Problem 1

In Figure 1 is shown a power transmission that consists of a motor, a gear box and a drum. Attached to the drum is a wire that holds a vertically translating payload.

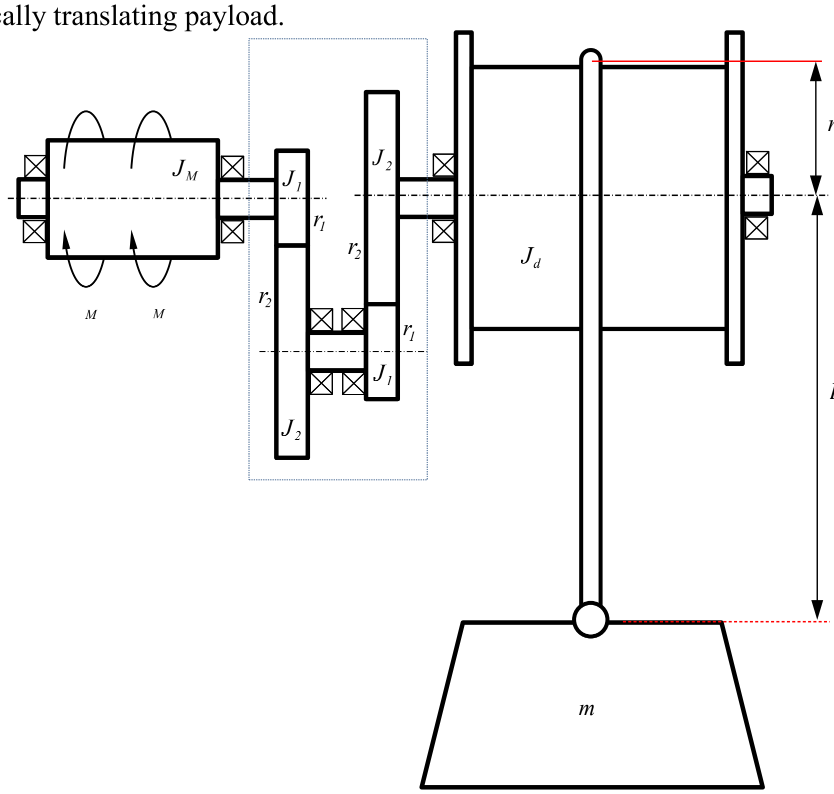


Figure 1 Payload connected via a wire to a drive train that consists of a motor, a gearbox and a drum.

The following inertia data is given: $J_m = 0.8\ kgm^2$, $J_1 = 0.1\ kgm^2$, $J_2 = 1.5\ kgm^2$, $J_d = 8\ kgm^2$
And $m = 10000\ kg$. The following geometry data is given: $r_1 = 80\ mm$, $r_2 = 480\ mm$, $r_d = 600\ mm$, and $L_0 = 10\ m$. During hoisting, it is desired that the motor speed, $\omega_m^{(ref)}$, should ramp up from 0 $\frac{rad}{s}$ to 12 $\frac{rad}{s}$ in 2 seconds and then keep the speed constant at 12 $\frac{rad}{s}$.

The torque provided by the motor is to be controlled by a PI-controller based on the reference and measured motor speed, i.e.

$$M_m = K_p \cdot e_\omega + \frac{K_p}{\tau_i} \cdot \int_0^t e_\omega \cdot dt$$

Where the speed error is

$$e_\omega = \omega_m^{(ref)} - \omega_m$$

The maximum torque that the motor can provide is $M_{max} = 2000\ Nm$ and the minimum torque is $M_{min} = 0\ Nm$.

a) Find suitable values for the controller and simulate the first four seconds of a hoisting situation. The motor starts from rest.

b) Next, assume that the motor torque required by the controller cannot be obtained immediately. Model the torque build up as a first order system with a time constant, $\tau_{tq} = 0.15\ s$:

$$\dot{M}_m = \frac{1}{\tau_{tq}} \cdot (M_m^{(ref)} - M_m)$$

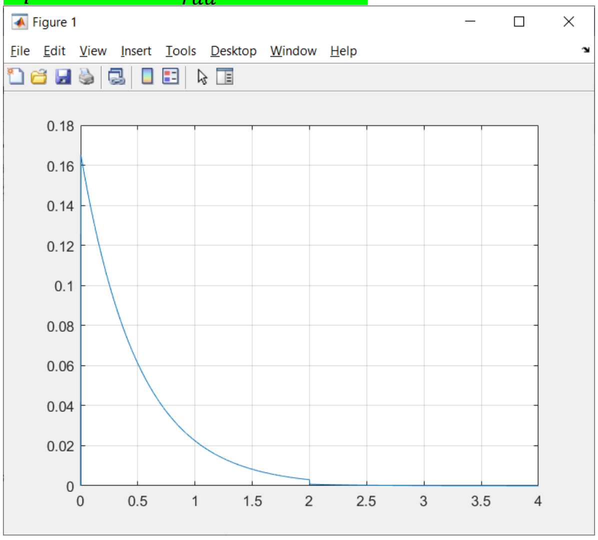
Where the reference motor torque is the controller output:

$$M_m^{(ref)} = K_p \cdot e_\omega + \frac{K_p}{\tau_i} \cdot \int_0^t e_\omega \cdot dt$$

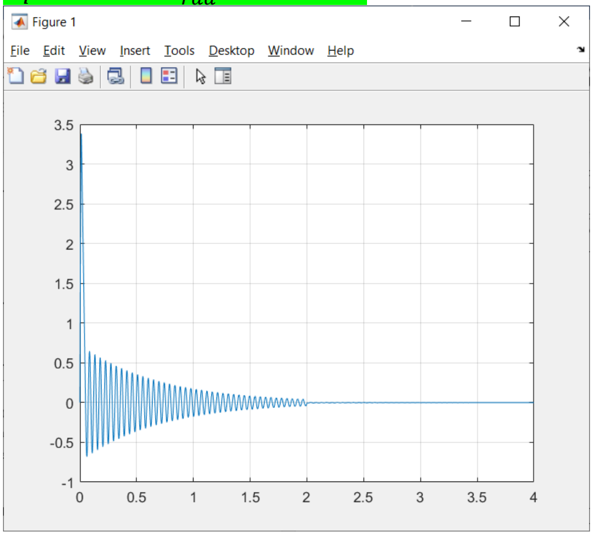
Find suitable values for the controller and simulate the first four seconds of a hoisting situation. The motor starts from rest. Initial value for the motor torque is $M_m = 0$.

c) Next, assume that the speed measurement is only updated with a sample frequency of 1 kHz. Find suitable values for the controller and simulate the first four seconds of a hoisting situation. The motor starts from rest.

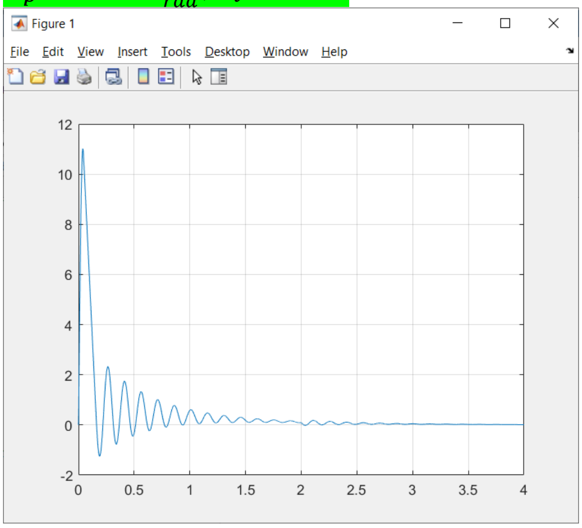
a) Velocity error in [rad/s] vs time [s], $K_p = 10000 \frac{Nms}{rad}, \tau_i = 0.5\ s$



b) Velocity error in [rad/s] vs time [s], $K_p = 10000 \frac{Nms}{rad}, \tau_i = 0.5\ s$



c) Velocity error in [rad/s] vs time [s], $K_p = 1000 \frac{Nms}{rad}, \tau_i = 1.0\ s$



Problem 2

An electric circuit is shown in Fig. 2 and consists of a voltage supply, three resistors, and two capacitors.
The two fixed resistances have the same resistance $R_1 = R_3 = 200\ \Omega$. The variable resistance can take any value between $R_{2,min} = 0\ \Omega$ and $R_{2,max} = 10\ \text{k}\Omega$. The capacitance of the capacitors are $C_1 = 60\ \mu\text{F}$ and $C_2 = 2\ \mu\text{F}$. The supply voltage is ramped up to a constant value of $U_S = 12$ V, according to Fig. 3.

At time t = 0 s the voltage drop across both capacitors are $U_{C1} = U_{C2} = 0$ V.

The variable resistance is to be controlled by a PI-controller based on the reference and measured voltage at the first capacitor U_{C1}. The reference value of U_{C1} is always 60% of U_S, i.e.

$$R_2 = K_p \cdot e_U + \frac{K_p}{\tau_i} \cdot \int_0^t e_U \cdot dt$$

Where the voltage error is

$$e_U = U_{C1}^{(ref)} - U_{C1} = 0.6 \cdot U_S - U_{C1}$$

Find suitable values for the controller and simulate the system for 1 second. Plot the voltage error.

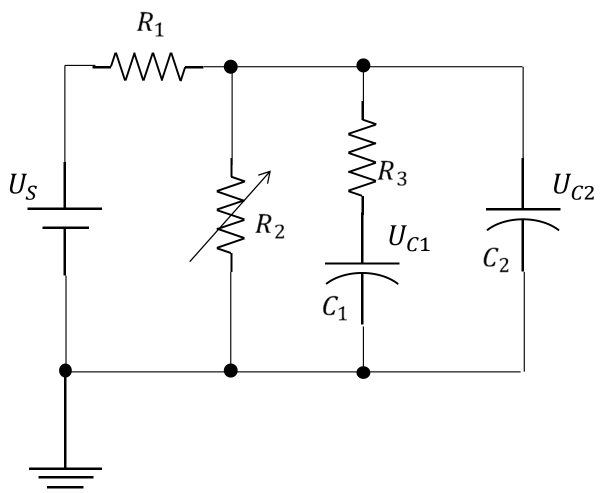


Figure 2 Electric cicuit.

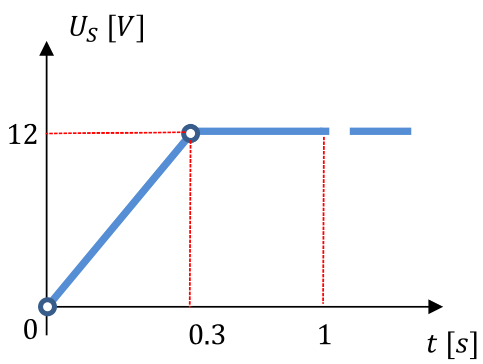
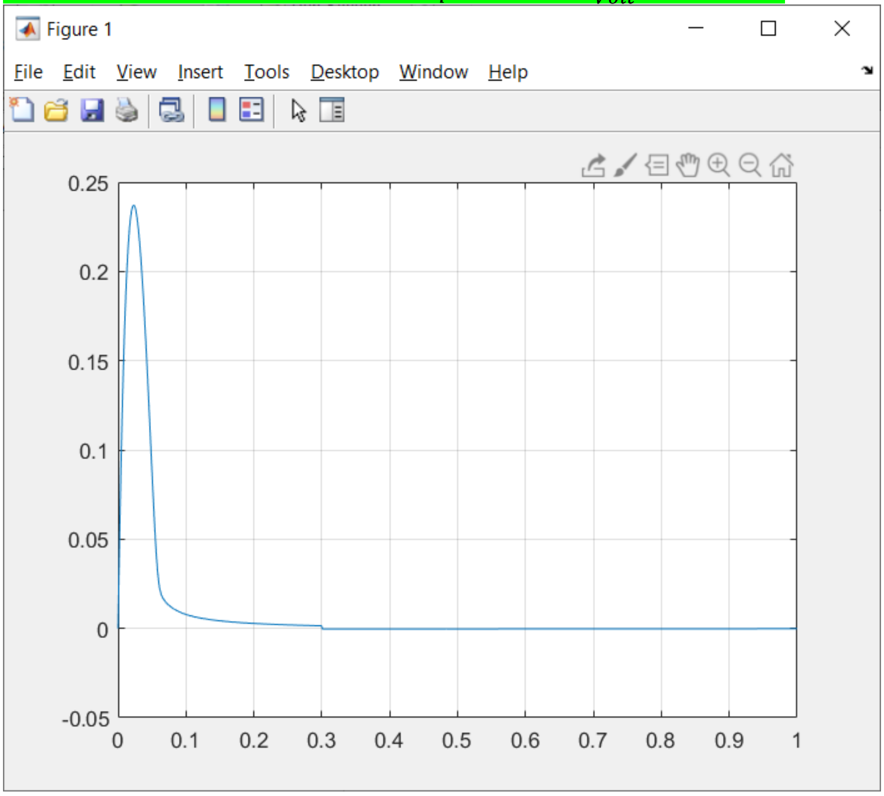


Figure 3 Variation of voltage supply vs. time.

Voltage error in [V] vs time [s], $K_p = 30000 \frac{Ohm}{Volt}$, $\tau_i = 1.0\ s$



Problem 3

In Fig. 4 is hydraulic system with a pressure source, a fixed orifice, a variable orifice and a cylinder supporting a payload.

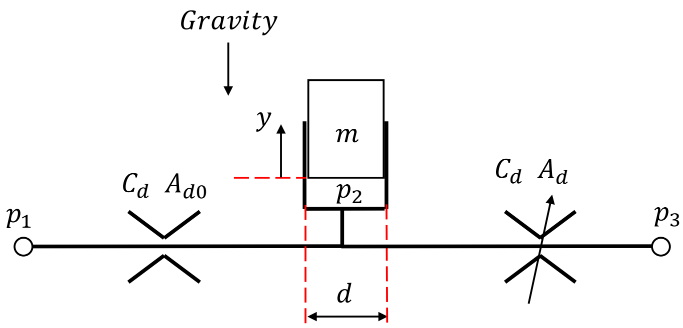


Figure 4 Hydraulic system consisting of a pressure source, an orifice and a payload.

The following data is given for the fluid: density $\rho = 850\,\frac{kg}{m^3}$ and oil stiffness $\beta = 900\,\frac{N}{mm^2}$.
The orifice discharge data: $C_d = 0.55$ and $A_{d0} = 2\ mm^2$. The variable orifice has a maximum opening of $A_{d,max} = 15\ mm^2$ and a minimum of $A_{d,min} = 0\ mm^2$.

Piston/payload data: diameter $d = 63\ mm$ and $m = 3200\ kg$.

The volume of the cylinder chamber is variable. It is a function of the piston travel

$$V_2 = V_{2,min} + A \cdot y$$

where $V_{2,min} = 2000 cm^3$ and the piston area is referred to as A.

The initial pressure $p_2^{(init)}$ holds the payload in static equilibrium. Initially, $y = 0$ and $\dot{y} = 0$.
The pressure sources are constant $p_1 = 150$ bar and $p_3 = 0$ bar.

a) The variable orifice is to be controlled by a PI-controller based on the reference and measured position of the mass. The reference position of the mass is $y^{(ref)} = 20\ mm$. The control law is:

$$A_d = -K_p \cdot e_y - \frac{K_p}{\tau_i} \cdot \int_0^t e_y \cdot dt$$

Where the position error is

$$e_y = y^{(ref)} - y$$

Find suitable values for the controller and simulate the system for 8 second. Plot the position error.

b) Next, the variable orifice is to be controlled by a PI-controller based on the reference and measured velocity of the mass. The reference velocity of the mass is $\dot{y}^{(ref)} = 10\ mm/s$. The control law is:

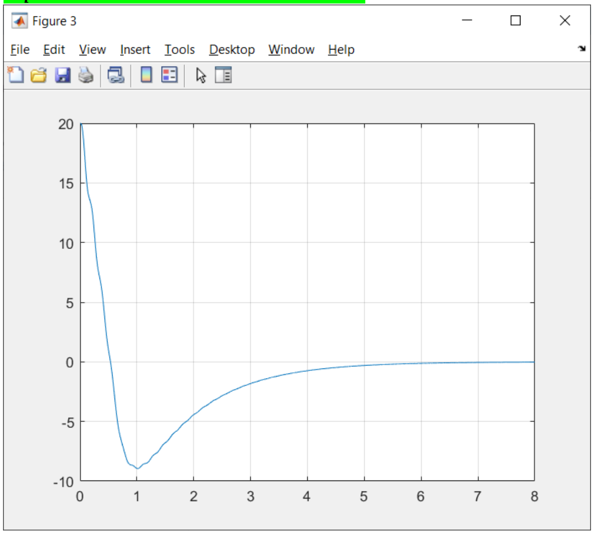
$$A_d = -K_p \cdot e_v - \frac{K_p}{\tau_i} \cdot \int_0^t e_v \cdot dt$$

Where the velocity error is

$$e_v = \dot{y}^{(ref)} - \dot{y}$$

Find suitable values for the controller and simulate the system for 8 second. Plot the velocity error.

a) Position error in [mm] vs time [s],
$K_p = 0.0002\ m\ ,\ \tau_i = 1.3\ s$



b) Velocity error in [mm/s] vs time [s],
$K_p = 0.00025\ m \cdot s\ ,\ \tau_i = 1\ s$