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# Tuning of cascade electric drive with current, speed, and position loops control. An example

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**Abstract.** The aim of the research is to examine the tuning of controllers in mechatronic systems through analysis and synthesis of current, speed and position loops in adjustable electric drives (EDs). Structures of current, speed and position optimal controllers are synthesized on the basis of the approach for cascaded control. Examples of generalized models of the considered EDs have been developed. Transient processes of the coordinates of the control system at different tuning, references, and load of the EDs are obtained. The MATLAB Simulink software environment is used for modelling. The examples are applicable to the synthesis and tuning of EDs for mechatronic systems with DC and AC motors.

## INTRODUCTION

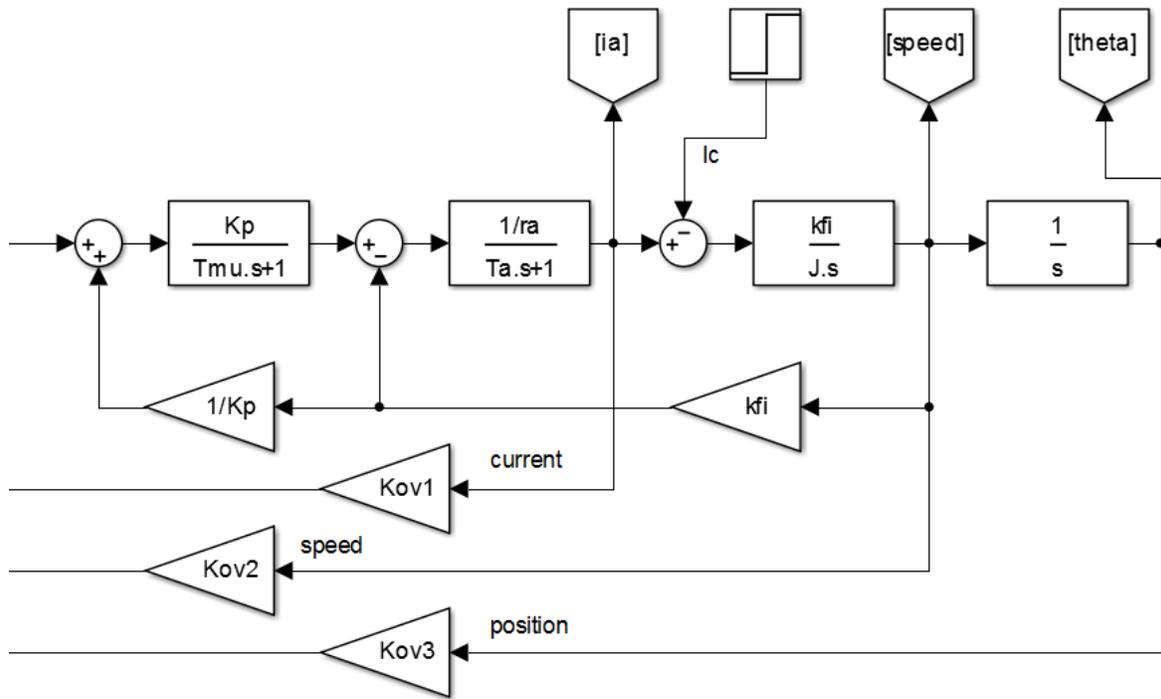
There is always a primary control objective combined with a secondary control objective and with a tertiary control objective when deploying a cascade control system structure. For the electrical drives and power converters, the primary objective could be used to control a DC motor's position, the secondary objective could be used to control a DC motor's angular velocity; however, the third objective is to regulate the current flow. Generally, all industrial DC drives for position and velocity control use a PI cascade control structure. The key to the success of the cascade PI control systems for these applications lies in the large difference between the time constants of the secondary plant and the primary plant [1,2]. For instance, the response time of the current is much faster than that of a motor's velocity. There are a few distinguishing features when using a cascade control system as discussed below. The design of a cascade control system begins with the tertiary controller for the inner-loop system. The bandwidth of the inner-loop control system is selected to be sufficiently large so that its dynamics can be neglected when designing the secondary controller.

The steady-state error needs to be considered in the design of the tertiary controller and in the implementation of the current constraints. Bearing in mind that the steady-state error changes with respect to the parameters of the system when using a proportional (P) controller, it is fair to say that the benefit of simplicity may be lost when taking into consideration performance robustness, which may be one of the key reasons why the majority of the industrial current controllers uses a PI controller.

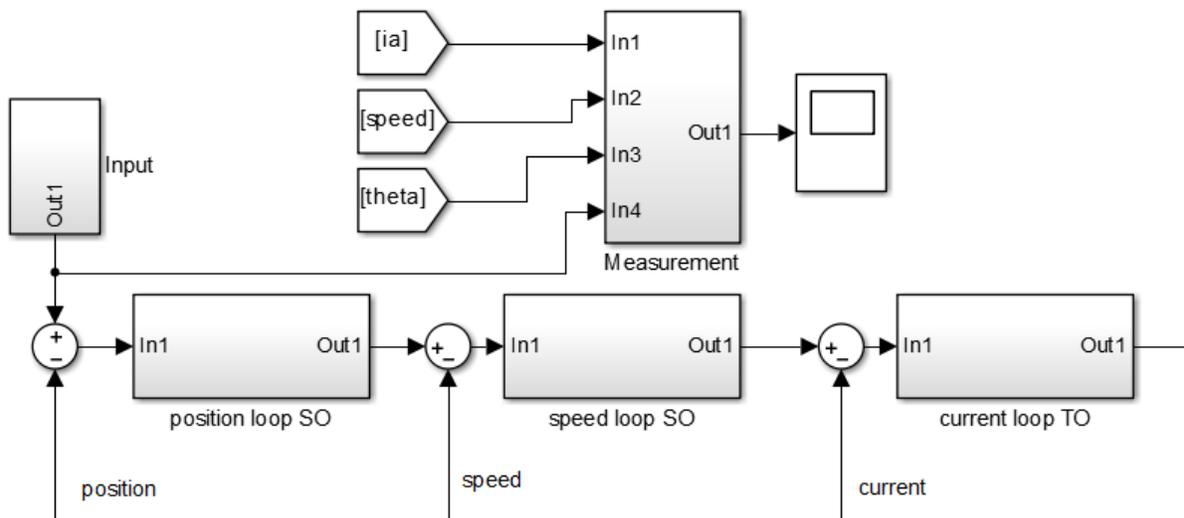
The aim of the research is to test the cascade structures for optimization of the controllers in the control systems of the electric drives by using models, to systematize and supplement the quality indicators in the electric drives with cascade control of current, speed and position.

## ELECTRIC DRIVE MODEL

With the cascaded control methodology [3,4,5], a positional DC electric drive with cascade coordinate control is synthesized [6]. The control object (fig.1a) consists of a DC motor with separate excitation and a power voltage converter (controllable rectifier). The model provides an additional positive speed feedback ( $k_{fi}/K_p$ ) to compensate for the back-electromotive force (BEMF).



**FIGURE 1a.** Simulink model of the DC motor, the power voltage converter, and the feedback of the current, the speed and the position.



**FIGURE 1b.** Simulink model of the current, the speed, and the position control loops, input subsystem, and measurement subsystem.

The controller loops consist of a tertiary current controller (fig. 2) and a secondary speed controller (fig. 3) and a primary position controller (fig. 4). The model provides a synthesis of various structures of the control loops. The choice of a particular structure determines the presence of FOTF filters and the value of the coefficient  $\mathbf{a}$  [5].

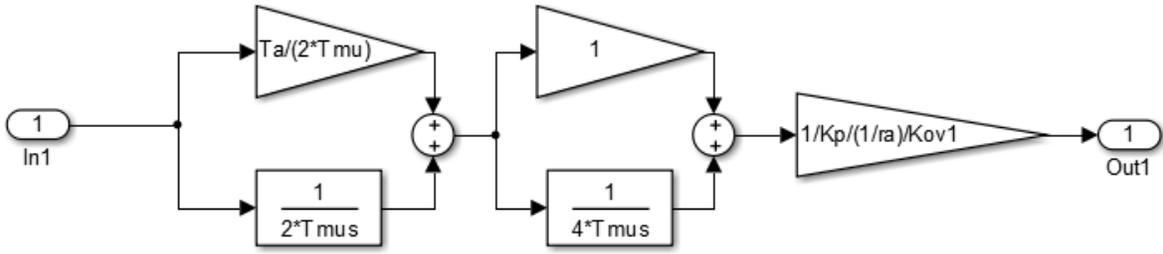


FIGURE 2. Simulink model of the tertiary current controller loop set to SO.

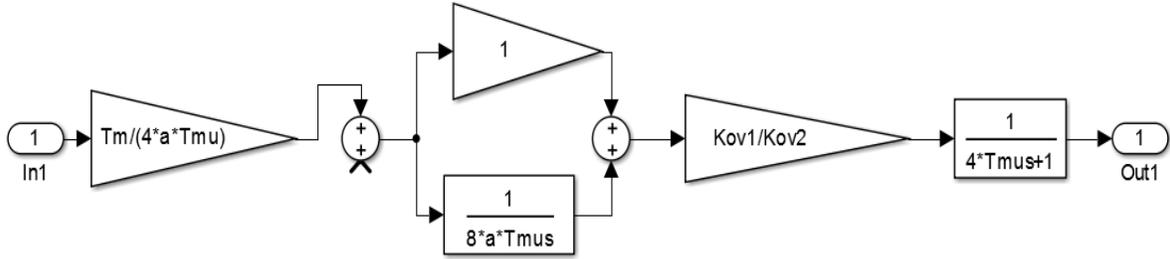


FIGURE 3. Simulink model of the secondary speed controller loop set to SO.

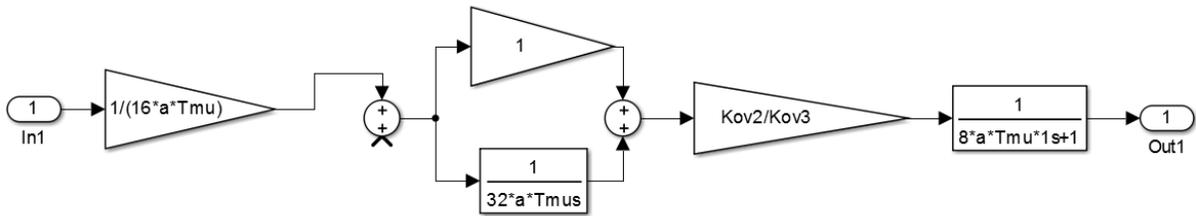


FIGURE 4. Simulink model of the primary position controller loop set to SO.

## A TRANSIENT IN THE LINEAR POSITIONING SYSTEM WITH TO-TUNING CONTROLLERS AND STEP FUNCTION REFERENCE

Fig.5 shows the transient process by reference and disturbance in the linear positioning system with current controller tuned to TO (PI controller), speed controller tuned to TO (P controller) and position controller tuned to TO (P controller).

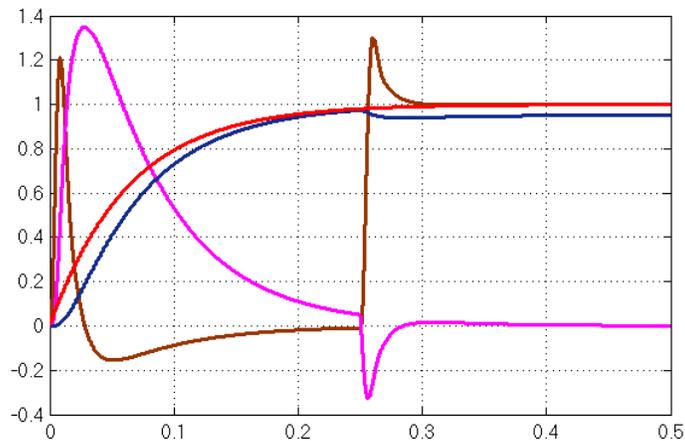


FIGURE 5. Linear positioning system with TO-tuning and a step input of reference.

The ED provides a first order transfer function (FOTF) filter time constant for the position reference in order to limit the coordinates within the linear behavior of the system and reduce output overshooting. The electric drive control system is astatic in terms of setpoint and static in terms of load.

The scales and dimensions of the coordinates on the y axis are: Reference - 1:1, rad; Position - 1:1, rad; Speed - 1:8, rad/s; Current - 1:15, A. Along the time axis [t] = s.

### A TRANSIENT IN THE LINEAR POSITIONING SYSTEM WITH TO-TUNING CONTROLLERS AND LINEAR INPUT OF REFERENCE

Fig.6 shows a transient process and a steady-state motion of the linear positioning (tracking) system with TO-tuning controllers and linear input of reference.

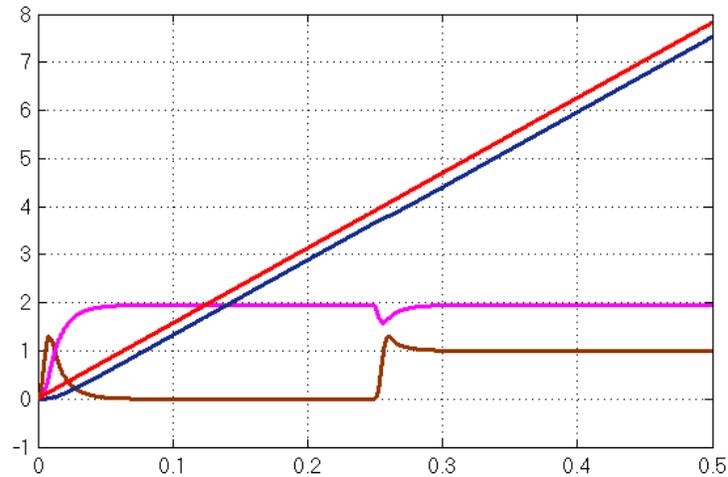


FIGURE 6. Linear positioning system with TO tuning a linear input of reference.

### A TRANSIENT IN THE LINEAR POSITIONING SYSTEM WITH SO-TUNING CONTROLLERS AND STEP INPUT OF REFERENCE

Fig.7 shows the reference and the disturbance transient process in the linear positioning system with a current controller tuned to TO, speed controller tuned to SO, and position controller tuned to SO. The system has a feedforward compensator with filter time constant for the reference by position (32Tmu) and speed (8Tmu) in order to limit the coordinates within the linear behavior of the system. The electric drive control system is astatic in terms of setpoint and astatic in terms of load.

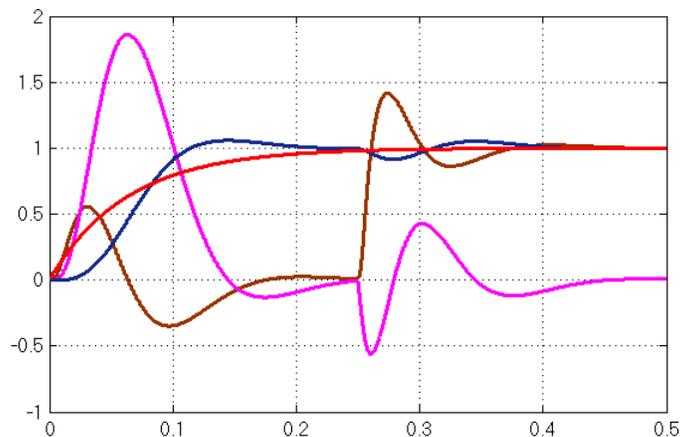
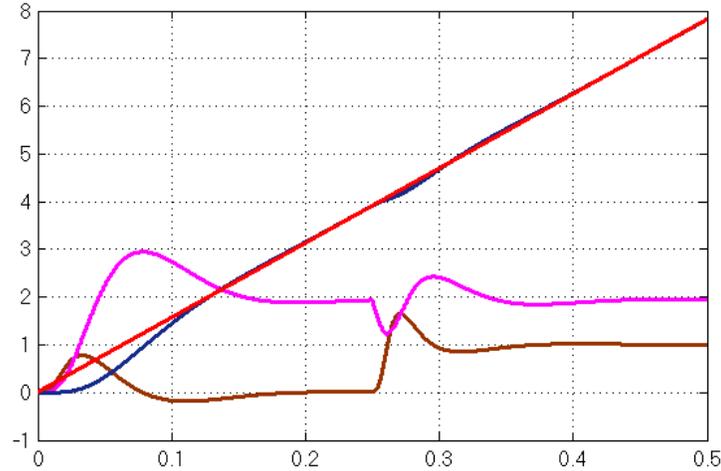


FIGURE 7. Linear positioning system with SO-tuning and a step input of reference.

## A TRANSIENT IN THE LINEAR POSITIONING SYSTEM WITH SO-TUNING CONTROLLERS AND LINEAR INPUT OF REFERENCE

Fig.8 shows the reference and the disturbance transient process of the linear tracking system of fig.7 and a linear position reference.



**FIGURE 8.** Linear positioning system with SO-tuning and a linear input of reference.

### APPENDIX

m-file of position electric drive model:

$K_p=110$ ;  $k_{fi}=1$ ,  $V/(rad.s^{-1})$ ;  $r_a=1, Ohm$ ;  $K_d=1/r_a$ ,  $Ohm^{-1}$ ;  $K_{ov1}=0.25$ ;  $K_{ov2}=0.1$ ;  $K_{ov3}=0.2$ ;  $T_{mu}=0.001$ , s;  $L_a=0.005$ , H;  $J=0.020$ ,  $kg.m^2$ ;  $T_m=J.ra.kfi^{-2}$ ;  $T_a=L_a/ra$ ;  $a=2(SO)$ ,  $a=1(TO)$ .

### CONCLUSION

Computational experiments were performed with cascaded control systems for electric drives and optimal tuning of controllers applicable in mechatronic systems, synthesized by symmetric and technical optimum, which is based on the separation of essential parts in the synthesis of control. The parameters of the controllers are summarized and dynamic models are synthesized, verifying the proposed settings. The developed models are useful, first of all, in the learning process - because they are simple and clear enough to make a transition from the transfer function theory structures to the synthesis of the cascaded control systems. Secondly, the developed models correspond well with the real physical phenomena and can be used in solving various additional tasks, in particular in the analysis of the influence of additional feedback to compensate for BEMF, for example. Thirdly, there are no restrictions for the methodology to be applied to other machines and processes, and with settings which are different from the ones proposed in this research - such as a setting of linear optimum, as well as in the case of current relays controllers or current PWM controllers and digital controllers.

When using a cascade control system, a complex plant is decomposed into three subsystems. For the electrical drives and power converters, these subsystems are first order systems or second order systems. Because of the large difference between the time constants of the subsystems mentioned above, PI and PID controllers can be designed separately and effectively using the models of the subsystems.

With the inner-loop current control, a high gain feedback control is used in practice to overcome the effects of nonlinearities. The resistance and inductance in the current systems are likely varying with respect to temperature and operating conditions. With high gain feedback control, the impact of their variations on the current regulation is reduced.

Over-current protection is necessary in the control of electrical drives and power converters. Because there is a tertiary control objective, the calculated current signal may exceed its limits due to a large load. With the cascade control structure, the limits of the current signal can be easily implemented with an anti-windup mechanism as the

constraints on the manipulated variable of the tertiary controller. In the cascade control system design, the inner-loop current control system will have a much larger bandwidth than the one used in the outer-loop control system. Dual sampling rate is used in the implementation of the cascade control system in which the outer-loop control system is sampled in a much slower rate. As a result, the computing resources for the entire control system is reduced. The tertiary current controller can be either a proportional (P) controller or a PI controller. When designing a P controller for the inner-loop system, special attention is paid to the steady-state gain of the closed-loop system that will be used in the model of the second controller design. Because the steady-state error is not a key issue for the tertiary control system, the deployment of P controller could provide the benefit of simplicity.

A typical feature of these systems is the increase of the oscillations of the control loops and the increase in the duration of the transient processes. Cascade control systems can be adjusted with other indicators of the optimization procedures. The dynamics of the internal current loop are determinative for the dynamics of these systems. Recently, hardware current loop accelerators have began to be implemented in these circuits in order to increase these dynamics.

If necessary, other structures and adjustment methods can be used – for example PD position control in a structure with cascade control or PID linear position control in a structure without a speed controller, and with or without a speed feedback.

The study is not exhaustive, but shows potential for solving the tasks of synthesis and tuning of control systems for electric drives, including power converters with a different principle of operation and digital controllers.

## ACKNOWLEDGMENTS

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