Exercise 14 Testing The Complete Plantwide Control System

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 this exercise several complete candidate architectures are evaluated.

II. CONTROL TECHNOLOGY

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

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

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

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:

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

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 inner cascade controllers were given in exercise 11, for the level controllers in exercise 12. Tuning results for all the remaining controllers are given in Tables 1 and 2.

Table 1. Final Tuning Constants From Bump Testing E-Feed Controlling Reactor Level

Loop	K_P	τ(min)	θ(min)	K_C	T_R(min)
React P-React CWT	-42.3	33.3	1.6	-0.02	30
G/H-D/E	1.52	96.2	43.2	.6	400
Prod-C Feed	2.51	104	16	0.6	60
Purge B-Purge	-41	1000	12	-0.0366	250
Purge F-Purge	-3.06	519	25	-0.490	130
React A/C-A Feed	7.81	657	12	1.00	164
React A-A Feed	50	442	~0	0.06	110
Purge A-A Feed	59.2	382	~0	0.05	96

Table 2. Final Tuning Constants From Bump Testing Condenser Cooling Water Controlling Reactor Level

Loop	K_P	τ(min)	θ(min)	K_C	T_R(min)
React P-React CWT	-35.9	21.4	3.73	-0.025	30
G/H-D/E	2.79	107	35	.4	400
Prod-C Feed	1.76	96	6	0.852	60
Purge B-Purge	-41	1038	12	-0.0366	260
Purge F-Purge	-3.81	645	25	-0.394	161
React A/C-A Feed	7.34	597	12	1.00	149
React A-A Feed	59.6	438	~0	.05	109
Purge A-A Feed	88.9	474	~0	.034	119

The loops involving the purge, and A-Feed, had a very slow, integrating type response when bump testing was carried out. The gain, K_p, and time constant, τ, were estimated by measuring the initial slope of the response (slope = step size*(K_p/τ)), and using a value of K_p determined from the steady state gain matrix. This procedure avoided having to wait for very long periods for the bump tests to come to steady state. The tunings for the A-Feed were further adjusted by closed loop testing. For the case where the condenser cooling water temperature is used to control the reactor level, the E-Feed is ratioed to the C-Feed.

III. COMPUTER EXERCISE

Once the entire plantwide control system has been properly tuned, it will be tested on how well it rejects disturbances and achieves set point changes. The m-file *plantwide* can be used for this purpose. The following disturbances should be simulated:

IDV(1) to IDV(9), and IDV(11) and IDV(14). Results for IDV(10), IDV(12), and IDV(15) are similar to those for IDV(9), IDV(11), and IDV(14) respectively. The upset involving catalyst drift, IDV(13), is not considered in this exercise. In addition the following step changes should be made as suggested by Downs and Vogel [1]: 1) -15% change in the production rate; 2) change in the product mix from 50G/50H to 40G/60H; 3) -60 kPa change in the reactor pressure; 4) +2% change in the composition of B in the purge. For comparison the schemes below in Table 3 will be investigated, and the class will be separated into different groups to study the 8 strategies. In each of these schemes the following loops are the same: separator level-separator exit flow, stripper level-product flow, product flow-C feed flow, reactor pressure-reactor cooling water temperature, G/H in product-D/E feed ratio, and the stripper temperature-steam flow. Differences between the various schemes are given in Table 3. For schemes 1 to 4 the condenser cooling water set point, recycle valve, and agitator are not manipulated. For schemes 5 to 8 the recycle valve, and agitator are not manipulated, and the E-Feed is ratioed to the C-Feed.

Table 3 Plantwide Strategies To Be Investigated

Plantwide Strategy	Loops
1	reactor level-E feed, reactor feed A/C-A feed, purge B-purge
2	reactor level-E feed, reactor feed A-A feed, purge B-purge
3	reactor level-E feed, purge A-A feed, purge B-purge
4	reactor level-E feed, purge F-purge, reactor feed A-A feed
5	reactor level-cond CW temp, reactor feed A/C-A feed, purge B-purge
6	reactor level-cond CW temp, reactor feed A-A feed, purge B-purge
7	reactor level-cond CW temp, purge A-A feed, purge B-purge
8	reactor level-cond CW temp, purge F-purge, reactor feed A-A feed

IV RESULTS ANALYSIS

Of the plantwide strategies investigated which gives the best performance? Are all the upsets and set point changes handled effectively? If not what can be done to handle them? Which scheme do you recommend for implementation based on your testing? How do the two approaches to controlling the reactor level compare to one another in terms of their ability to achieve tight level control?

V. REFERENCES

[1] Downs, J. and Vogel, E.,"A Plant-Wide Industrial Process Control Problem", Computers and Chemical Engineering, **17**, 245-255 (1993).