

This problem set reviews the old procedure of estimating closed-loop stability by the Bode method, as well as tuning by gain and phase margins. The pretext is a change of controlled variable for the stirred reactor of Lesson 6; you will use the linearized model of Lesson 6 to do the engineering for this change. It should provide a striking illustration of the effect of nonlinearity on our linear models.

Again, use the spreadsheet “exothermic reactor for pset8.xls” to calculate steady-state conditions.

In Lesson 6, we decided to control reactor temperature, hoping that composition would be satisfactory. However, we sell composition, not temperature, so when we find a reliable on-line composition sensor, we happily install it. Now we must reconsider the control system, because the controlled variable has changed: our new objective is to control composition by manipulating coolant flow, and we let temperature float. Suppose that the valve gain  $K_v$  is  $-0.0002 \text{ m}^3 \text{ s}^{-1} \text{ \%out}^{-1}$ , and the sensor gain  $K_s$  is  $0.5 \text{ \%in m}^3 \text{ mol}^{-1}$ .

- (1) Take reference conditions for the linearized model at the hot steady state in the PSet 8 spreadsheet. Set  $T_I$  to 3 s,  $T_D$  to 0, and find the controller gain  $K_c$  (units are  $\text{\%out \%in}^{-1}$ ) that meets  $\text{GM} = 2$  and  $\text{PM} = 30^\circ$  limits.
- (2) Then assume that you choose to operate at the cold steady state. For better accuracy, you adjust the linear model parameters to this new reference condition. However, you leave the controller tuned as in (1). At what GM and PM are you now operating?
- (3) In Lesson 6, we found that the temperature control loop was intrinsically stable. Why can the composition loop, for this same process, be made unstable?
- (4) Would you recommend retuning the controller for the cold condition? Please explain.
- (5) Why did we specify an air-to-close valve?
- (6) How can the sensor we specified possibly work at both hot and cold operating conditions?