Cleveland State University
Department of Electrical and Computer Engineering
Control Systems Laboratory

Experiment #3

Closed Loop Steady State Error and Transient Performance

INTRODUCTION

The two primary things a control system must do are to move the controlled output to the set point with little or no final error, and to do it as quickly as possible without excessive overshoot or oscillation. The ability of the control system to do the first of these is expressed by the system's steady state error performance, and the ability of the control system to do the second is expressed by its transient performance. You know from the lecture course that a unity feedback control system's steady state error performance can be predicted from the feedback system's ***type—or the number of integrations (or poles at the origin) in the forward path of the control loop.*** A type-0 system (no integrations or poles at the origin in the forward path) has a nonzero steady state error to a constant set point and can't follow a ramp or a parabola in the set point at all (the error eventually becomes infinite to either of these inputs); a type-1 system with one integration in the forward path has zero error to a constant set point, can follow a ramp in the set point but with an offset or error, and can't follow a parabola at all; and a type-2 system has zero error to a constant and to a ramping set point, and can follow a parabola but with an error or offset.

Generally speaking, no matter what system is being controlled and what controller is used, as controller gain is increased the steady state performance improves, i.e. the final error between the controlled output and the set point decreases (if it is a type-0 system, what decreases is the error between the output and a constant set point; if it's a type-1 system, what decreases is the error between the output and a ramping set point since with a type-1 system there is always zero error to a constant set point). Again, generally speaking, as controller gain is increased the transient performance also improves in that the time it takes the output to reach the set point decreases. However, a value of gain is usually reached where further increases cause the transient performance to deteriorate in the sense that the controlled output—in responding so fast—overshoots the set point and may even exhibit a decaying oscillation about the set point. Once that gain value is reached, a tradeoff exists—as gain is increased further—between a reduced steady state error on the one hand and deteriorating transient performance on the other. If gain adjustments for a given controller cannot produce both acceptable steady state error and transient performance, a different controller (generally more complicated) must be used.

This experiment explores these general control system characteristics using the torsion mechanism. Specifically, the experimental objectives are to:

(i) demonstrate reduction in steady state error as controller gain is increased;
(ii) demonstrate improvements in transient response as controller gain is increased;

(iii) demonstrate deterioration of transient performance with further increases in gain beyond those used in (ii) above;
(iv) reinforce the idea of system type and its use as a means of predicting steady state performance of a feedback loop.

What you will do in this experiment to achieve these objectives is control plate position first with a proportional (P) and then with a proportional-plus-integral (PI) controller, and the set point will be—at different times, of course—a constant or a ramp.

PRELAB

You should come into the lab with a clear understanding of system type and the errors different system types have for different kinds of set points (constant, ramp, parabola).

1. Draw a block diagram of the plate position control loop showing just two blocks—the controlled system and the controller. ***Label each signal (arrow) with* THREE *names: a word name, units, and a symbol.*** Why is the system a unity feedback system?

2. Based on the model for the controlled system that you developed in Experiment #2, what is the system type for the torsion mechanism if it is being controlled with a proportional controller? What should its steady state behavior be for a constant set point? What should its steady state behavior be for a ramping set point?

3. What is the transfer function of a PI controller? What is the system type if a PI controller is used with the torsion mechanism? What should the feedback system's steady state behavior be for a constant set point? For a ramping set point? For a parabolic set point?

PROCEDURE

MAKE SURE ALL POWER IS TURNED OFF!

Part I—Response to a Step Change in a Constant Set Point with a Proportional Controller: Set up a real-time control loop for controlling plate position with a proportional controller. Make the set point step change equal 180 degrees, make the step occur two seconds after t = 0 so that you can observe it on the actual mechanism, and use a two-input **MUX** block feeding a graph block so you can observe both the set point change and the response on the same graph. Once you think you have the proper set-up, **ASK THE INSTRUCTOR TO CHECK IT OUT BEFORE APPLYING POWER TO THE MECHANISM. ALSO, BE PREPARED TO SAY WHAT THE STEADY STATE ERROR SHOULD BE FOR THIS SITUATION.**

a) With the controller gain set to 0.001, observe the step response and note both the steady state and transient performance. Print this graph showing the response. After you observe and print the entire response, you can read the final position more accurately by changing the max and min values on the graph's ordinate. What should the steady state error be? What did you observe it to be? **What is the % steady state error?** If the steady state error observed does not match your theoretical expectations, what explains the differences? Repeat this experiment a few times and note that the result is not repeatable. Why is that? **MAKE NOTES OF YOUR OBSERVATIONS.**

b) Repeat part a) for controller gain values of 0.002, 0.003, 0.004, 0.005, 0.01, and 0.02. In each case make the same observations and record the same data as in a), **but also compute percent overshoot and record settling time if overshoot and oscillations appear. MAKE NOTES OF YOUR OBSERVATIONS.**

c) Choose the controller gain that you feel gives you the best step response.

d) Can you get both good transient performance and good steady state error performance in response to a step change in the set point with this controller? Why or why not?

DISCUSSION QUESTIONS

1. Discuss what theory says the steady state error performance for this control loop should be when a step in the set point is applied and a proportional controller is used. Include in this discussion ideas about "system type," your knowledge of the plant's (controlled system's) transfer function from Experiment #2, and your knowledge of the controller's transfer function. You may want to refer to the closed loop block diagram you did for the Pre-Lab.

2. Now discuss what you ***observed*** the actual error to be, ***and explain any differences.*** Include in this discussion the effect of controller gain on the error, and any other observations you made in the lab regarding the steady state error for this part of the experiment. In this discussion use the actual data you took in the lab, and use the general observations you made. Be specific. If things observed do not match theory, you must discuss this and attempt to say why there are differences—and please, don't say a difference between theory and practice is because of *experimental error.*

3. Repeat question #1 regarding the transient response of this control loop. What does theory say should happen to the percent overshoot and settling time as the controller gain is increased? As part of this discussion, ***sketch a root locus diagram*** for this particular control loop to help you answer this question (from this and previous experiments you know all you need to know about this control loop to *sketch* a root locus diagram for it—and remember, a sketched root locus give the general shape of the root locus without using actual numerical values. Of course, if some numerical values are available they should be used to help improve the sketch). In theory, what effects does controller gain have on the transient response? You need to discuss these things—not just give one or two word answers like yes, no, good, bad, a lot, very little, see plot, etc.

4. Now discuss what you ***observed*** the ***actual*** transient response to be. What did you observe regarding the effect of controller gain on transient response? Explain any differences. How well do the observations compare to theory? Is what you observed consistent with the root locus diagram? Remember, explain things—no one word answers.

5. Is it possible to get both good steady state error performance and good transient performance out of this control loop when using a proportional controller? Discuss this and cite your observations and data—don't just say yes or no.

<u>Part II—Response to a Ramp in the Set Point with a Proportional Controller</u>: Use the same control loop for plate position control as in Part I, but in this part plate position is to follow a ramping set point rather than a step change in set point as was done previously. Simulink does not have a ramp generator to use for the set point, but a ramp can be generated easily by integrating a step. Set this up, have the ramp start at $t = 0$, and choose the step size so that the ramp has a slope of 600 deg/sec, i.e. we want the plate position to increase at a rate of 600 deg/sec. Set the graph's ordinate to 0-20,000, and the time axis to 0-30 sec. Once you think you have the proper set-up, **ASK THE INSTRUCTOR TO CHECK IT OUT BEFORE APPLYING POWER TO THE MECHANISM. ALSO, BE PREPARED TO SAY WHAT THE STEADY STATE ERROR SHOULD BE FOR THIS SITUATION.**

a) With the controller gain set at 0.00005 (why are these and the previous gains so small?), observe the ramp response and note both the steady state and the transient performance. Print this graph showing the response. What should the steady state error be? What did you observe it to be? **CALCULATE THE STEADY STATE ERROR.** If the steady state error observed does not match your theoretical expectations, what explains the differences? Repeat this experiment a few times and note whether or not the result is repeatable. If so, why? If not, why not? **MAKE NOTES OF YOUR OBSERVATIONS.**

b) Repeat part a) for controller gain values of 0.0001, 0.0005, 0.001, 0.005, and 0.01. In each case make the same observations and record the same data as in a), and **CALCULATE THE STEADY STATE ERROR.** Make sure you also observe the actual mechanism as it ramps in position. Print these responses and be prepared to explain why they have the shape they do, and which ones you think are good, i.e. which gain values you think produce a good response. **MAKE NOTES OF YOUR OBSERVATIONS.**

c) Use the best controller gain value from Part I for steps to see how it performs here when the set point is a ramp. Do you get good transient and steady state error performance for this "best step controller gain"? Can this controller produce good response for both steps and ramps in the set point? Why or why not?

<u>DISCUSSION QUESTIONS</u>

1. Plot the steady state error vs controller gain for this part.

2. Using your knowledge of the transfer functions of the plant and controller, and your Pre-Lab block diagram, determine the theoretical expression for the control system's steady state error to a ramp and **DISCUSS WHAT THIS EXPRESSION MEANS.**

3. Now discuss what you observed in the lab regarding the steady state error for this part. Do your observations match the theoretical predictions? Discuss both similarities and differences. What was the effect of controller gain on the error? Does this square with theory?

4. Discuss the transient response you observed in this part. Why does it have the shape it does? Could you get good transient response to a ramp with this controller? Discuss this ***and cite actual responses and data.***

5. Is it possible to get both good steady state error performance and good transient performance out of this control loop when using a proportional controller? Discuss this and cite your observations and data—don't just say yes or no.

6. Can you get good performance (steady state error and transient) to both steps and ramps in the set point with this controller? Discuss this and cite your observations and data—don't just say yes or no.

<u>Part III— Response to a Step Change in a Constant Set Point with a PI Controller</u>: This is the same situation as in Part I (i.e. the set point is stepped from one value to another) except that here a PI controller rather than just a proportional (or P) controller will be used. As long as there is an error between the controlled output and the set point, the integral portion of a PI controller will integrate that error and so steadily increase the control signal—in this case the control voltage—in an attempt to drive the mechanism to the set point exactly. The controller Simulink provides is actually a PID (**P**roportional, **I**ntegral, and **D**erivative) controller—we will obtain a PI controller from it by setting the derivative gain to zero. Simulink's PID controller can be found by opening **Simulink Extras**, looking under **Additional Linear** functions and dragging the PID controller (NOT the one with approximate derivative) into the control program.

a) Set up the position control loop with a PID controller. The set point will undergo 180 degree step changes, and make sure you can view the set point and the response on the same graph. Set the controller's derivative gain to zero (so that it's a PI controller), and begin with a proportional gain of 0.002 and an integral gain of 0.001. Once you think you have the proper set-up, **ASK THE INSTRUCTOR TO CHECK IT OUT BEFORE APPLYING POWER TO THE MECHANISM. ALSO, BE PREPARED TO SAY WHAT THE STEADY STATE ERROR SHOULD BE FOR THIS SITUATION.**

b) Make several step changes in the set point and observe the response of the actual mechanism as well as the response as plotted on the graph. Make sure you discuss the characteristics of the response among yourselves. **MAKE NOTES OF YOUR OBSERVATIONS.** Is the response what you thought it would be? Why or why not? Is it repeatable? Why or why not? Do you consider this an unacceptable or an acceptable response? Why or why not? Print the response so you have a record for your report.

c) Now vary the proportional and integral gains to see if you can improve the response. What effects do changes in proportional gain have on the response? Changes in integral gain? **IF THE SYSTEM SEEMS TO BE GOING UNSTABLE, STOP THE SIMULATION IMMEDIATELY.** When you think you have the best gains you can find, ask the instructor to review them. Do you consider this an acceptable response to a step in the set point? Why or why not?

DISCUSSION QUESTIONS

1. Discuss the steady state error performance for this control loop when a PI controller is used. Include in this discussion ideas about "system type" and what theory says the error for this particular control loop with a step in the set point should be, what you observed the actual error to be, the effect of controller gain on the error, and any other observations you made in the lab regarding the steady state error for this part of the experiment. In this discussion use the actual data you took in the lab, and use the observations you made. Be specific. If things observed do not match theory, you must discuss this and attempt to say why there are differences.

2. Discuss the loop's transient performance. Could you get good transient performance? Give evidence either way. What effects did proportional gain have on the transient response? What effects did integral gain have?

3. Is it possible to get both good steady state error performance and good transient performance out of this control loop when using a PI controller? Discuss this and cite your observations and data—don't just say yes or no.

Part IV—Response to a Ramp in the Set Point with a PI Controller: The objective of this part of the experiment is to see how a PI controller will perform when the set point is a ramp rather than a step.

a) Change the set point to a ramp rather than a step, and use the same ramp as in Part II. Also change the settings on the graph block so that you can view the ramp (use the same settings as in Part II), and start with proportional and integral gains equal to the best gains you found above for a step response.

b) Observe the ramp response and discuss whether or not you think it is a good response. What is the transient performance like? What is the steady state error? What should the error be? Discuss this response with the instructor.

c) Now make changes to the proportional and integral gains to see if you can improve the response. When doing this—**IMMEDIATELY STOP THE SIMULATION IF THE SYSTEM BECOMES UNSTABLE.** Discuss your best gains and your best response with the instructor.

DISCUSSION QUESTIONS

1. Using your knowledge of the transfer functions of the plant and controller, and your Pre-Lab block diagram, determine the theoretical expression for the control system's steady state error to a ramp with this (PI) controller, and **DISCUSS WHAT THIS EXPRESSION MEANS.**

2. Now discuss what you ***observed*** in the lab regarding the steady state error for this part. Do your observations match the theoretical predictions? Discuss both similarities and differences. What was the effect of controller gain on the error? Does this square with theory?

3. Discuss the transient response you observed in this part. Why does it have the shape it does? Could you get good transient response to a ramp with this controller? Discuss this ***and cite actual responses and data.***

4. Is it possible to get both good steady state error performance and good transient performance out of this control loop when using a PI controller? Discuss this and cite your observations and data—don't just say yes or no.

5. Can you get good performance (steady state error and transient) to both steps and ramps in the set point with this controller. Discuss this and cite your observations and data—don't just say yes or no.