EE313 - Signals and Systems - Fall 2009

PID Control Mini-Project
Due: Friday, Nov. 13, 3pm

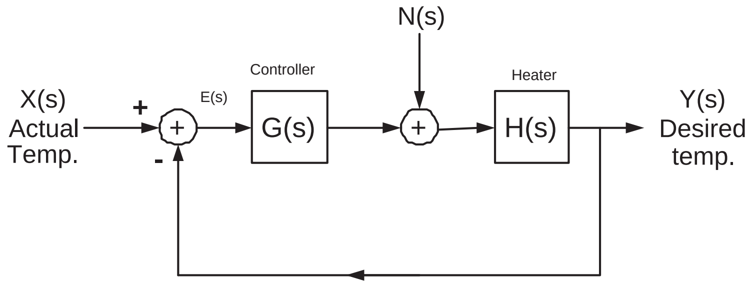
On this homework project, you must work with one or two partners and turn in one writeup for your team.

1. (100 pts) A PID Controller

   In order to test a new semiconductor, the VLSI engineers at your company have asked you, the resident control expert, to design a controller that will take their sample through a specified temperature profile. They provide a 25 Watt heating element, and the following specification:

   The system must heat the semiconductor from 0° F to 150° F, with less than 2°F overshoot, and have settled to 150 ± 0.5°F within 2 minutes.

   A block diagram of the system is shown below:



   Your responsibility is to provide the VLSI team with a transfer function $G(s)$ that is capable of meeting the above specification. The VLSI team has circuit experts who will then implement that transfer function in a circuit, assuming it is reasonably simple. PID controllers are very simple to build as RLC circuits.

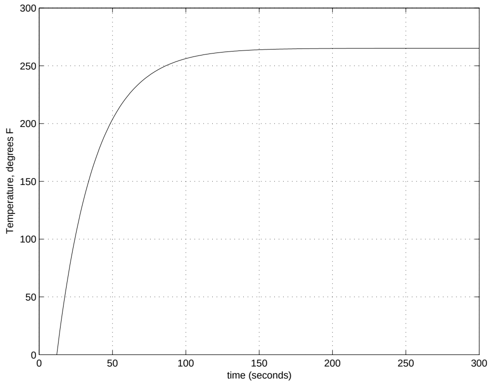
   The first thing to do when designing a control system is to understand the system you are trying to control. You turn the heater on full blast to see how the system responds, since this will give you all the information you need in order to design an appropriate PID controller. With the system stabilized at room temperature, you crank on the heater at time $t = 0$, and observe the following plot of temperature vs. time (two versions are provided, one is a closeup). We'll assume in this analysis that the noise $N(s)$ is zero.

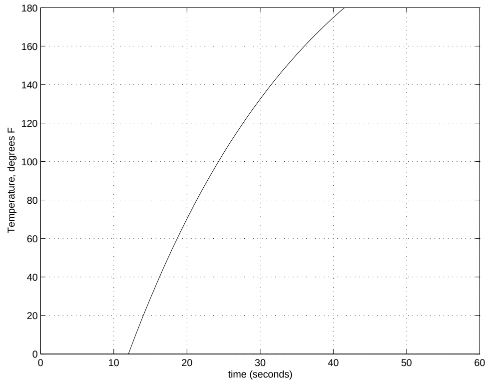
   (a) From the plotted response, it appears that this is a simple first order system with some time lag. An appropriate model appears to be:

   $$H(s) = \frac{Re^{-st_D}}{\tau s + 1}$$

   Where t_D is the time lag and τ is the system time constant. From the plot and using analytical tools like the Final Value Theorem, find estimates for R, τ, and t_D.

   (b) Let's add proportional control to the system. That is, $G_c(s) = K_p$. For a first trial, let $K_p = 1$. It is suggested that you do this using Simulink for Matlab of LabVIEW. I have posted a basic Simulink Tutorial, you can also find numerous examples of PID controller design in both Simulink and LabVIEW with an appropriate web search.





i. Make a bode plot of your total closed-loop transfer function.
ii. What is the gain margin and phase margin?
iii. Try adjusting K_p up and down to see if you can get closer to the desired response.
iv. Can you meet the required specification using only proportional control?

(c) Now, let's add integral control to help correct for the steady-state error. This implies that the controller transfer function is now:

$$G_c(s) = K_p(1 + \frac{1}{s\tau_I}) = K_p + \frac{K_I}{s}$$

(The second form is required for entering PID control info in Simulink). A reasonable starting value for τ_I might be $5/\omega_{gain}$, where ω_{gain} is the frequency at which the gain is one. You can also consider other possibilities for choosing τ_I, there are many methods and tutorials on PID parameter selection available on the internet.

i. Are you able to meet the required specifications with PI control? Explain.
ii. Include a plot of the response using the best K_p and K_I that you determined.

(d) Now, let's design a PID controller. The controller transfer function is now:

$$G_c(s) = K_p(1 + \tau_D s + \frac{1}{\tau_I s}) = K_p + K_D s + \frac{K_I}{s}$$

The integral time constant typically must be at least four times larger than the derivative time constant τ_D.

i. Determine a reasonable value for τ_D or equivalently K_D.
ii. Plot the total system response for PID control.
iii. What is your steady state error? Maximum overshoot?