Lab 8: Lead-Lag Compensator Design

Introduction

In the previous lab, we performed system identification of the XY stage. Since we have a plant model now, we can apply control design technique to satisfy some design requirement. However, we expect errors in our system identification. In fact, we neglected static friction in the model structure that used for system identification, and we did not consider other dynamics such as time delay in communication. To cope with uncertainties in our model, we can put stability margins. (e.g. gain margin and phase margin)

Our controller design uses lead-lag compensator. Lead compensator is commonly used for improving stability margins. Lag compensator is used to improve the steady state performance. Lead compensator achieves the desired result through the merits of its phase-lead contribution. Lag compensator accomplishes the result through the merits of its attenuation property at high frequencies.

In this laboratory exercise, a lead compensator will be implemented on the XY stage. The plant model was identified in a previous lab.

Experimental Objectives

Completion of the laboratory exercise will have required you to:

- Design a lead-lag compensator.
- Implement the compensator designed to control position of the XY stage.

Experimental Procedure

Choose the design requirement

1. Since the plant of XY stage is type 1 system, it has zero steady state error in position for the closed loop system, we need to set steady state velocity error requirement, $veolocity\ error\ in\ steady\ state = 1/K_v$. We choose our $K_v = 100$. We choose a large value since we expect friction to reduce our ability to track this velocity.
2. For nonlinear systems, especially with poor models, a good conservative guess for the phase margin is 60^o. Recall that the relation between phase margin and damping ratio is approximated by $\zeta = \frac{\phi_m}{100}$.
3. We will take the Gain Margin to be 20 dB.

X – STAGE: Design Lead Compensator by hand

1. Find the value of K_C needed to meet the K_v requirement. Using the method described in Question 1 of the prelab.
   K_c = ____________

2. Create a transfer function in MATLAB for your model of the X-stage.
   (e.g. $sys = \frac{400}{s(0.05s+1)}$).
3. Find the phase margin and the damping ratio of your system combined with the controller gain K_c using the "margin" command in MATLAB. Comment on how you would expect the system to perform (steady state error and transient response) if the design stopped with this step.

   $\phi_m =$__________ $\zeta = \frac{\phi_m}{100}=$____________________
4. Calculate the desired amount of phase lead to add:
   $\phi_{cm} = \phi_d - \phi_m + 10^o =$________________
5. Calculate the attenuation factor

   $\alpha = \frac{1-\sin\ \phi_{cm}}{1+\sin\ \phi_{cm}} =$______________
6. Calculate the location of the maximum phase contribution, ω_m using your solution to Question 2 in the prelab.
   ω_m=______________
7. Calculate the corner time constant

   $\mathrm{T} = \frac{1}{\omega_m\sqrt{\alpha}} =$______________
8. With this information, create the transfer function for C(s) in MATLAB.
9. Show the following plots to your TA:
   a. Plot the Bode, Nyquist and Root-Locus plots for your open loop system, C(s)G(s). Mark the relevant on these graphs by right clicking and looking into the options.
   b. Plot the closed loop system performance using the "feedback" and "step" function in MATLAB.

Y- STAGE: Design of a Lead Compensator Using the SISOTOOL

For the Y-stage you will repeat the above procedure with the MATLAB SISOTOOL.

Load the identified model of XY stage into MATLAB. And start SISOTOOL by typing "SISOTOOL(sys)" in the command window. Use design compensator to add lead compensator. Adjust your lead compensator and the gain of controller until it satisfies the design requirement.

Note:

1. Poles in very high frequency might not be effective, since the controller is implemented to the Simulink block which runs at some finite sampling frequency (2 kHz). So locate pole of your controller where it can be implemented effectively.
2. In real system, there is time delay and other high frequency dynamics ignored in our modelling. These additional dynamics add more phase decrease in high frequency. So you might need more phase margin in your design with the nominal model, to cope with these types of uncertainties.
3. Show the following plots to your TA:

a. Plot the Bode, Nyquist and Root-Locus plots for your open loop system, C(s)G(s).

b. Plot the closed loop system performance.

4. Export your controller from *SISOTOOL* to *Matlab workspace*.

Implementation of the designed controller in XY stage position control

Use LTI system block in Simulink to implement the controller in the Simulink model, xy_stage_start.mdl in N:\Hydrauliclab. Use the following position reference signals:

5. Square wave with 5 cm amplitude at 0.5 Hz
6. Sinusoidal 5 cm amplitude at 5 Hz

Try to increase the gain of controller for faster response and smaller steady state error. Check what gain gives undesirable behavior (Unstable response, jittering, etc) and compare it with the gain margin you had in controller design.

Lab Report

1. Write down your design requirement and show your work in controller design. In addition, present the Bode plot of transfer function of the designed compensator with plant model.

2. Compare the position tracking plot of the real XY stage with Simulink simulation and discussion what causes the discrepancy.(make sure to attach the plot of the signals: output, reference, control)

3. Were you able to increase the gain in the real XY stage up to the GM in your design ? If you couldn’t then explain why it is different from what was expected.