Laboratory 3: Bode / Nyquist Design

In this experiment, you will design a dynamic compensator for the servomotor system, using the Bode and Nyquist plots and MATLAB as design tools. The following performance specifications must be satisfied by the closed-loop system:

- The steady-state error $e(t)$ for a RAMP input $r(t) = K_r \cdot t$ must be zero;
- The steady-state tracking error $e(t)$ for a sinusoidal input $r(t) = \sin(\omega t)$ must be less than 0.5% for $\omega < 0.1$;
- The phase margin θ_m must satisfy $45^\circ < \theta_m$
- The bandwidth of the closed-loop system must be between 8 and 10 rad/s.

The controller design must be based upon the model you identified in Lab 1.

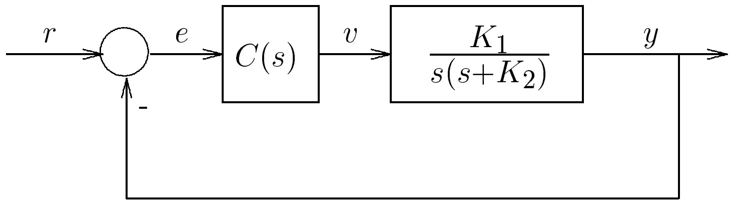

Figure 1: Simplified servomotor block diagram.

1 Preparation

The laboratory preparation involves designing the controller $C(s)$ so the closed-loop system satisfies the above specifications, and then implementing it in discrete-time.

1. The ramp-tracking specification implies the controller is of the form $C(s) = C_1(s)/s$, i.e., the open-loop system requires two poles at the origin. Using the MATLAB function `bode`, plot the magnitude of $P(j\omega)/(j\omega)$. Print-out the plot.
2. On the plot, indicate the low-frequency specification.
3. Using the plot, use loopshaping to design $C_1(s)$. The final controller $C(s)$ should be no more than third order.
4. Using the `bode` function, plot both the magnitude of $P(j\omega)/\omega$, and $C(j\omega)P(j\omega)$.
5. Using the `bode` function, plot the phase of $C(j\omega)P(j\omega)$. Is the phase margin specification satisfied?

6. Using the `nyquist` function, plot the Nyquist plot of $P(s)/s$, and $C(s)P(s)$.

7. With MATLAB, plot the step response of the closed-loop system using `lsim` or `step`.

8. Using the bilinear transformation, compute a discrete-time approximation $\hat{C}(z)$ to the $C(s)$ computed in Step 3. $\hat{C}(z)$ should be no more than third-order. You may wish to use the MATLAB command `bilinear` to do this. Assume the controller sample rate is 250Hz.

9. Modify the source `lab.c` to implement the dynamic controller. To implement the filter's state, use `static float` variables in the `Control` subroutine.

2 Laboratory Procedure

1. Make sure the servomotor system is wired correctly. Your job is to connect the servomotor box, the power amplifier, and the bench-top interface board. **Again, PLEASE DO NOT ATTEMPT TO CONNECT THE RIBBON CABLE FROM THE BENCH-TOP INTERFACE BOARD TO THE COMPUTER. LET THE TA DO THIS.**

2. Compile and run your version of the program `lab.c`. Use the same step input $r(t)$ as in Lab 1. Save the actual angle $y(t)$, the reference $r(t)$ to a data file.

3. Load the experimental data into MATLAB, and plot $r(t)$ and $y(t)$ versus time t. Does the step response compare with the simulated one computed in Step 7 of the pre-lab?

3 Before Leaving Lab

Before leaving lab, make sure to do the following.

- Show the TA your pre-lab. The TA will check that it is done, and he/she will check for correctness. He/She may also ask questions to ensure that you know the lab procedure, so make sure you are prepared before coming to lab. (That is for your own good - if you aren't prepared, you won't finish.)

- Demonstrate to the TA the servomotor system closed-loop step response.

- Show the TA the MATLAB step response plots from Pre-lab Step 7 and Procedure Step 2.

4 Laboratory Notebook Write-Up

Your laboratory report should include a description of the procedure, the work done in the pre-lab, including answers to the questions, a listing of your C code subroutines, the step response plots, the Bode plots, and the Nyquist plots.

Questions...

1. Consider a continuous-time system

$$G(s) = \frac{C(s)P_1(s)}{1 + C(s)P_1(s)}$$

   that satisfies design specification number 1. Explain why *any* such $G(s)$ *must* overshoot if $r(t)$ is a unit step, regardless of the other design specifications and regardless of the controller $C(s)$. In other words, explain why it is impossible to design a $C(s)$ to satisfy specification 1 that does *not* overshoot when $r(t)$ is a unit step. (Hint: Think about the type of $C(s)P_1(s)$.)