



KTH Machine Design

Dynamics and Motion control

Exercises part III
Position and velocity control



3. Control design for the simulated DC-motor model.

The result of the exercises should be an executable M-scripts with Simulink files. Simulation results should always at least show the controlled state, (**velocity or position**), the **reference signal**, the **error** and the **control signal** (voltage). Do not forget to plot the control signal it is very important since it gives a lot of information about the closed loop control performance.

Velocity control

3.1 Continuous time velocity controllers

For design and analysis you should use the linear model from exercise 1.2 and for closed loop simulation in **Simulink** you should use a model which includes as much details as possible, i.e., the inductance from exercise 1.1 and the static friction from exercise 1.3.

P-control

Design a P-controller by using root locus, select a pole that gives a faster but not too fast closed loop response compared with the response of the motor without control.

- Check the amplitude and phase margins.
- Simulate the closed loop controller using a reference signal that i) is a step (What is a reasonable amplitude?) and ii) a sin wave (try different frequencies and observe the gain and phase between reference signal and motor speed). Try for example

$$v_{ref}(t) = 10 \sin(0.2t) \text{ and } v_{ref}(t) = 200 \sin(20t) \quad (1)$$

as reference velocity.

PI-control

To get rid of the static error in the P controller design a PI-controller by pole placement, start by choosing both closed loop poles near to where the single closed loop pole of the P-controller was.

This is an excellent time to test the difference between error and output feedback. The error feedback will probably give an overshoot (depends a little on the location of the poles) for a reference step and the output feedback will give a step response without overshoot. Why?

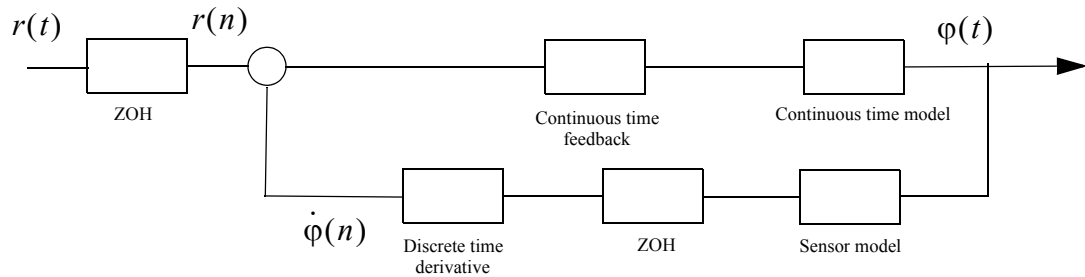
- Simulate and make an analysis as was done with the P-controller.

Deliver the following for the final designs:

1. Closed loop poles and zeros.
2. Time response to reference steps and reference sine wave.
3. Phase and amplitude margins

3.2 Discrete time controllers

Before you actually design a discrete time controller you can analyse your continuous time design from exercise 3.1 by simulating it as a sampled system micro-processor implementation as shown below for the case with error feedback. This means that you also should include the sensor model (exercise 1.4) with discrete time derivation of the sensor position. Use the Simulink option Sample time colours to see which blocks simulates continuous and which that simulate discrete.



- Use the designed P and PI-controllers from exercise 3.1 and simulate with sampling period $Ts_1 = 0.05$ and $Ts_2 = 0.005$. Use a quantization level of $Q_1 = 2048$.

Does it work?

- To understand the behavior of the simulation analyse the feedback by discretizing the linear DC-motor model with zero order hold sampling and approximate the PI-controller with e.g. Tustins approximation, the P-controller is not a dynamic controller and has not to be discretized. Analyse the closed loop behavior for the designed controllers, P and PI, poles and zeros, amplitude and phase margins. Do it for both sampling intervals, Ts_1 and Ts_2 .
- To design a good P or PI-controller for a specific sampling period we have to discretize the DC-motor model with that sampling period and then design with root locus or pole placement. Select discrete closed loop pole locations based on the continuous poles and the sampling period..

What is the maximum theoretical gain for the P-controller with Ts_1 and Ts_2 respectively?

- Simulate the redesigned PI-controller and show some results similar to those from exercise 3.1.

Position control.

3.3 Continuous time position controllers

Design P, PD and PID controllers using the same technics as with the velocity control design. That is, root locus, pole placement, amplitude and phase margins.

- Only the results from the final design of the PID controller has to be delivered.

3.4 Discrete time position control

As above the controller should run on to different micro controllers where one has $Ts_1 = 0.01$ and the second $Ts_2 = 0.001$.

3.5 Control of the hydraulic cylinder.

Design a velocity controller using poleplacement for the cylinder, exercise 1.6.

Design decisions you have to make are:

Which approximations can be done in the linear model used for design.

Selection of operating points.

Selection of control structure

Selection of closed loop poles.

Don't forget to test if the controller works for both positive and negative directions.

When you are satisfied, design a position controller in an outer loop round the velocity controller so that you get a cascaded control structure where the output of the position controller is the reference velocity for the velocity loop.

If the closed loop poles for the position loop are sufficiently slower compared to the closed loop poles of the velocity controller then it is possible to use the simple model

$$y = \frac{1}{s}v \quad (2)$$

where v is the velocity and y the position to design the position controller. 10 times slower should work without problems, try to find a limit in the difference in closed loop poles.

A potential problem can be that if you set a reference position, e.g. $y_{ref} = 0.2$ and if the gain in your position controller is large, say 100, then you will get a very high reference velocity at time zero, in this case 20 [m/s]. Either you have this as a design constraint or you design a better reference signal that is not just a step.

Make a discrete time approximation of the controllers. What is the longest sample period you can select without losing to much performance?