Problem 1 (Analysis of a Feedback System)
Consider the feedback system defined by the plant

\[ P = \frac{1}{s(s-1)} \left[ \frac{10^4}{s + 10^2} \right]^5 \left[ \frac{10^6 - s}{10^5} \right]^3 \left[ \frac{s + 10^8}{10^8} \right]^3 \]

series compensator

\[ K = \left[ \frac{9(s+1)^3}{s^2} \right] \left[ \frac{81}{s + 81} \right]^3 \]

command pre-filter \( W = \left[ \frac{1}{s+1} \right]^3 \) and sensor dynamics

\[ H = \left[ \frac{10^{10}}{s + 10^{10}} \right]^6 \]

(a) What is the approximate closed loop transfer function \( T_{ry} \)? Determine all important closed loop poles) for computing the response to a unit step reference command. Determine the associated time constants \( \tau \), settling times \( t_s \). What is the expected settling time? Determine any relevant damping factor \( \zeta \), overshoot to a step command \( M_p \), time to peak for a step command \( t_p \), and rise time \( t_r \).

(b) Approximate the output \( y \) when \( r = 10 \sin(t) \).

(c) Approximate the steady state output \( y_{ss} \) when \( r = 10 + \cos(t + 20^\circ) \) and \( d_i = \sin(100t - 35^\circ) \).

(d) Sketch and interpret magnitude plots for \( T_{d,y} \), \( T_{d,y} \). (Note: Neglect all high frequency terms to do this.)

(e) Determine \( r \) such that \( y_{ss} = 10 - 0.1\sin(0.01t + 30^\circ) \) when \( d_i = 1 + 2\cos(0.01t + 40^\circ) \). Is this \( r \) unique?

(f) How can you maintain the step command following properties of \( T_{ry} \) without a command pre-filter?

Problem 2 (Bode Magnitude and Phase)
Sketch Bode magnitude and phase plots for the open loop transfer function \( L = PKH \) in Problem 1. Identify the upward gain margin \( \uparrow GM \), downward gain margin \( \downarrow GM \), phase margin \( PM \), and associated frequencies on your plots. Compute all gain and phase margins and the associated frequencies. Compute the delay margin \( DM \) and the associated frequency.

Problem 3 (Root Locus)
Construct a root locus for the feedback system defined in Problem 1. Determine the number of asymptotes, the angle of each asymptote, the center of gravity, and all imaginary crossovers. Carefully label all important features on your plot. Provide a stability summary. Hint: Build up your root locus!

Problem 4 (Nyquist)
(a) Sketch a complete Nyquist plot. Show margins on your plot. Use Nyquist and root locus ideas to provide a complete stability summary.

(b) Determine lower bounds (based on gain and phase margins) for the peak sensitivity and complementary sensitivity.

(c) Given upper bounds \( \alpha \) and \( \beta \) on the peak \( |S| \) and \( |T| \), determine bounds on the gain and phase margins.

Problem 5 (Control System Design)
(a) Pole Placement. Suppose that we have a plant

\[ P = \frac{(s + 2)}{s(s+1)^2} \left[ \frac{10^3}{s + 10^3} \right]^2 \left[ \frac{10^3 - s}{s + 10^3} \right] \]

Design a feedback control system such that the closed loop system (1) is stable, (2) exhibits zero steady state error to ramp output disturbances \( d_o \), (3) exhibits a settling time to step commands \( r \) of \( t_s \approx 5 \), (4) overshoot close to 10% when a step command is issued. Support your design with a (simple) root locus plot.
(b) **Design for Bandwidth and Phase Margin.** Suppose 
\[ P = \frac{1}{s-1} \left[ \frac{20-s}{s+20} \right] e^{-0.1s} \]. Design a feedback control system such that the closed loop system (1) is stable, (2) exhibits zero steady state error to ramp input disturbances, (3) \( \omega_g = 3 \text{ rad/sec} \), (4) \( PM = 60^\circ \), (5) impact of high frequency sensor noise on controls is addressed, (6) overshoot to step commands is addressed.

(c) **Design for Velocity Error and Phase Margin.** Suppose 
\[ P = \frac{1}{s-1} \left[ \frac{20-s}{s+20} \right] e^{-0.1s} \]. Design a feedback control system such that the closed loop system (1) is stable, (2) exhibits zero steady state error to step input disturbances, (3) exhibits a velocity error \( |k_v| < 0.1 \), (4) exhibits a \( PM \approx 60^\circ \) (with a minimal unity gain crossover frequency), (5) addresses impact of high frequency sensor noise on controls, (6) addresses overshoot to step reference commands.

(d) **Pole Placement.** Consider the following LTI plant 
\[ P = \frac{1}{(s-1)(s-3)} \]. Design a feedback control system such that the closed loop system (1) is stable, (2) exhibits zero steady state error to step input disturbances, (3) has dominant closed loop poles at \( -\frac{1}{2} \pm j\frac{\sqrt{3}}{2}, -7 \). Address control action as well as overshoot in the system output. Hint: Pick a controller structure with suitable degrees of freedom. Solve for all controller coefficients. Show that the desired dominant closed loop poles have been achieved. What might you expect the overshoot and setting time to be for a step reference command?

**IMPORTANT FEEDBACK**

Everyone will be expected to fill out an end of semester survey. This is where we really want you to give us detailed feedback. We will give you time to turn in the survey so that it does not interfere with your final exams. **PLEASE** do a VERY GOOD job - especially if you are NOT taking the EEE480 final and/or you are borderline!

Please give VERY detailed comments on what can be done to improve the lectures, the labs, the course, and the text in particular. We are particularly interested in your (very) specific comments on how the text can be improved.

1. How would you like interactive problems, exploiting game quality animation, throughout the text (ebook)?
2. How would you like to be able to submit answers (including control designs) to the ebook and get immediate responses? with hints? and see how you stand relative to the class?
3. How would you like to have access to all of the above via the www? so you can access it via your smartphone?
4. How would you like to be able to access MATLAB during exams?

Karan will be getting the survey to you (with instructions) soon!