

Exercise 11 Tuning The Inner Cascade Controllers

I. OBJECTIVE

The objective of exercises 10 to 14 is to demonstrate how one can tune loops once a plantwide control architecture has been selected. The Tennessee Eastman simulation [1] is used and in exercise 14 several candidate architectures are evaluated. Once the reactor cooling water loop has been tuned one can proceed with tuning the remaining loops. The fastest loops, namely the inner cascade loops, are tuned first. This exercise deals with tuning two of the inner cascade loops, the C-Feed flow controller, and the condenser cooling water temperature controller.

II. CONTROL TECHNOLOGY

a) OVERVIEW: The following nonlinear dynamic model is used to simulate the Tennessee Eastman process [1]:

$$\dot{x} = f(x, u) \quad (1)$$

$$y = g(x, u) \quad (2)$$

where x is the state vector, u is the vector of manipulated variables, and y is the vector of process measurements. The vector, y , contains all the available process measurements, including those for the 10 inner cascade loops. Several MATLAB m-files have been written to interface with the FORTRAN simulation of eqns. 1 and 2. These m-files allow one to carry out reaction curve tests on the process, and to simulate it with various loops closed. Once a plantwide control architecture is decided upon, its loops can be tuned by starting with the fastest loops and proceeding to the slowest loops. All the controllers used in exercises 10 to 14 are PI controllers. They are implemented in velocity form as:

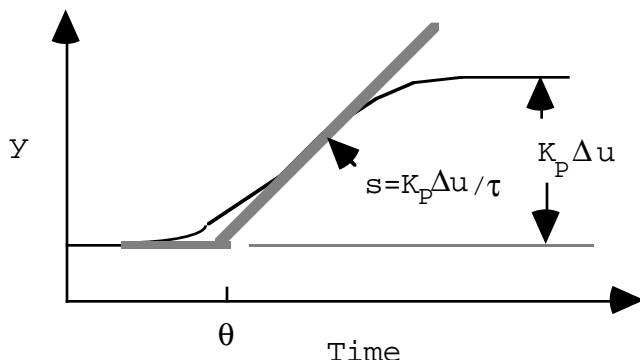
$$\Delta m v(t) = K_c(\varepsilon(t) - \varepsilon(t-1) + \varepsilon(t)\Delta t / T_R) \quad (3)$$

where $\Delta m v$ is the change in manipulated variable, $\varepsilon(t)$ is the error at time t , K_c is the controller gain, and T_R is the reset time. The integration time step used in the simulation is 1 sec. Note that some of the routines ask for simulation times in seconds, and others in minutes.

After the reactor cooling water loop is tuned, all of the remaining 9 inner cascade loops can be tuned using the same methodology. To illustrate this methodology two specific loops, namely the C-Feed flow controller, and the condenser cooling water temperature controller, are tuned in this exercise. For this purpose the m-file *dyncas* can be used. This routine asks the user to input PI parameters for the reactor cooling water loop. Then a reaction curve is generated for the two inner cascade loops under

study by bumping their control valves, one at a time. A typical reaction curve generated by this bump test is illustrated in Figure 1.

Figure 1. Reaction Curve



The y axis is the measurement after a step input is introduced to the manipulated variable, u . The steady state change in y , $K_p \Delta u$, maximum slope, s , and the effective dead time, θ , are measured from the plot. From the slope and steady state change, t and K_p can be calculated knowing Δu ¹. During the bump tests for the 2 loops, the reactor cooling water loop should be closed, and the value of K_C and T_R found in exercise 9 implemented.

III. COMPUTER EXERCISE

Carry out a bump test for the C-Feed flow controller, and the condenser cooling water temperature controller. Plot the results of bump testing each case. Using the tuning charts given in Marlin [2], estimate values for K_C and T_R . The PI parameters developed from the bump tests should be considered as starting values. These values should be adjusted by checking the closed loop performance of the inner cascade loops. The m-file *primary* can be used to fine tune the closed loop performance of the inner cascade loops. This m-file asks for the PI parameters of the inner cascade loops to be input. The m-file also asks for a list of variables to be plotted. Both of the inner loops can be tested by bumping their set point, and plotting the corresponding measurement, measurement 4 for the C-Feed flow, and measurement 22 for the condenser cooling water temperature. If necessary the PI parameters for the inner cascades should be adjusted and the closed loop test run again until a satisfactory response is obtained.

IV. RESULTS ANALYSIS

¹ The software asks for a % input for a bump test. If, for example, the steady state value of $u = 50\%$, then a 1% bump corresponds to $\Delta u = .01 \cdot 50 = 0.5\%$, and a 2% bump corresponds to $\Delta u = .02 \cdot 50 = 1\%$, etc.

How fast can the C-Feed flow be changed? How fast can the condenser cooling water temperature be changed? Why is a negative gain required for K_C for the condenser cooling water temperature loop, and a positive gain for the C-Feed flow loop?

V. REFERENCES

- [1] Downs, J. and Vogel, E., "A Plant-Wide Industrial Process Control Problem", *Computers and Chemical Engineering*, **17**, 245-255 (1993).
- [2] Marlin, T., *PROCESS CONTROL Designing Processes and Control Systems for Dynamic Performance*, Mc Graw Hill, New York, N.Y., p. 301 (1995).