Exercise 13 Tuning The Outer 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 inner cascade loops and the level loops have been closed, the outer loops can be tuned. This exercise deals with tuning two of the outer loops, the Reactor Pressure - Reactor CW Temperature controller, and the Product G/H - D/E Ratio controller.

II. CONTROL TECHNOLOGY

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

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

$$y = g(x,u) \tag{2}$$

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:

$$\Delta mv(t) = K_C(\varepsilon(t) - \varepsilon(t-1) + \varepsilon(t)\Delta t / T_R) \tag{3}$$

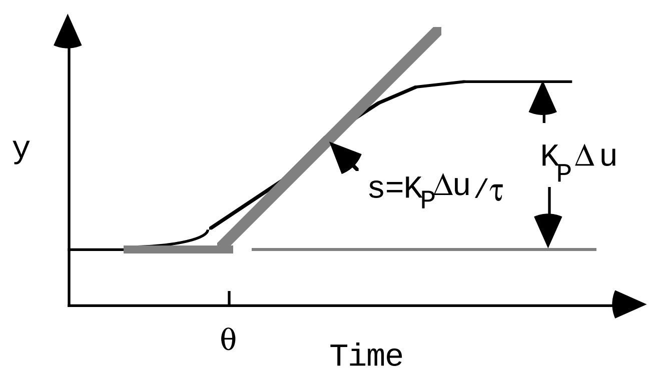
where Δmv is the change in manipulated variable, e(t) is the error at time t, K_C is the controller gain, and T_R is the reset time. The integration time step used in the simulation is 1 sec. Note that some of the routines ask for simulation times in seconds, and others in minutes. Results for tuning the level controllers are given in Table 1. After the inner cascade and level loops are tuned, bump tests on the outer loops can be carried out. To illustrate this methodology two specific loops, namely the Reactor Pressure - Reactor CW Temperature controller, and the Product G/H

Table 1. Final Level Tuning Constants From Closed Loop Testing

Manipulated Variable	K_C (ΔSP/%)	T_R(min)
Prod SP	-.07	200
Sep Exit SP	-.12	200
E Feed SP	1500	200
Cond CW Temp	6.00	200

- D/E Ratio controller, are tuned in this exercise. For bump tests the m-file *primary* can be used. This routine asks the user to input PI parameters for the inner cascade and level loops. Then a reaction curve can be generated for the outer loops under study by bumping their manipulated variables, one at a time. Two different reactor level control strategies are studied. In the first the E-Feed is used for level control, and in the second the condenser cooling water is used. A bump test for each outer variable and each level scheme needs to be carried out, resulting in a total of 4 bump tests. A "typical" reaction curve generated by a bump test is illustrated in Figure 1.

Figure 1. Reaction Curve



However, due to the nature of Tennessee Eastman process, the bump tests on the outer loops may not be "typical". 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, τ and K_P can be calculated knowing Δu[1]. During the bump tests for the 2 loops, the inner cascade and level loops should be closed using the tuning parameters given in exercise 11 and Table 1 above.

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[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 Δu = .01*50 = 0.5%, and a 2% bump corresponds to Δu = .02*50 = 1%, etc.

III. COMPUTER EXERCISE

Carry out a bump test for the Reactor Pressure controller, and the G/H ratio controller using the m-file *primary*. Consider the two different level controller schemes, using the E-Feed and the Condenser CW Temperature. Plot the results of bump testing for all cases. Using the tuning charts given in Marlin [2], estimate initial values for K_C and T_R. The PI parameters developed from the bump tests should be considered as rough starting values. These values should be adjusted by checking the closed loop performance of the outer cascade loops. The m-file *plantwide* can be used to fine tune the closed loop performance of the outer cascade loops. In order to use *plantwide* the D/E loop must be operational. Thus, the G/H - D/E loop should be checked first in closed loop operation, and then kept closed when the Reactor Pressure controller is checked. The PI parameters for the two outer cascades should be adjusted and the closed loop tests run until a satisfactory response is obtained.

IV. RESULTS ANALYSIS

For the E-Feed Reactor Level scheme answer the following questions. How fast can reactor pressure be changed? How fast can the G/H ratio be changed? Report the values of K_C and T_R for each loop. For the Condenser CW Temperature Reactor Level scheme answer the following questions. How fast can reactor pressure be changed? How fast can the G/H ratio be changed? Report the values of K_C and T_R for each loop. Give an explanation as to why the bump test for Reactor Pressure has the shape that it does for both reactor level schemes. Why is the response of the G/H ratio so much slower than the response of the reactor pressure. Explain. If the boiling liquid in the reactor were a pure component, increasing reactor temperature would increase the pressure. What happens in the reactor if temperature is increased? Does the pressure increase or decrease? Can you offer an explanation for this behavior?

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).