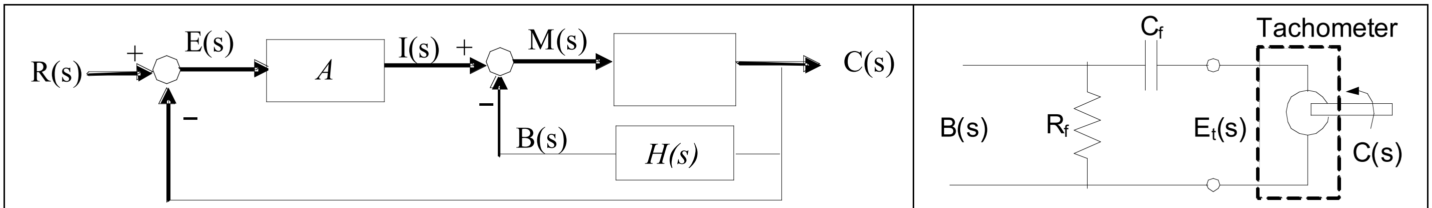
ME Ph.D. Qualifying Examination — System Dynamics and Controls, Spring 2008

Choose **3** of the following **4** questions to answer.

Problem 1

Consider the closed-loop compensation system as shown in Fig. (a), where $G_p(s) = \dfrac{K}{s(s+1)(s+5)}$.



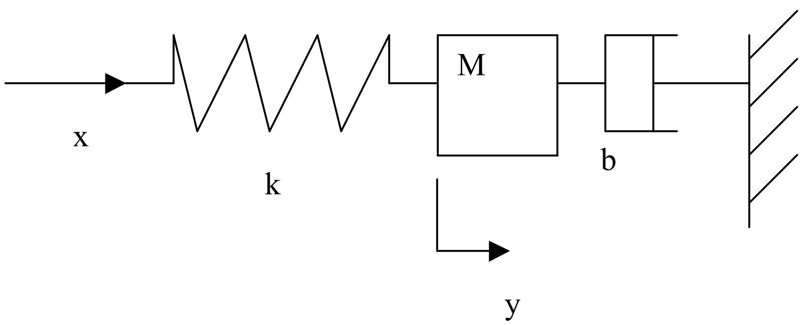
(a) Block diagram | (b) Tachometer with a RC network

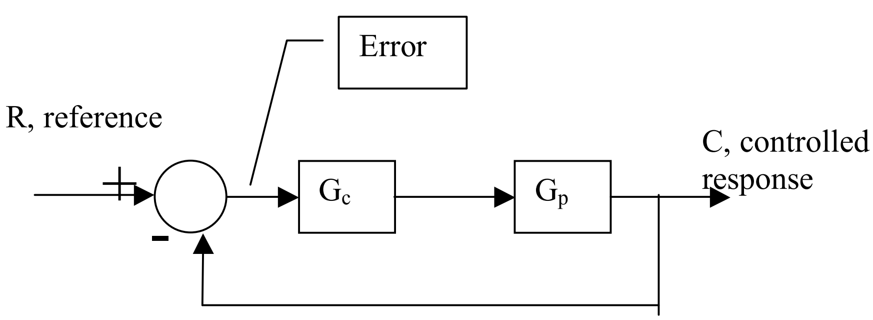
You are asked to explore the effect of 2nd derivative feedback on the system performance using the *root locus* technique. For a position system, an accelerometer will generate such a signal. An approximation to this desired signal may be generated by modifying the output of a tachometer, which has a transfer function $E_t(s) = K_t s$, with a high-pass filter as shown in Fig. (b).

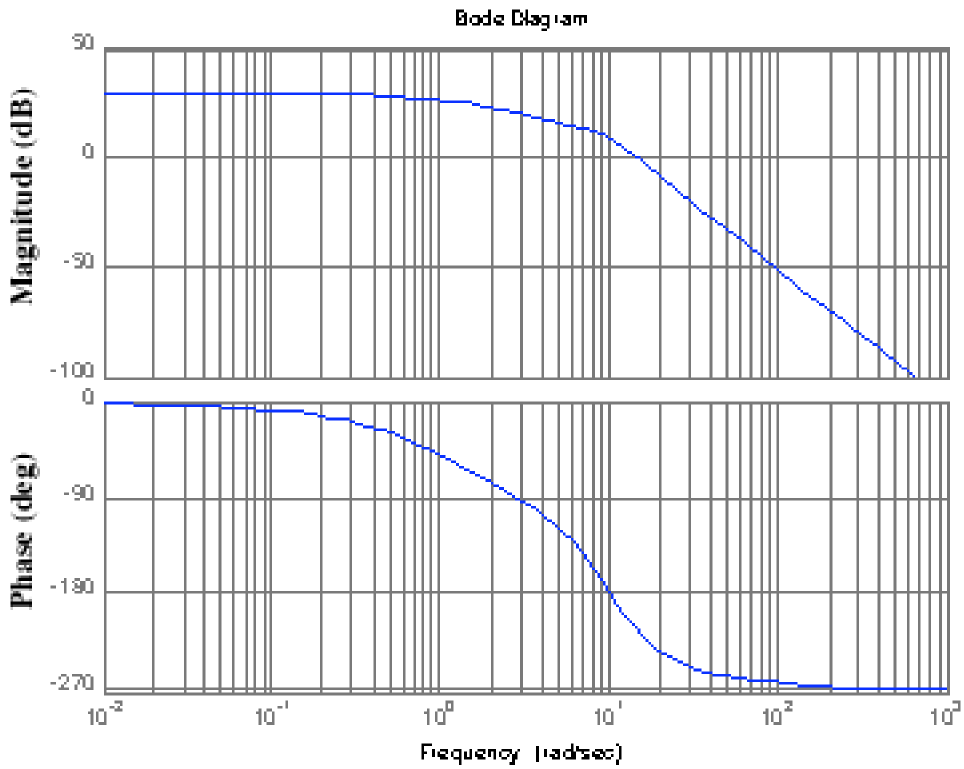
(1) Show that the open-loop transfer function has a pair of zeros and sketch the root locus.

(2) Using the *root locus* technique, discuss the effect of the 2nd derivative feedback on the ramp error coefficient, and the time response of the complete system; for this part, you may assume that the two zeros are real.

Problem 2 (two pages)
The frequency response of the spring-mass-damper system driven by an actuator displacement x is given below. The displacement of the actuator x has a first order lag with known time constant $\tau = 1$ sec. when driven by the input to the plant actuator.
(a) This plant is to be placed into a feedback loop as shown below with $G_c = K = 1$. What response do you expect from the closed loop system?
(b) Find the gain K (based on the Bode plot) to achieve a phase margin for the closed loop system of 50 degrees. What is the steady state error to a unit step reference input to the closed loop system for this case? What is the steady state error to a unit ramp reference input to the closed loop system for this case?
(c) Propose a controller that would produce zero steady state error to a step input. You do not need to find the controller gains, but justify your answer mathematically.
(d) Consider K = 0.1 and a unit amplitude sinusoidal reference input to the system. What will be the steady state response of the closed loop system?
(e) Estimate the system parameter k/M from the Bode plot.







Bode Diagram
Magnitude (dB)
50
0
-50
-100
Phase (deg)
0
-90
-180
-270
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Frequency (rad/sec)

Problem 3

Consider a unity-feedback control system whose feedforward portion consists of a proportional controller followed by a plant *G(s)* with

$$G(s) = \frac{1}{s^2 + 4s + 3}$$

(1) Suppose the reference input to the unity-feedback control system is zero. Let us take the proportional gain to be one. Suppose it is desirable to have the output *y(t)* of the control system to be te^{-2t} . What is (are) the possible choice(s) of the initial conditions?

(2) Is it possible that for some special case of the initial conditions, the output $y(t) = e^{-2t}$? Explain.

(3) Suppose the output *y(t)* is known (but not necessarily in the form of (1) or (2)). We would like to use this output information to identify the initial conditions. Show explicitly how the initial conditions are calculated based on *y(t)*. (*Hint:* The output is in a special form.) This problem is very interesting. Some people call it the *observability*. But we can solve it without even knowing what this *observability* is.

Problem 4

Aerial lifts, also known as cherry pickers, are used to lift people up so that they can work on power lines, trees, and other tall objects. A picture of such a device is shown in Figure 1. The bucket where the humans ride is extended upward by rotating around joint 1 and joint 2. Joint 3 is a turntable that provides rotation around the vertical axis. All three axes are powered by hydraulic fluid that is pressurized by the truck engine. The valves that control the hydraulic fluid are opened and closed by a joystick in the bucket. As the mechanism is extended further and further, it tends to oscillate more and more. This makes it difficult for the human operator to control.

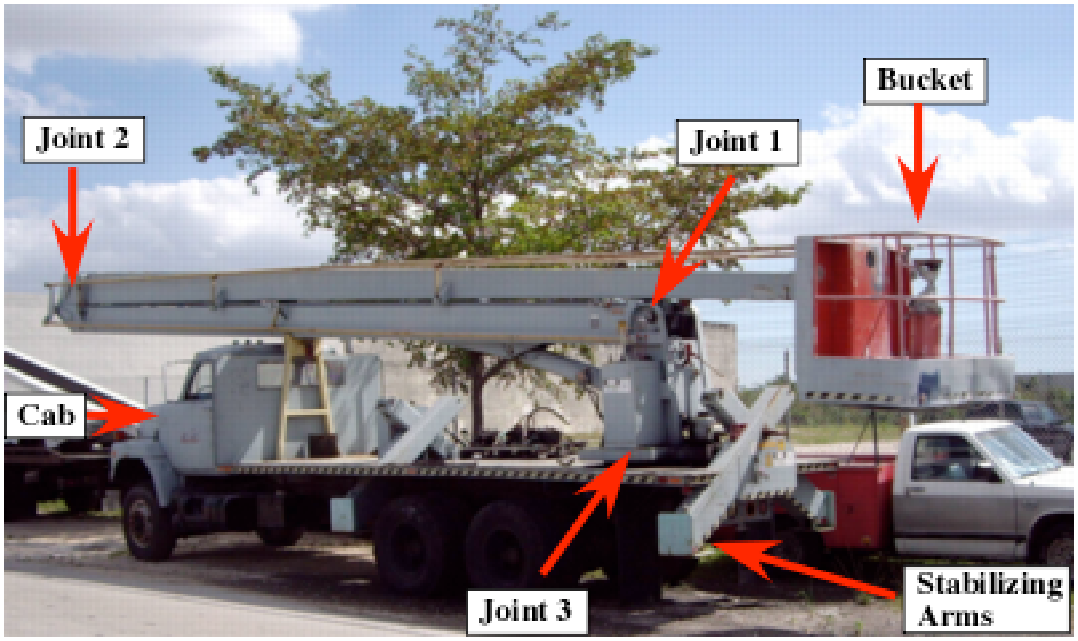


Figure 1: Cherry Picker.

1) Assume the truck is not moving, joint 1 and 2 are only slightly extended so that the bucket is slightly above the cab of the truck, and the stabilizing arms are **not** deployed. Create a model that captures the dynamics of the system when the arm is rotated about the vertical axis (by moving joint 3).

2) Sketch the endpoint (bucket) response as a function of time, assuming the rotational motion is driven by a step change in velocity (the joystick is quickly pushed forward to open the valve). Plot the time response for one full rotation of joint 3.

3) How would the model need to be changed to account for vertical extensions of the bucket?

4) Sketch the endpoint response to a short velocity pulse input to joint 1 (a quick press on the joystick) when the arm is 50%, 70%, and 90% extended. Label the key differences.

5) What type of control system could be added to make the machine easier to operate? What sensors would be needed by your controller?