Chapter 1

Lab #5: Root Locus Design

Objective

The purpose of this lab is to use the EPS Torsional Disk System (TDS) to learn how to apply root locus techniques to a real, physical system. You have already seen how PID works on the system in the last lab. Now, you are going to see some of your experience validated analytically by analyzing the root locus for the ECP system.

The lab will consist of two main components. First, you will determine the root locus for the system given the “collocated” outputs (the outputs that are located at the same place as the input) and the “noncollocated” outputs (the outputs that are located somewhere other than the input location). (This will help you see why stabilizing the top disk is intrinsically harder than stabilizing the bottom disk.) Next, you will iteratively determine what “good” values of a PID controller are based on the root locus.

Note that this lab will be a two-week lab.

Warning:

As usual, please always run the ECP unit with someone holding the power button, in case something happens to go wrong.
1.1 Pre-Lab Tasks

Read this entire document before starting the lab. Aside from that, you may wish to create a VI that will take the model of your system and plot a root locus.

1.2 Tasks

1.2.1 Task #1–Root Loci for Disk 1 and Disk 3 Outputs

Task: Draw a block diagram that represents the system with a proportional controller. Label all the blocks and all the lines that connect the blocks. Lastly, give the physical units for each line.

Task: In LabVIEW, create the root locus for each output (disk 1 and 3). Which system is “more” stable using proportional feedback? Defend your answer. Test this hypothesis experimentally. For each disk, experimentally estimate the value of $K$ where the system destabilizes. You may approach this estimation problem in whatever way you find most convenient—just detail it in your writeup.

Task: Now assume that you have a PD controller of the form $C(s) = K(1 + K_Ds)$ so that $K_D$ represents that ratio of the damping to the gain. Assuming that $K_D$ varies from 0 to 1, plot the root locus for five relevant ratios that you choose. (Again, do this for both disk 1 and disk 3 outputs.) What is the best choice from your perspective? Defend your rationale of your choice and test it experimentally. Explain your experimental results.

Task: Based on the root locus of your choice of ratio, try to estimate what value of $K$ and $K_D$ would give a rise time of 1 second and less than 30% overshoot (Yes, again for for both disk 1 and disk 3 as outputs). Implement your design in hardware. How close do you get?

Task: Based on the root locus for each output and your choice of $K$ and $K_D$, can you add an integral term $K_I$ to your PID controller in order to get rid of steady-state error?

1.2.2 Task #3–Lead/Lag Controller

Task: We know that PID controllers can be approximated by “Lead/Lag” controllers. How does your root locus analysis change if you replace the PID controller with a Lead/Lag controller?

1.2.3 Task #4–Root Loci for Uncertainties

Task: For your choice of $K$ and $K_D$ above, plot the root locus for two parameters you think introduce the largest amount of uncertainty. For instance, you can plot the root locus with respect to $c_1$ and with respect to $k_1$, if you think these add the most uncertainty. You may find Mathematica or another symbolic toolbox helpful for this problem.
**Task:** Based on the root locus, do these parameters represent a threat to the stability of the system (for either disk 1 or disk 3 as outputs)?

**Task:** Based on the root locus, how do these parameters affect the performance of the system?

### 1.2.4 Task #5–Design for and Difficulties with Disk 3

**Task:** Can you design a different compensator (perhaps with complex poles) that makes the system stable with better performance? Can you improve upon your PID controller performance? Try this first using the root locus tool, then in simulation, and finally (if you are convinced you have a good design) try it in hardware. If you didn’t get a design you liked, discuss what the obstacles were and what you tried to use to overcome them.

Remember, if you get stuck on some part of the lab, ask your classmates, the TA, or myself.