Examination + answers:

Course name:	**Mechatronic System Design**
Course code:	**WB2414-08**
Date:	**April 7th, 2011**
Time:	**9:00 - 12:00**
Contents:	**4 Questions (10 points (+1))**

Remark: Like the January examination maximum 10 points can be earned, with additional the given point for an empty paper. One point can be seen as a bonus point to compensate other flaws.

Question 1 (3.5 points) (motion control)

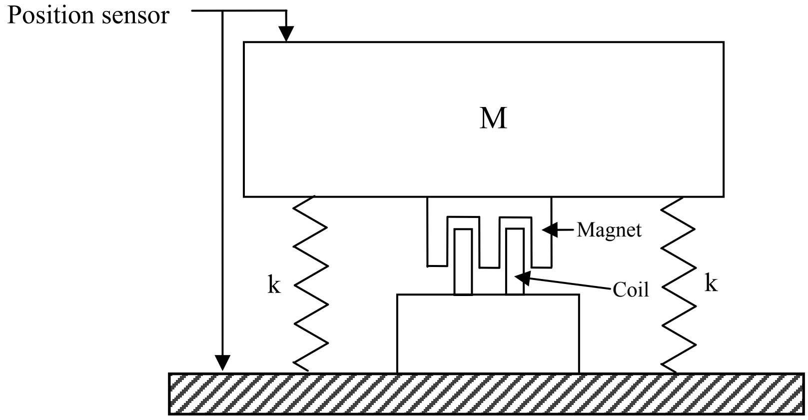

Figure 1: Vibration table

A vibration table is used to test the sensitivity of several objects for vibrations as shown schematically in Figure 1. The system is position controlled to achieve a constant position amplitude over a frequency range from 0 Hz until 1 kHz (+/- 3 dB).

The system consists of:

- A mass M of 3kg.
- 3 springs with a stiffness of $k = 10^3$ N/m each between the mass and the ground.
- An amplifier-Lorentz actuator combination with a total combined frequency independent transfer function of 10 N/V between the mass and the ground.
- A position sensor between the mass and the ground of 10^3 V/m.
- An optimally tuned PD-feedback controller between the sensor and the amplifier-Lorentz actuator (damping and overshoot: Q~1.3, ζ~0.7).

Question 1A (2 points)

Draw the open loop bode plot (magnitude and phase) of the transfer function of the total system. Include relevant values for resonance frequency, slope and magnitude. Draw the bode plot in three parts:

1. The mechanics including the amplifier, Lorentz actuator and sensor (0.7 pts)
2. The controller (0.7 pts)
3. The combined total system (0.6 pts)

Question 1B (1.5 points)

An object under test with a mass of 9 kg is placed on the table. This mass is rigidly connected to the table. The side effects of the static load due to gravity may be neglected.

To compare the effect of the added mass first draw an approximation of the amplitude bode plot of the closed loop without the added object en then in the same plot add the approximated closed loop amplitude bode plot of the system with the added mass. Comment the differences caused by the additional mass in respect to the bandwidth, damping and magnitude of the relevant lines (slope and level).

Propose improvements in the controller, when needed for optimal stability and/or bandwidth with the higher mass. Also comment the robustness these improvements, when the mass is be taken off again under closed loop control.

Figure 2: Linear motor driven positioning system

Question 2 (2 points) positioning systems and actuators

A linear motor driven positioning system (Figure 2) has to make a displacement of 20 mm in not more than 80 ms from standstill to standstill.
The moving mass of the system is 12kg.

Question 2A: (0.5 points)

With what minimal acceleration level can the displacement be made in the specified time in an ideal situation when all dynamic factors are neglected. Draw a graph of the acceleration, velocity and position as a function of time for this ideal situation? Make a drawing with values.

Question 2B: (1 points)

The motor is a linear Lorentz actuator with the following non ideal properties:

R_{motor} : 10 Ω
L_{motor} : 10 mH
F_{motor} : 10 N/A

Draw a graph of the voltage over the motor coil terminals during the step as a function of time, when driven with a current, that would be necessary for the acceleration profile calculated at question A. Comment the different factors that contribute to this voltage.

Question 2C: (0.5 points)

The amplifier can deliver maximum +/-200V. What measure should be taken to prevent the amplifier from clipping? This means that the output voltage of the amplifier is not allowed to exceed the power supply voltage.

Question 3 Electronics (3.5 points)

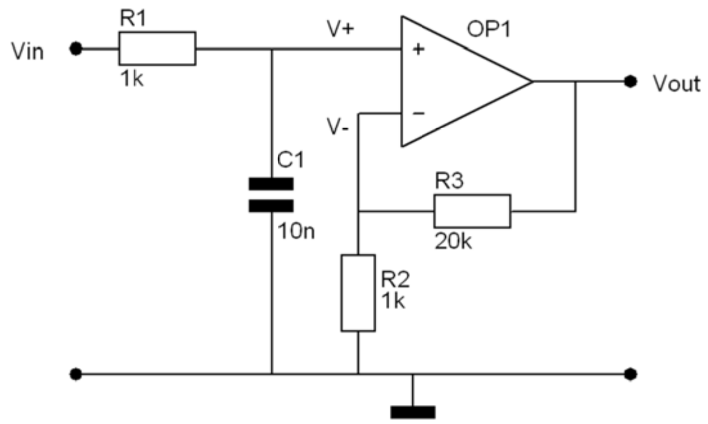

Figure 3. Filter with opamp

Consider the filter circuit given in Figure 3. You are going to determine the properties of this circuit. In the first part of the analysis you may assume that the operational amplifier (opamp) is ideal. To the input a generator is connected that gives a sine wave output, of which we can vary the amplitude and the frequency.

Question 3A: (0.3 points)

What is the input impedance of this circuit, that the generator connected to the input of this circuit would "see" at very low frequencies?

Question 3B: (0.3 points)

What is the input impedance that the generator connected to the input of this circuit would see at very high frequencies?

Question 3C: (0.5 points)

Describe in words what this circuit does as a function of frequency.

Question 3D: (0.4 points)

Sketch a magnitude Bode plot as a function of frequency for the node V+. Indicate the slopes as e.g. +1 or -1. What is the corner frequency?

Question 3E: (0.4 points)

Sketch a magnitude Bode plot as a function of frequency for the node V-. Indicate the slopes as e.g. +1 or -1. What is the corner frequency?

Question 3F: (1 points)

Now you will calculate in three steps the full transfer function from the input to the output, to determine what the corresponding Bode plots for the output are.

Step one: Calculate the full transfer function Vout/Vin with the resistors and capacitor as general complex impedances Z_1 to Z_4. Hint: start by determining the voltage at node V+, then at node V-. Then you know the current through resistor R3, and hence also through R2, and hence the output voltage.

Step 2: Put in the frequency-dependent impedances for the capacitor and the resistors. Rewrite your transfer function in such a way, that the time constant involved is clearly recognizable. Also write it out individually, as in e.g. $\tau_1 = R_3C_1$. Calculate the corner frequency in kHz.

Step 3: Based on your analysis of the circuit and the equation you obtained after step 2 sketch the magnitude Bode plot for the full transfer function Vout/Vin. Indicate the slopes as e.g. +1 or -1, the corner frequency, and the amplitude gain at low frequencies. You don't have to convert the gain to dB, just indicating the gain is enough

The last part of the question deals with the non-ideal properties of such a circuit.

Question 3G: (0.3 points)

Why do you need a power supply (not indicated in the schematic) for this circuit?

Question 3H: (0.3 points)

At very high frequencies, the opamp circuit of Fig 3 always suffers from the fact that the feedback resistor has some very small but noticeable parasitic capacitance Cp (~1pf) across it. Please draw a schematic like Fig. 3, including this capacitor and
Sketch the corresponding magnitude Bode plot. Indicate the slopes as e.g. +1 or -1, and indicate the position of the (now 2) corner frequencies.

Question 4 Lorentz actuator (1 point)

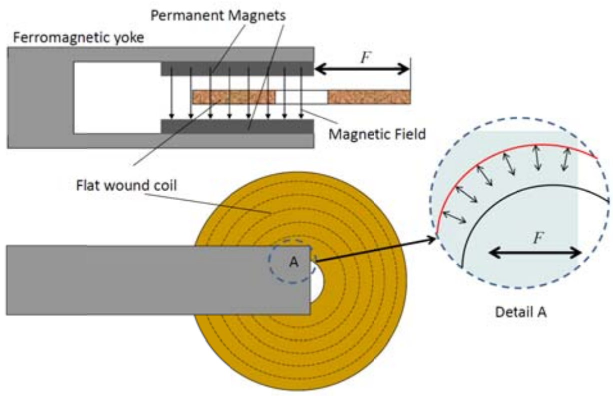

Figure 4 Basic Lorentz type actuator

The basic Lorentz type actuator of Figure 4, for use in a position controlled system, suffers from a lot of inefficiency. One part is due to the fact that most of the coil is outside the air gap and during the lectures solutions were suggested to reduce these problems.
One other problem is the fact that the air gap between the permanent magnets is quite large as it needs to accommodate the coil. Optimising the design of this type of actuator always deals with the right geometry for all the parts.

The following questions need to be answered using common sense and a qualitative knowledge of the material from the course

Question 4A: (0.5 point)

A sometimes suggested solution for the air gap problem is to make the coil of a ferromagnetic material, like isolated wound wires of iron. This wire is normally used for heating because iron has a factor 6 higher resistivity then copper, but its relative magnetic permeability is a factor 100 higher than copper, which could be a benefit in this configuration.

Explain why you think this option is never used in practice. Only a qualitative answer is needed as it should show to what extent you understand requirements on actuation and the principle of this actuator type. Your answer should not be more than 10 sentences and needs to address the following aspects:

- Magnetic flux density
- Saturation
- Magnet size and configuration
- Efficiency (Energy consumed vs force)
- Force behaviour in general (Force to current and stiffness)

Question 4B: (0.5 points)

As an alternative one might consider creating a coil with copper windings interleaved with iron parts, where 50% of the coil volume consists of iron and 50% of copper. Is this a configuration, that can give a more optimal result? Only a rough estimated reasoning of less than 10 sentences is required using the same aspects as for Q4A.