TUT

Faculty of Automation, Mechanical and Materials Engineering
IHA-3206 Servo Systems
Exam 15.12.2010, Reza Ghabcheloo

The students are allowed to use notes and text books.

1) A tank is fed at the top by a flow. Liquid is withdrawn from the bottom by a control valve. Dynamics of the system S are governed by the following differential equation

$$S: \qquad \dot{l} = -2u\sqrt{l} + f_{in},$$

where l is the height of the liquid in the tank (output), u is the valve input (control signal), f_{in} is the inflow (disturbance).

   a) Find the equilibrium state l_0 at operating point $u_0 = 0.5$, and $f_{in0} = 2$.
   b) Linearize the system around the equilibrium point (l_0, u_0), and identify the linear system with incremental variables $\Delta l = l - l_0, \Delta u = u - u_0$. (*Note*: $\frac{\partial\sqrt{x}}{\partial x} = \frac{1}{2\sqrt{x}}$)
   c) What is the transfer function $\Delta l/\Delta u$? Is the system stable at this operating point?
   d) Design a pure gain controller k_p to place the eigenvalue of linearized system at -1. That is, to find control gain k_p with control law $\Delta u = -k_p \Delta l$.
   e) What will be the steady-state error to disturbance $f_{in} = 2.5$ and control gain $k_p = -\frac{3}{16}$. Use the linear system for your calculations.

2) Design controllers $F(s)$ and $R(s)$ (2DOF control design) in Figure 2, with plant $P(s) = 1/s^2$, such that the bandwidth for disturbance rejection is 2rad/s and for reference tracking 1rad/s. (select reasonable performance for your desired transfer functions). Furthermore, we would like to have no steady-state error to step inputs at reference y_d or disturbance d.
   Hint: Choose the desired transfer functions in such a way that the resultant controllers are proper. You may need to increase the order of the desired transfer function (that is, to increase the number of the poles) to be able to satisfy all the constraints.

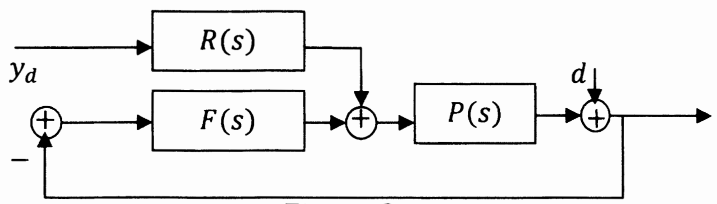

Figure 2

3) Figure 3 shows the Bode plot of a simplified hydraulic actuator for position control. The plant is denoted by $P(s)$. To improve the transient response, we would like to design a lead controller for $P(s)$.
Note: Notice the low damped natural frequency at 18.8[rad/s]. Due to this pick in the Bode magnitude, standard Lead or PD design will not work as expected, because the bode magnitude may cross 0dB at two different points, one somewhere around 18.8[rad/s] and the other at some lower frequency, which will be the actual bandwidth of the closed-loop system.
   a) Design a lead controller; Choose to add at least 60deg phase to the loop-gain around or above 18.8[rad/s].
   b) Present an approximate Bode plot of your controller on Figure 3.
   c) What is the approximate bandwidth of the closed-loop system. What are the gain and phase margins?
   Hint: Do not forget to add the phase and magnitude of the controller to the system before measuring the requested parameters.
   d) What is the steady-state error of the control system to step and ramp inputs?

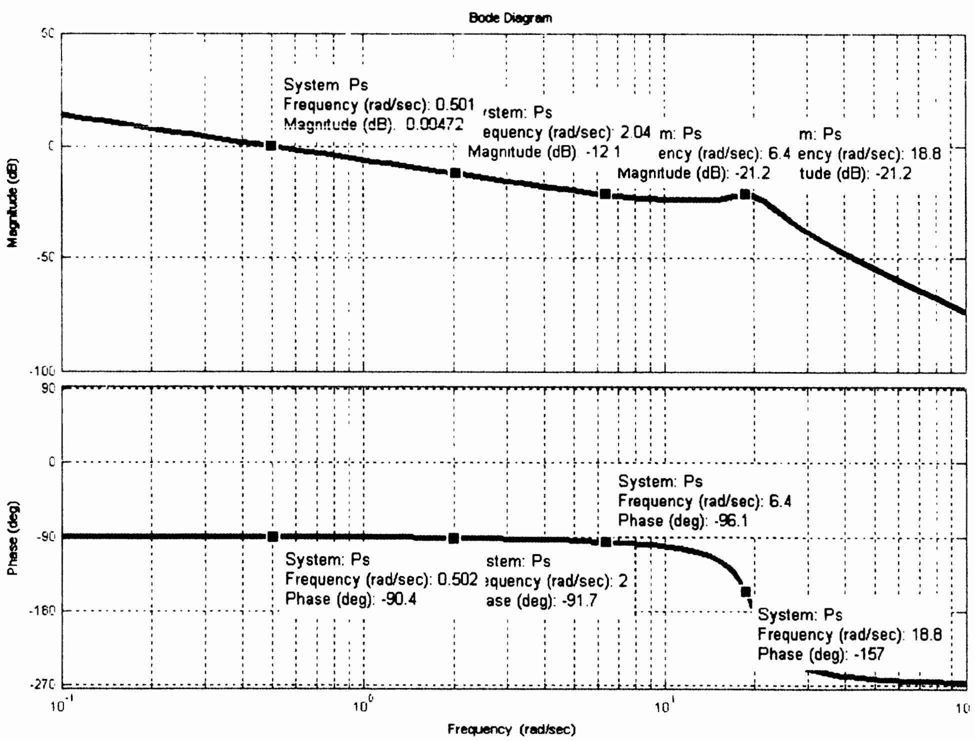

Figure 3