MAE 106 Lab 3 Quiz and Midterm Exam
2007
University of California, Irvine
Department of Mechanical and Aerospace Engineering

Part 1: Lab 3 Quiz

In Lab 3, you built a motor velocity controller, using a proportional feedback controller.

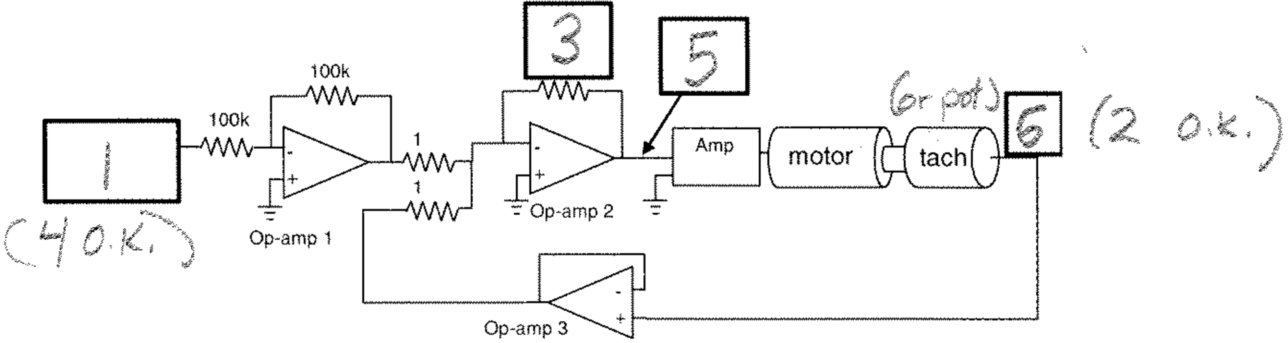
1. Assume that you want to control the position (i.e. angle) of the motor shaft instead of its velocity. Choose the letter for the correct control law, and the numbers that correctly state what each variable represents. Assume G>0 and that a positive input to the motor/amplifier causes a shaft rotation in the positive direction.

Control Law: A

variables: u = 5 G = 3 θ_d = 4 θ = 2

A: $u = -G(\theta-\theta_d)$	1. Desired motor speed	5. Control input to motor/amplifier
B: $G = u(\theta-\theta_d)$	2. Actual motor angle	6. Actual motor speed
C: $u = -G(\theta_d-\theta)$	3. Feedback gain	7. Derivative Gain
D: $G= u/(\theta+ \theta_d)$	4. Desired motor angle	8. Bode's value

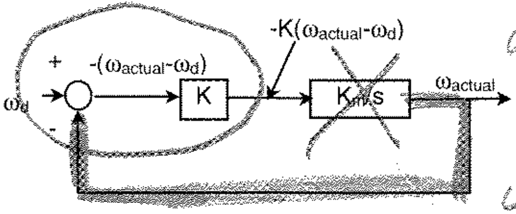
2. Below is a control circuit that you could use to implement the P-type ~~position~~ velocity control. Using the same numbers selected from 1-8 above, label the empty boxes with the correct numbers.



3. Below is a block diagram of the velocity control system you built in lab. What is the transfer function of this system?

Transfer function is letter: A

A. $H(s) = KK_m/(s+KK_m)$
B. $H(s) = (K+K_m)s/K$
C. $H(s) = K(s+K)$
D. $H(s) = (KK_m+s)/K$



$$\omega_a = \frac{K_m}{s} K(\omega_a - \omega_d)$$
$$\omega_a\left(1 + \frac{K_mK}{s}\right) = \frac{K_mK}{s}\omega_d$$
$$\frac{\omega}{\omega_d} = \frac{\frac{K_mK}{s}}{1 + \frac{K_mK}{s}} = \frac{K_mK}{s+K_mK}$$

4. Put a big, thick line through the part of the block diagram that corresponds to the tachometer and its signal. Put an "X" through the part of the block diagram that corresponds to the motor and amplifier . Circle the part of the block diagram that you implemented with op-amps.

Part 2: Midterm

Problem 1 (24 pts). For some questions, more than one letter may apply. In that case, write all the letters that apply.

An oscilloscope is used to measure this:

2 Answer: b a) resistance b) voltage c) current d) capacitance

An op amp is described by the following input output equation:

2 Answer: d a) $V_+=V_-$ b) $V=KV_+$ c) $\iota = 0$ d) $V=K(V_+-V_-)$

What is the period of a sine wave with a frequency equal to 3 Hz?

2 Answer: b a) .66666*pi sec b) 1/3 sec c) 1.5*pi sec d) 1.5/pi sec

A notch filter attenuates:

2 Answer: b a) high frequencies b) a band of frequencies c) low frequencies

A first-order, low-pass filter causes a phase shift in a sinuosidal input. The amount of phase shift at the cut-off frequency is:

2 Answer: c a) 90 deg b) 180 deg c) 45 degrees d) 70.7 deg

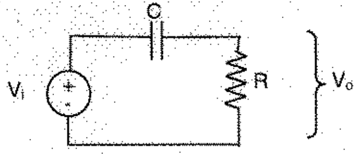
A feedback controller has the disadvantages that: Answers: b, c, f 2x3 = 6
A feedback controller has the advantages that: Answers: d, g 2x2 = 4

A feedforward controller has the disadvantages that: Answers: a 2
A feedforward controller has the advantages that: Answers: e 2

a) it requires an accurate model of the plant
b) it has to allow an error to develop before it does anything
c) delay causes it to go unstable
d) it only requires basic knowledge of the plant
e) it can theoretically produce error-less control
f) it requires a sensor
g) it can cancel unexpected disturbances

Problem 2 (20 pts)

Shown below is a circuit that can filter a signal. Assume you input a sinusoidal voltage at frequency ω. By how much will the output voltage be scaled and phase-shifted?



$$V_0 = \frac{R}{R+\frac{1}{SC}} V_i = \frac{RCS}{1+RCS} V_i$$

$$H(s) = \frac{RCS}{1+RCS} \qquad H(j\omega) = \frac{RCj\omega}{1+RCj\omega} \Rightarrow 5 \text{ points}$$

$$|H(j\omega)| = \text{Mag. Response} = \frac{RC\omega}{\sqrt{1+(RC\omega)^2}}$$

$$\phi_{H(j\omega)} = \text{phase numerator} - \text{phase denominator}$$

$$= \tan^{-1}\frac{RC\omega}{0} - \tan^{-1} RC\omega$$

$$= 90^\circ - \tan^{-1} RC\omega$$

when $\omega = 0$ $|H(j\omega)| = 0$

as $\omega \to \infty$ $|H(j\omega)| = 1$ } High pass

Scaling = Magnitude Response

$$\frac{RC\omega}{\sqrt{1+(RC\omega)^2}}$$

5 points

Phase shift = Phase Response

5 points

$$90^\circ - \tan^{-1} RC\omega$$

What type of filter is this (circle one): 5 points

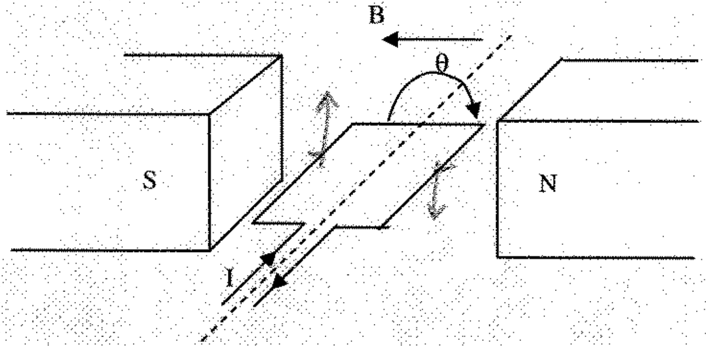
Low pass filter [✓ High pass filter] Notch filter Band-pass filter

Problem 3: 26 pts

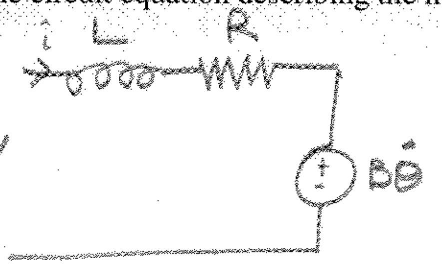
8 a. Shown below is a diagram of a DC brushed motor. Assume that the commutation stops working, such that current flows only in the direction shown. At what angle θ will the armature come to rest? Assume the armature is initially at θ = 0° as shown when the commutation fails, and that positive θ is defined clockwise looking into the page, as shown.

$F = i\vec{l} \times \vec{B}$ +4

$\boxed{+90^\circ}$



8 b. For the rest of this problem, assume the commutation is working. Draw the circuit model, and write the circuit equation describing the motor:



$V = iR + L\frac{di}{dt} + B\dot{\theta}$

10 b. Assume the motor's torque constant is B. Find the torque the motor produces as a function of time when:

- the shaft of the motor is held fixed $\omega = \dot{\theta} = 0$
- a constant voltage v is applied across the motor at time = 0
- the initial current i(t = 0) through the inductor is zero

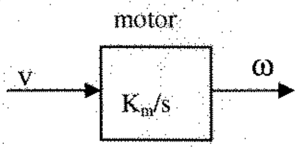
$iR + L\frac{di}{dt} + \cancel{B\dot{\theta}}^{\,0} = V$ $\quad T = Bi$ +2 $\quad i = e^{-t/\tau_c}$ $\quad \tau_c = \frac{L}{R}$ $\quad L\frac{di}{dt} = iR$ $\quad \frac{di}{dt} = i\frac{R}{L}$

$L\frac{di}{dt} + iR = V$ $\quad i(0) = 0$ $\quad i = \frac{V}{R}$ part +2

$$\boxed{T = \frac{BV}{R}\left(1 - e^{-t/\tau_c}\right) \qquad \tau_c = \frac{L}{R}}$$

Problem 4: 30 pts

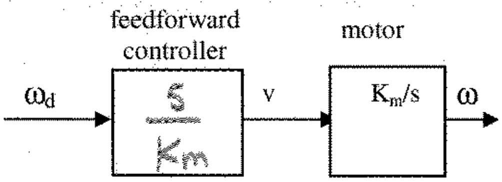
You want to control the speed of a motor. You are using a current amplifier with the motor, so the speed is related to the input voltage to the current amplifier by the following transfer function:



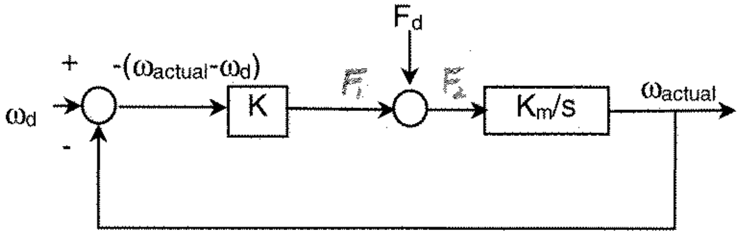
where v is the voltage input to the motor and ω is the angular velocity of the shaft and K_m is a constant.

Shown below is a block diagram of an open-loop (i.e. feedforward) controller for the motor, where ω_d is the desired output of the motor. What transfer function should the controller box have to make the output equal the desired output? Write this function controller box.

10 pts



One of the major benefits of feedback is its ability to cancel the effects of unmodeled "disturbances". Assume you build a feedback controller, but there is a disturbance force F_d affecting the motor:



You can view the effect of F_d on ω_{actual} as being described by a sort of filter. What type of filter is it and what is it's cutoff frequency?

$$\omega_a = \frac{K_m}{s} F_2 = \frac{K_m}{s}(F_d + F_1)$$

$$= \frac{K_m}{s}(F_d - K(\omega_a - \omega_d))$$

10 pts Type of filter: Low Pass Filter

10 pts Cutoff frequency: KK_m

$$\omega_a\left(1 + \frac{KK_m}{s}\right) = \frac{K_m}{s}F_d + \frac{KK_m}{s}\omega_d$$

$$\omega_a = \frac{K_m}{s+KK_m} F_d$$

$$\omega_a = \frac{\frac{K_m}{s}}{1+\frac{KK_m}{s}} F_d + \frac{\frac{KK_m}{s}}{1+\frac{KK_m}{s}} \omega_d$$

$$\omega_a = \boxed{\frac{K_m}{s+KK_m}} F_d + \frac{KK_m}{s+KK_m} \omega_d$$