself is designed in such a way that it tries to reduce the error with the help of the manipulated variable [1].

In the case of more demanding closed-loop control system, we can detect cases where the use of an established PID controller is not sufficient. For this purpose, non-linear closed-loop controllers, such as e.g. fuzzy logic or neural networks, are gaining prominence. These are much more difficult to implement in industrial controllers, which usually contain already embedded controllers. Therefore, our goal was to design and implement an external position controller developed in the MATLAB-Simulink environment and import it into the TwinCAT 3 programming software (Beckhoff soft-PLC). Due to the limitations of the equipment available, the design and testing was carried out on an electric linear servo axis, where we have compared different types of position closed-loop controllers and their responses to set value.

2 System overview

For the above-described research, we have used Festo FESTO-DGE-25-500 linear axis, which converts rotary motion into linear motion using a toothed belt. The controlled trolley on the linear axis was enhanced to be able to attach up to 5040 g weight in order to change the mass of the control system. To control the linear axis, we have used a Beckhoff AM8113-0F20 servo motor, which has an integrated 18-bit absolute incremental encoder, which allows us to accurately control speed, acceleration and position (Figure 1).

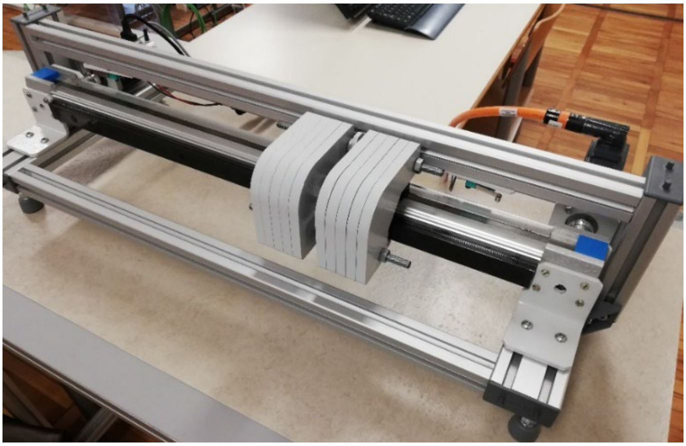

Figure 1: Festo toothed belt linear axis with Beckhoff servomotor.
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3 Closed-loop controllers in TwinCAT3

The servomotor is controlled using a closed-loop controller consisting of a trajectory generator and position tracking system. The trajectory generator outputs the position reference (set position) and the speed of change of the position (tangent of the position trajectory) that are fed to the input of the closed-loop position controller. The closed-loop controller uses cascade principle (Figure 2), where the speed and current loops are already set up inside the Beckhoff controller. Our task was to research and implement only various position closed-loop controllers.

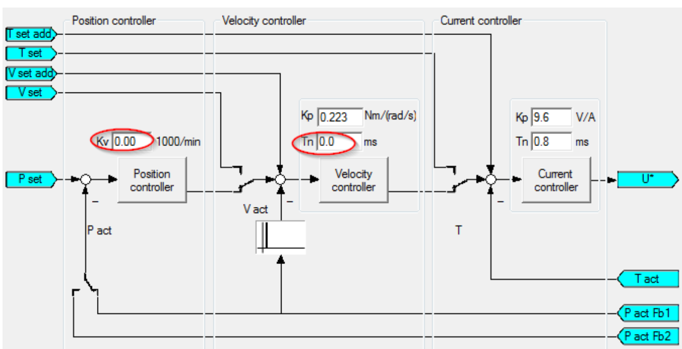

Figure 2: Beckhoff servomotor closed-loop controller in TwinCAT 3.
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The proportional-integral-differential controller (PID) works on the principle of a feedback loop, where the error is calculated on the fly with the help of the feedback loop. and contains three parts. These parts are proportional part (P), integral part (I) and differential part (D). Each part contains its own parameter, with the help of which the individual part can be increased or decreased. The influence of the individual part of the controller on its output is interpreted in terms of time. Thus, the proportional part is depended on the current error, the integral part is depended on the accumulation of past errors, and the differential part is depended on the rate of change of the error [2, 3]. The PID controller built into the TwinCAT 3 software is shown in Figure 3.

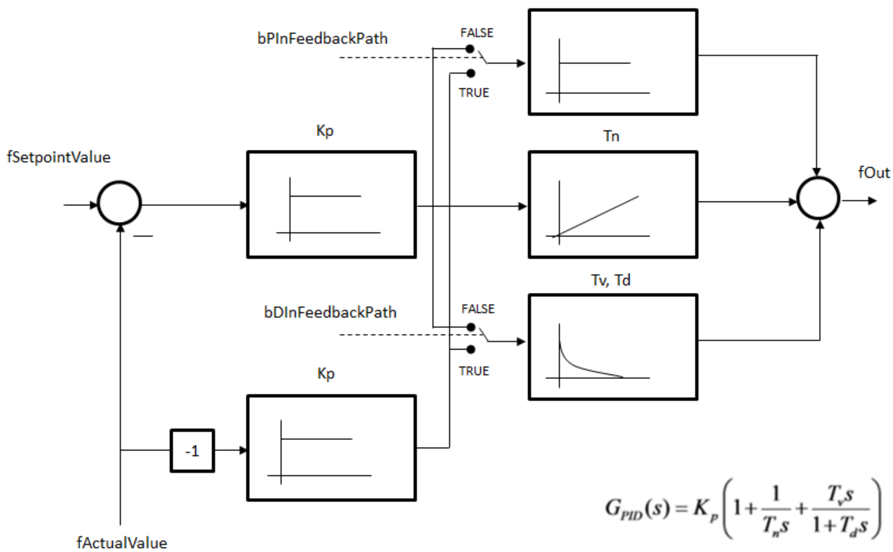

Figure 3: Beckhoff PID controller in TwinCAT 3.
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3.1 Setpoint generator

The TwinCAT 3 software has built-in trajectory generator added to the program block for position control. For the calculation of the trajectory, the trajectory generator block requires several inputs: the initial and final position; initial, maximum and final speed; and the acceleration/deceleration, which determine the fastest speed change.

4 Development and implementation of MATLAB – Simulink closed-loop controller

We have designed and implemented PID and fuzzy logic position controller using the MATLAB-Simulink programming environment, in which we can design different types of linear and non-linear closed-loop controllers.

In addition to designing the controllers, we can generate and export the software code of the designed controller, which is suitable for implementation into TwinCAT 3 and can be directly imported into Beckhoff soft-PLC. To begin with, we have created an external PID controller and compared its operation to standard TwinCAT 3 embedded PID controller.

4.1 MATLAB – Simulink PID controller

The PID controller in MATLAB-Simulink was designed using the transfer function, consisting of individual blocks, which were connected into a whole system. The transfer function consists of different blocks such as addition, multiplication, division, delay, input and output block. Figure 4 shows the scheme of the implemented PID controller. The implemented scheme has to be moved into the subsystem in order to generate the export code, which is then imported into Beckhoff programming environment using the *PLCopenXML* standard.

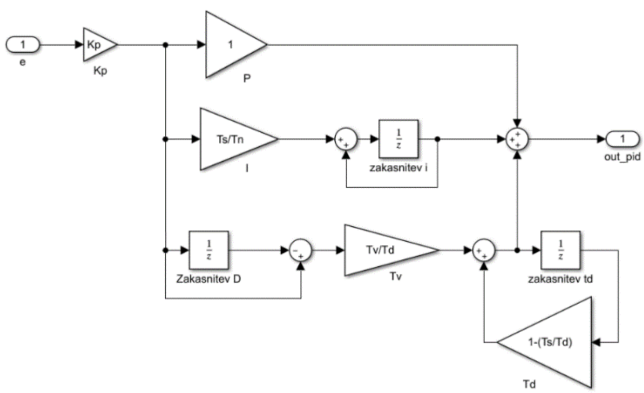

Figure 4: MATLAB – Simulink PID controller.

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4.2 MATLAB – Simulink fuzzy logic controller

Fuzzy logic controllers are nonlinear type controllers used in signal processing, pattern recognition, and other control systems. They use soft and blurred quantities, similar to human perception, where the response is far from mathematically precisely defined rules. Thus, it cannot be described by exact equations.

The designed fuzzy logic controller, created in MATBLAB-Simulink, is shown in Figure 5. The transfer function is based on the presented programming blocks. [4, 5]

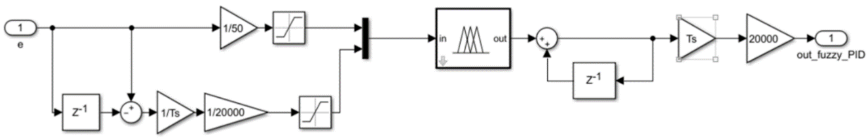

Figure 5: MATLAB – fuzzy controller.
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5 Results

The aim of the research was not only the design of external closed-loop controllers, but also their implementation and corresponding tests, where we have compared the responses of TwinCAT 3 and the created external MATLAB-Simulink controllers. In this way, we were able to check whether the axis position system and the controller used were correctly designed and implemented. If we have implemented everything correctly, the response of both systems should be the same.

5.1 Comparison of Beckhoff integrated PID controller and MATLAB – Simulink PID controller

Figure 6 shows the response of the system using integrated Beckhoff PID controller and imported external MATLAB-Simulink PID controller using optimal parameters determined by the Ziegler-Nichols method. The blue line shows the error between the desired (set) value and the actual value of the axis position, the orange shows the generated position trajectory representing the desired (set) value, the red shows the actual position of the axis, and the green shows the start of the step change. It can be seen from the figure that the operation and the response of the external MATLAB-Simulink PID controller is very similar or nearly the same as TwinCAT 3 embedded controller. In this way, we have confirmed the adequacy of the design of external controllers and their implementation into the TwinCAT 3 Beckhoff environment.

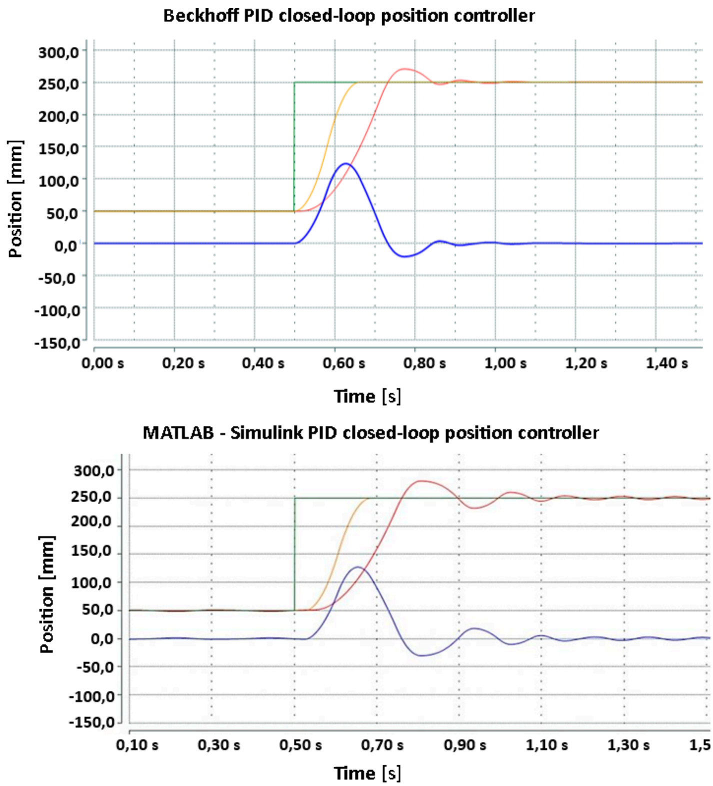

Figure 6: Comparison of Beckhoff integrated PID controller and MATLAB – Simulink PID controller.

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5.2 Comparison of PID controller and fuzzy logic controller

In addition to creating an external closed-loop controller, the goal of our research was to create and implement a fuzzy logic (non-linear) controller. In this way, we were able to define how the two controllers react in different conditions, such as, for example, a change in the mass of the system. In the below comparison the PID controller was set according to the Ziegler-Nicholson method and additionally fine-tuned manually, and then compared to the designed fuzzy logic controller [5]. The results, presented in Figure 7 and Table 1 show that the PID and fuzzy logic controllers respond very quickly to the step change. We can notice better response from the fuzzy logic controller, which has less overshoot and it is faster when using less precise dead band position deviation. In this case, the difference between the controllers is smaller because the PID controller was optimized for a system without additional mass.

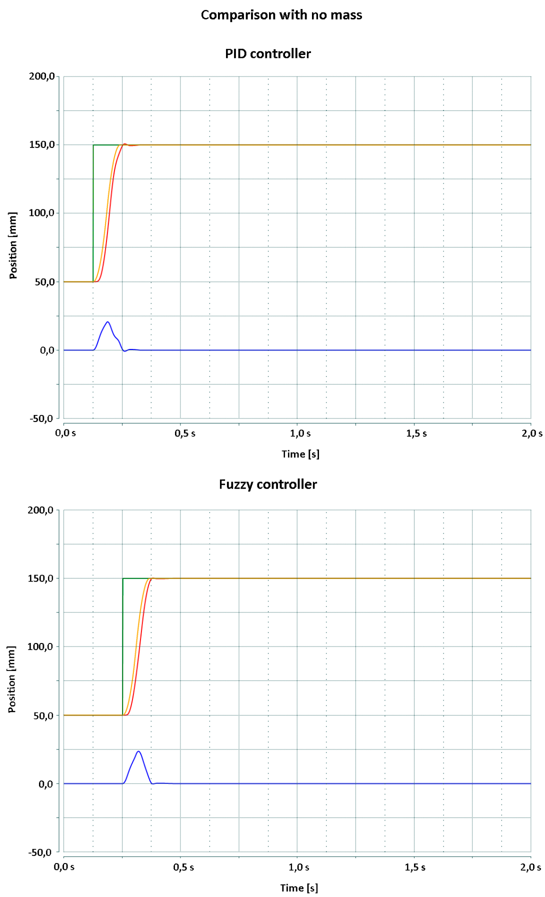

Figure 7: Comparison of PID and fuzzy closed-loop position controller without added mass.

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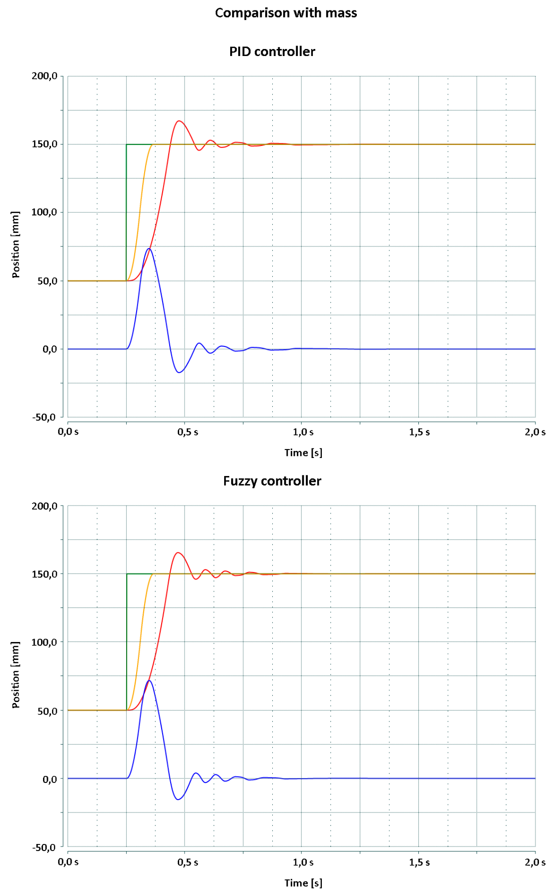

Figure 8: Comparison of PID and fuzzy closed-loop position controller with added mass.

Table 1: Comparison of PID controller and fuzzy logic controller – without mass

		PID	Fuzzy
Dead band position deviation [ms]	0.01 mm	194	197
	0.5 mm	164	122
Maximal overshoot [mm]	Positive	0.84	0.23
	Negative	0.53	0.28
Maximal position deviation [mm]		20.69	23.62

However, when adding additional mass to the system (results in Figure 8 and Table 2), the response of the fuzzy logic controller is better, since the nonlinear controller compensates for the additional mass. The PID controller parameters were defined and optimized without mass, so with added mass it is no longer optimally set.

Table 2: Comparison of PID controller and fuzzy logic controller – with mass

		PID	Fuzzy
Dead band position deviation [ms]	0.01 mm	1033	790
	0.5 mm	682	629
Maximal overshoot [mm]	Positive	17.29	15.55
	Negative	4.32	3.95
Maximal position deviation [mm]		73.67	71.8

The presented results reveal that a well-tuned PID controller can perform the position control operation just as well as a non-linear or fuzzy logic closed-loop controller when the PID parameters are optimized for the application. Major deviations in operation occur when we change the weight of the load, as the controller is not optimized for given load and conditions. Thus, in the case of variable weight of the load, a non-linear or fuzzy logic controller is preferred.

6 Conclusion

In the scope of the research, we have analysed the operation of externally designed and further implemented controllers in the TwinCAT 3 Beckhoff system. Due to the limitations of the equipment available, the design and testing was carried out on an electric linear servo axis, although the final implementation will be done on various fluid power systems.

We have validated the conformity of their operation with an PID controller example. To this extent, we are now able to design various controllers using the MATLAB-Simulink tool and integrate them into Beckhoff industrial soft-PLC controllers.

Further on, the research revealed that the fuzzy logic controller performs better under unsteady conditions, as the latter can compensate for additional changes without changing the parameters. Although fuzzy logic closed-loop controller needs greater processing power due to demanding algorithms, which can be achieved by using high-end soft- PLCs in industrial applications.

Upgrading embedded closed-loop position controller with an external one allows us to use more advanced, more complex, more responsive and faster controllers.

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