1

******* PART 1: MOTOR SPEED CONTROLLER DESIGN *******

Upload the Bode plot for the open-loop motor system (in which the input is voltage and the output is angular velocity) (You may upload your plot here or in a separate file you upload at the end.) (Non-anonymous question ⓘ) (1 Point)

2

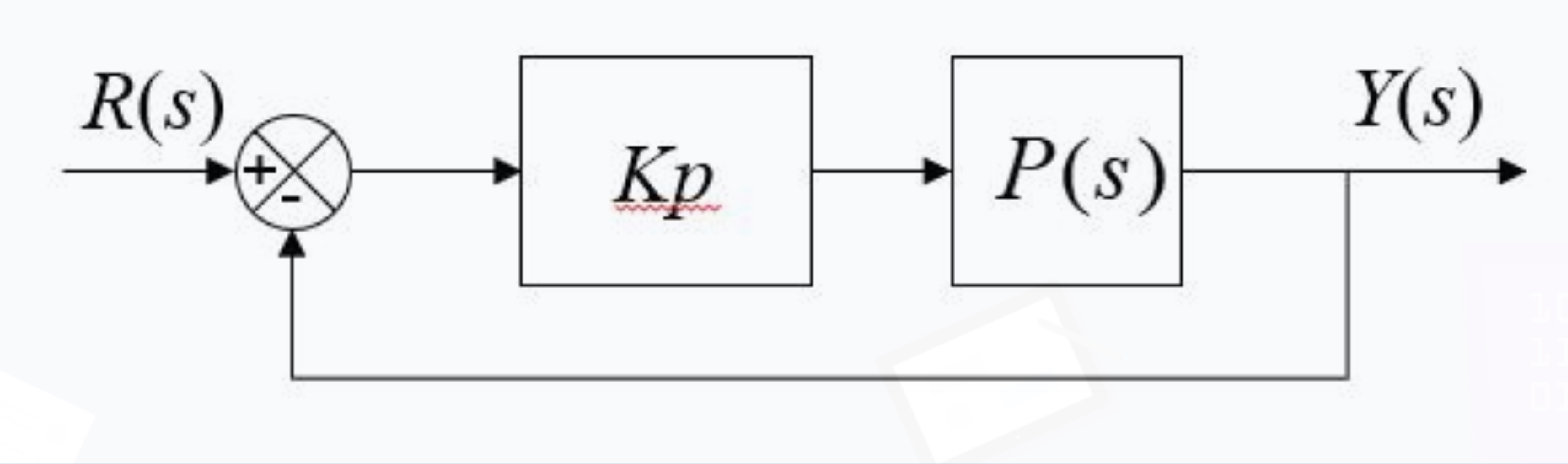
Inspect and record the gain margin. (1 Point)

11

Very briefly, describe how you determined the the Kp that makes the closed-loop system critically damped. (1 Point)

12

Consider the closed-loop system with a proportional controller only, determine the closed-loop steady-state error to a unit step reference input using the Kp you determined in question 10. Submit your hand calculations and record your answer below. (1 Point)



13

Consider the closed-loop system with proportional control only, determine the closed-loop steady-state error to a unit **ramp** reference input using the Kp you determined in question 10. Submit your hand calculations and record your answer below. (1 Point)

14

What is the new phase margin of the system with the Kp determined in question 10?

(1 Point)

15

While the phase margin in 14 should seem acceptable, briefly discuss why this high of a gain is not practical in reality.

(1 Point)

16

******* PART 2: SERVO POSITION CONTROLLER DESIGN *******

Now plot the open-loop Bode plot for the servo motor (position control) plant. Upload the Bode plot. (Non-anonymous question ⓘ) (1 Point)

17

Now plot the Nyquist plot for the servo motor (position control) plant. Upload the Nyquist plot. (Non-anonymous question ⓘ) (1 Point)

18

What is the gain margin for the open-loop servo system?

(1 Point)

19

What is the phase margin for the open-loop Bode plot for the servo motor (position control) system? (1 Point)

20

Indicate the gain necessary for a phase margin of 60 degrees.

(1 Point)

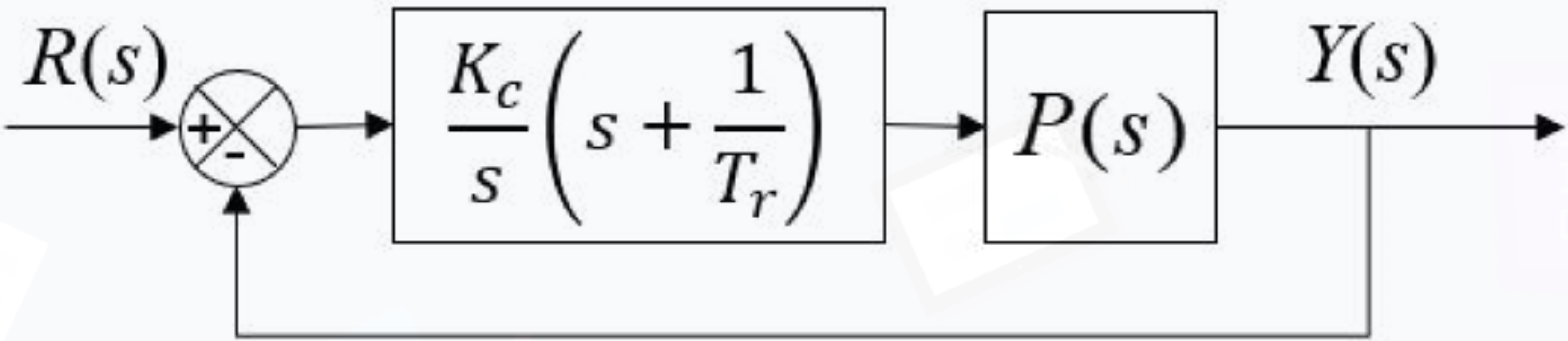
3

Inspect and record the phase margin. (1 Point)

21

Since the gain in question 19 is likely too high, let's see if we can add integral control to eliminate the error and achieve acceptable transient behavior. How does the PI compensator as shown change the low frequency and high frequency slopes of the magnitude and phase plots and predict how will this affect the transient and steady-state response characteristics.

(2 Points)



22

Upload the PI-compensated Bode plot with the integral reset rate set at $T_r = 0.01$ s (preferably overlay your PI-compensated Bode plot with the uncompensated Bode plot).

(Non-anonymous question ⓘ) (1 Point)

23

After inspecting the PI compensated Bode plot, do you notice anything that concerns you? Would increasing or decreasing the compensator gain Kc mitigate your concerns? Why or why not?

(2 Points)

24

Plot the Nyquist plot for the PI-compensated system with the integral reset rate set at Tr = 0.01 s (Kc=1). Upload the Nyquist PI-compensated plot. (Non-anonymous question ⓘ) (1 Point)

25

What feature of the PI-compensated Nyquist plot indicates the stability of the closed-loop system? How does changing Kc change the Nyquist plot and how does it affect the stability of the closed-loop system? (1 Point)

26

******* CONTROLLER DESIGN USING controlSystemDesigner MATLAB GUI *******
Open the controlSystemDesigner GUI window for the open-loop servo system. With a 1-radian step reference, the design criteria are the following.

- Rise time is at least as good as or better than open loop (less or equal to 0.1 second)
- Overshoot less than 20%
- No steady-state error to reference inputs
- Error in the presence of a unit step disturbance (1 radian) input is less 0.05

In the following questions you will design compensation and detail your design method and selection.
****

Question 26. Firstly, what is the closed-loop error to a unit step reference for K=1?
(1 Point)

27

Does the model show any steady-state error to unit step disturbance inputs for the closed-loop system where K=1? (1 Point)

- ◯ No, there is not steady-state error.
- ◯ Yes, there is finite steady-state error.
- ◯ Yes, the error goes to infinity.

28

Add compensation in controlSystemDesigner window. Try to add an integrator to see if it is possible to eliminate any error to step reference and disturbance inputs. How does this affect your phase margin? (1 Point)

29

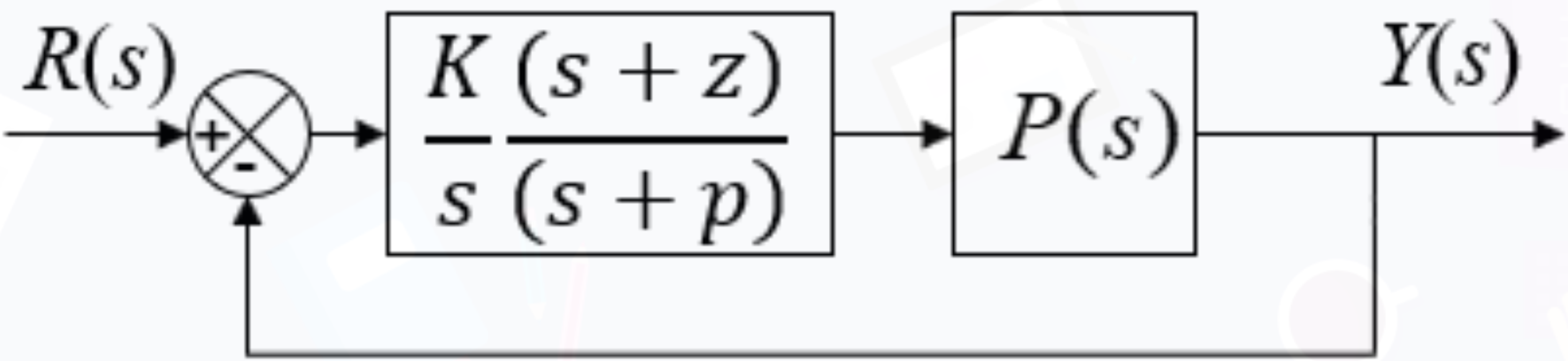
Now add a lead compensator (keep the integrator) to see if you are able to achieve acceptable transient and steady-state specifications of:

- Rise time is at least as good as or better than open loop (less or equal to 0.1 second)
- Overshoot less than 20%
- No steady-state error to reference inputs
- Error in the presence of a unit step disturbance (1 radian) input is less 0.05

Briefly describe your design method and choice of K, z and p, corresponding phase margin, and whether you were able to meet all the specifications.

(2 Points)

Hint: I was able to achieve all but one of the above design criteria.



30

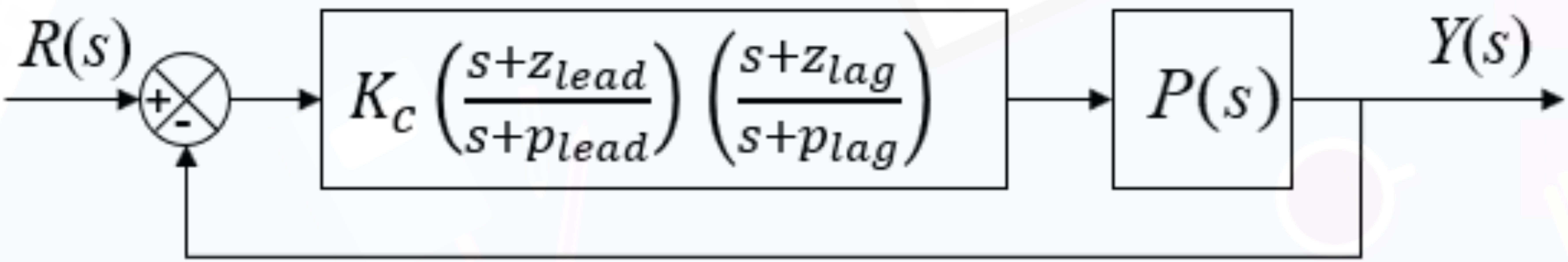
Remove the integrator (keep the lead compensator) and add a lag compensator and iterate your design to see if you are able to achieve acceptable transient and steady-state specifications of:

- Rise time is at least as good as or better than open loop (less or equal to 0.1 second)
- Overshoot less than 20%
- No steady-state error to reference inputs
- Error in the presence of a unit step disturbance (1 radian) input is less 0.05

Briefly describe your design method and choice of Kc, z-lead, p-lead, p-lag, and p-lead, corresponding phase margin, and whether you were able to meet all the specifications.

(2 Points)

Hint: I was able to meet all specifications in my design.



4

Inspect and record the bandwidth. (The bandwidth here is defined to be the frequency at which the frequency response has declined 3 dB (0.707) from its low-frequency value. You should consider the bandwidth for the open-loop motor system for speed control. Note when you are designing for position control this introduces a zero in the denominator of the transfer function and the low-frequency slope of frequency response magnitude has a slope of -20 dB/decade.)

(1 Point)

31

Upload the Bode plot and closed-loop step reference and disturbance responses of your compensator design. You may upload individual figures or a screenshot of your Control System Design workspace. (Non-anonymous question ⓘ) (3 Points)

32

Use the final value theorem to calculate the steady-state error to a 1-radian step disturbance. Leave your answer in terms of Kc, z-lead, p-lead, p-lag, and p-lead and the motor parameters, *Km* and *Kb*. (1 Point)

Leave your answer in symbolic form although you may want to plug in your numbers to make sure your design meets the specification that the error in the presence of a unit step disturbance (1 radian) input is less 0.05.

33

*** PART 3: QUBE MOTOR POSITION CONTROLLER IMPLEMENTATION AND TUNING ***
Create a new Simulink model with the Qube hardware in the loop (HIL) that includes your compensation design for the position control system. Upload a screenshot of your Simulink model. You may build off the position control lab exercise. (Non-anonymous question ⓘ)
(2 Points)

I made the reference input a square wave input with Amplitude of 0.5 and Frequency of 0.2 with a Constant offset of 0.5. Then I included a gain of 2*pi so that when starting the Qube disc at the zero degree position the square wave rotated the disc back and forth 360 degrees.

34

Upload screenshots of both the actual Qube closed-loop position control step reference response and 1-radian step disturbance response using your design. (Non-anonymous question ⓘ)

(2 Points)

35

Include the actual rise time, overshoot, ess to reference input, and ess to 1-radian disturbance input from your Matlab designed compensators implemented on the Qube motor.

(2 Points)

36

If necessary tweak your design to meet the specifications and describe your methods and final compensator design. Include the tweaked Kc, z-lead, p-lead, p-lag, and p-lead OR alternative controller you designed and final rise time, overshoot, ess to reference input, and ess to 1-radian disturbance input. (2 Points)

Note, if the controller you designed using the Control System Designer in Matlab met the specifications in the Qube responses you do not need to tweak your design and you will get full credit for #36-37. You are encouraged to see if you can make your controller even better! My compensation design met all of the specifications and even exceeded the overshoot and the disturbance error specifications (even if just slightly).

37

Upload screenshots of both the final Qube motor position step reference and disturbances responses of your design if you found it necessary to tweak your design to meet the specifications. (Non-anonymous question ⓘ) (2 Points)

38

Upload your calculations, Matlab code, and any plots not previously uploaded.

(Non-anonymous question ⓘ) (2 Points)

39

EXTRA CREDIT (Option #1): Compare your compensator design to the PID compensator you designed using specifications and pole placement during the Qube motor position control lab, in which zeta was set to 0.6 and the natural frequency 20 rad/s. Compare the responses of the PID compensator with P=1 and P=3 and your compensator from your frequency design method.

Discussion the differences in transient and steady-state reference and disturbance behavior and the pros and cons of the PID vs. lead-lag compensators. (2 extra points possible)

If you choose to skip the extra credit in questions 38-41, make sure you still answer questions 42-43 which are required.

40

EXTRA CREDIT: Upload comparison of the responses and/or Bode plots (either Matlab simulations or actual response of the Qube motor position) - 2 extra points possible

(Non-anonymous question ⓘ)

5

Inspect and record the crossover frequency. (The crossover frequency is the frequency at which the frequency response magnitude crosses 0 dB)

(1 Point)

41

EXTRA CREDIT (Option #2): Compare the performance of the compensators to triangular reference inputs. Explain differences in responses and analyze error with and without integral action or lag compensation (bonus points for comparing actual error to calculation error with an integrator or integral action/lag compensation). Discuss your analysis and show calculations. - 4 extra points possible

42

EXTRA CREDIT: Upload plots of your simulated and/or actual Qube response to triangular reference inputs. (Non-anonymous question ⓘ)

43

REQUIRED: Did you spend any time working on this outside of class time and if yes, how long? *

- ◯ No (only class time)
- ◯ Less than 1 hour
- ◯ 1-2 hours
- ◯ 3-4 hours
- ◯ More than 4 hours

44

REQUIRED: Include the names of students you collaborated with and briefly describe the nature of the collaboration. Also include your Procon Lab partner's name and how you both approached tuning the motor position control system. If you used any external references outside of class materials, also list them here. *

6

Is the open-loop system as modeled: (1 Point)

7

What is the time constant of the open loop response? (1 Point)

8

Determine the open-loop poles. Which pole dominates the response? (1 Point)

9

Plot and upload the open loop response to a unit step input (1 volt). Verify your time constant determined from the pole locations. (Non-anonymous question ⓘ) (1 Point)

10

What is the Kp for which the closed-loop system is critically damped? (1 Point)