Chalmers University of Technology

Department of Signals and Systems

SSY155 Applied Mechatronics

Examination date 090307

Time: 8:30-12:30

Teacher: Jonas Sjöberg, tel 031-772 1855.

Allowed material during the exam:

- Mathematical handbook of your choice.
- Calculator without plotting functionality
- 1 handwritten A4-page with information of your choice
- Scientific papers:
  - Nordin, M., Gutman, P.-O., Controlling mechanical systems with backlash - a survey, Automatica, (1633-1649), 38, 2002.
  - Roos, F., Johansson, H., and Wikander, J., Optimal selection of motor and gearhead in mechatronic application, Mechatronics, (63-72), vol 16, 2006.
  - Glad, T., and Ljung, L., Chapter 14 from Control Theory, Multivariable and Nonlinear Methods

The exam consists of 5 exercises of a total of 50 points. Nominal grading according to 23/30/40 points, you need 23 points to pass the course with grade 3, 30 points to pass with grade 4 and 40 to pass the course with grade 5. Solutions and answers should be written in English and be unambiguous and well motivated, but preferably short and concise.

Those who received 3 or 4 bonus points from the hand in assignments can skip the third problem in the exam, and you recieve 10 point for that problem for free. You should have recieved an email prior to the exam with your number of bonus points.

Results are mailed out latest March 18. You may check your grading of your exam on March 18 at 12.30-13.00 at the Department of Signals and Systems.

GOOD LUCK!

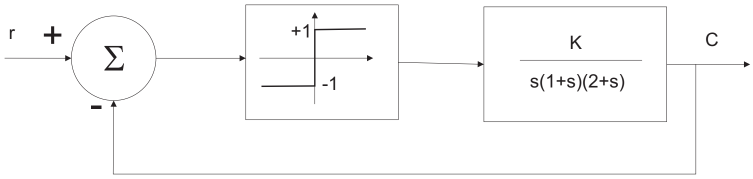
1. a Give three reasons why wireless sensors can be prefered. [3p]

   b Describe what path planing is and why it is important for industrial robots. [3p]

   c Which are the two main nonlinear control practices to handle backlash? [4p]

[10p]

2. Consider the following system, controlled with a relay in the feedback



and with $K = 1$. Relays, often gives oscillations in the system. One way to lower the oscillations is to introducea dead-zone in the relay.

   a Determine frequency and amplitude of the oscillation in the system. [5p]

   b Determine the necessary size of the dead-zone to decrease the amplitude of the oscillation by a factor 2. [5p]

3. A PM DC-motor with stall torque 20 Nm (at $\omega = 0$) and no load speed $\omega_{\max} = 200$ rad/s is used to power a fan with the following torque-speed relation (Nm)

$$T_{\text{fan}} = K\omega_m^2$$

At 1000 rpm the fan needs 500 Watt.

Decide the speed of the fan when it is powered by the motor and how much power it consumes.

[10p]

4. The final step, choosing the gear ratio in a mechatronic design is missing. From the product specifications of required speed cycle the following integrals are formed over one work cycle of the construction

$$
\begin{aligned}
k_1 &= \frac{1}{T}\int_0^T \ddot{\theta}_l^2(t)dt = 10\ \mathrm{s}^{-4} \\
k_2 &= \frac{1}{T}\int_0^T T_l^2(t)dt = 5\ \mathrm{N}^2\mathrm{m}^2 \\
k_3 &= \frac{1}{T}\int_0^T \ddot{\theta}_l(t)T_l(t)dt = 5\ \mathrm{Nm/s}^2
\end{aligned}
$$

For the work cycle the maximum speed and torque have also been recorded: $T_l^{peak} = 10$ Nm and $\omega_l^{\max} = 200\ \mathrm{rpm}$. A motor has been chosen with the following specifications: $\omega_{\max} = 4000$ rpm, $T_{\text{peak}} = 2$ Nm, $T_{\text{rated}} = 0.8$ Nm, $J_m = 0.01$ kgm^2. Assume an ideal gearbox.

(a) Calculate an optimal gear ratio N so that the demands on the electric drive powering the motor become as low as possible. [6p]

(b) It is possible to choose a cheaper motor with $T_{\text{peak}} = 1$ Nm, but all other parameters as the previous motor. Is there any point of not choosing this motor? How much different does the demand on the electric drive become? [4p]

5. Consider a resistance temperature detector (RTD) sensor used to measure the temperature in system. A Wheatstone bridge is used to measure the resistance. The sensor is described by

$$R = R_0(1 + \alpha(T - T_0))$$

where $\alpha = 0.004^oC^{-1}$, $T_0 = 0^oC$, and $R_0 = 200\Omega$. The sensor is placed at the position of one of the resistors (R_1) in the Wheatstone bridge, which is powered with $V_i = 10$ V (DC) and $R_0 = R_2 = R_3 = R_4 = 200\Omega$. What is the temperature when the voltage over the bridge $V_0 = 0.5$ V? [10p]

Chalmers University of Technology

Department of Signals and Systems

SSY155 Applied Mechatronics

090307

Solutions

Teacher: Jonas Sjöberg

Results are mailed out latest March 18. You may check your grading of your exam on March 18 at 12.30-13.00 at the Department of Signals and Systems.

1. a - Wire harness and connectors material cost, Cu is expensive.
   - Wire harness and connector claim cost, failures due to the environment in automotive applications (vibrations, dirt, heat, material fatigue, etc)
   - Certain applications can not use wired sensors, for example those located on rotating axles

   b The path describes how the robot should move from one position to an other, or how it performs a smooth movement while it is doing some work for example spraying). There are often many paths which results in the same path for the working tool. Hence, all these paths solve the specification for the tool. However, there might be large differencies how much energy it costs to follow the different paths. Also precision may vary.

   c "strong action in the backlash gap" and "weak action in the backlash gap".

2. a $\omega = \sqrt{2}$ and $C = 2/3\pi$.

   b The Nyquist curve of the linear part of the system is not changed but the describing function. The amplitude is halfen if the following equation hold

$$\frac{4}{\pi C/2}\sqrt{1-\frac{D^2}{(C/2)}^{2}} = \frac{4}{\pi C}$$

   where D is the dead-zone. The solution is $D = \sqrt{3}C/4 = 1/(2\pi\sqrt{3})$.

3. Given:

   $T_s = 20$ Nm, $\omega_{max} = 200$ rad/s

   $T_{fl} = K\omega^2$ Nm

   One point given:: $\omega_1 = 1000$ rpm $= 104.7...$ rad/s gives power $P_{fl_1} = 500$ W

Calculations:

Obtain K for the load: $P_{fl_1} = T_1 \cdot \omega_1 \Rightarrow T_1 = P_{fl_1}/\omega_1 = 500/104.7... = 4.77...$ Nm.

gives $K = T_1/\omega_1^2 = 4.35... \cdot 10^{-4}\ Nms^2/rad^2$

For the motor $T_{motor} = T_s(1 - \frac{\omega}{\omega_{max}})$

At equilibrium $T_{motor} = T_{fl} \Leftrightarrow T_s(1 - \frac{\omega}{\omega_{max}}) = K\omega^2$

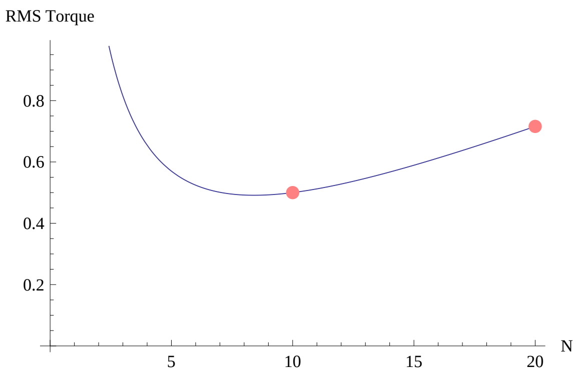
The solution of the quadratic equation gives $\omega = -114.8... \pm 243.15....$ Illustrate this solution by drawing the to curves. The intersection is the solution.

Since only positive solutions are of interst we obtain $\underline{\omega} = 128.31...\underline{\approx 128}$ rad/s

which gives $\underline{P_{fl}} = T_{fl} \cdot \omega = K\omega^3 = 919.83...\underline{\approx 920}$ W

4. (a) $N_{\text{max}} = \omega_{\text{max}}/\omega_l^{\text{max}} = 20$, $N_{\text{min}} = T_l^{peak}/T_{\text{peak}} = 5$. Within this interval T^m_{RMS} should be minimized with respect to N. That is, minimize

$$T^m_{\text{RMS}}(N)^2 = J_m^2 N^2 k_1 + \frac{k_2}{N^2} + 2\, J_m k_3$$



Taking the derivative and solving this gives minimum at $N = 8.4$. For that gear ratio one obtains $T^m_{\text{RMS}}(8.4) = 0.49$ Nm.

(b) Now $N_{\text{min}} = 10$ and $N = 8.4$ is outside the permitted interval. Best choice becomes $N = 10$ and $T^m_{\text{RMS}}(10) = 0.50$ Nm. It is a increase of less than 2 percentage which might motivates a change of motors depending on how much cheaper the second motor is.

5. Set $\Delta R = R_0\alpha(T - T_0)$, then

$$V_0 = V_i \frac{\Delta R/R_0}{4 + 2\Delta R/R_0}$$

The numeric values gives $\Delta R = 44\Omega$ and $T = T_0 + (244/200 - 1)/\alpha = 55^oC$.