CONTROL OF A REACTOR-FLASHER SYSTEM

Jong Ku Lee and Sun Won Park

Department of Chemical Engineering, KAIST, P. O. Box 150, Cheongryang, Seoul, Korea
(Received 17 April 1991 • accepted 2 August 1991)

Abstract—This paper presents a case study in which several multivariable control strategies were tested for a reactor-flasher system of an industrial chemical process. This reactor-flasher system which has three manipulated variables and three controlled variables is open loop unstable. Since the system variables interact severely, controlling the system is very difficult with the traditional PID control. We examined various control strategies such as multi-loop single variable control, modified single variable control with compensators, and PI control combined with Linear Quadratic Regulator (LQR), Linear Quadratic Gaussian (LQG)/Loop Transfer Recovery (LTR) and Dynamic Matrix Control (DMC) combined with LQR. DMC combined with LQR showed better control performance than the others while remaining robust in the face of modeling errors.

INTRODUCTION

Multivariable control has been studied over the last two decades. However, single variable control with cascade and feedforward control is predominant in the process industries. Though it is simple to be implemented, there are many processes which are difficult to control using it.

A reactor-flasher system is shown in Figure 1. The flow rates of the feeds to the reactor are almost constant most of the time. The reactor product goes to the flasher where the vapor leaves the overhead to a subsequent distillation unit. The liquid accumulates in the flasher base and is recycled back to the reactor. In this paper we call this stream recycle 1 and the stream which is fed to the reactor from the distillation unit is recycle 2. The reactor pressure is controlled by the gas feed rate and it is not important in this study.

We focus our attention on the control of the reactor temperature and the liquid levels in the reactor and the flasher. To control the levels, the flow rates of the product and the recycles are manipulated. The reaction is exothermic and the heat generated in the reactor is removed primarily by product flashing. The temperatures of recycles 1 and 2 are much lower than that of the reactor. Therefore, changes of the recycle flow rates interact with the reactor temperature and in addition this system is open loop unstable.

In this study, we find the best control strategy by comparing the control performance of five control strategies: multi-loop single variable control, modified single variable control with compensators, PI control combined with Linear Quadratic Regulator (LQR), Linear Quadratic Gaussian (LQG)/Loop Transfer Recovery (LTR), and Dynamic Matrix Control (DMC) combined with LQR[10]. Here, we propose DMC combined with LQR as a new method to handle open loop unstable systems.

MATHEMATICAL MODEL OF THE REACTOR-FLASHER PROCESS

The model equations of the reactor-flasher system are comprised of three equations: the mass balances of the reactor and flasher, the energy balance of the reactor. By simplifying the balance equations, we can get the mathematical model of the reactor-flasher system as follows[13] :

\[ \frac{dx}{dt} = Ax + Bu \]  
\[ y_m = Cx + Du \]

where \( x = [x_1, x_2, x_3]^T \)

\[ u = [u_1, u_2, u_3]^T \]

\[ A = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -2.2 \\ 0 & 0 & 13 \end{bmatrix} \]

\[ B = \begin{bmatrix} -1 & 1 & 1 \\ 0.67 & -1 & 0 \\ 0 & -0.66 & -1.6 \end{bmatrix} \]

\[ C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \]

\[ D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \]
All state variables represent deviations around the steady state condition. The state variable \( x_1 \) denotes the mass of liquid in the reactor; \( x_2 \) the mass of liquid in the flasher; \( x_3 \) the reactor temperature; \( u_1 \) the flow rate of the reactor product; \( u_2 \) the flow rate of recycle 1; \( u_3 \) the flow rate of recycle 2. The locations of the system poles on Laplace domain are 0, 0 and 13. Therefore, we find that this system is very unstable.

In the following simulation, we compare the performances of four control methods (multiloop single variable control, modified single loop control with compensators, PI control combined with LQR, LQG/LTR, DMC combined with LQR) when we change the reactor temperature setpoint by 0.3.

### SIMULATION RESULTS

1. **Multiloop Single Variable Control**

Single variable control means that only one output information is used in order to give a manipulated action into the system. That is, all controlled variables and manipulated variables are coupled one by one. In this system, the flasher level is controlled by the flow rate of reactor product and the reactor level is controlled by the flow rate of recycle 2 and the reactor temperature is controlled by the flow rate of recycle 1. Figures 2 & 3 show the process configuration and its block diagram with multiloop single variable control. In this case, it is very difficult to tune all parameters of PI controllers because the degrees of freedom is six and the process is unstable.

Georgiou, A. and Luyben, W. L. proposed a method to tune the control parameters of the unstable multivariable control system[8]. Since we have to solve four-step optimization problems to apply their method, it is practically impossible to apply it to more complex systems than 2×2 systems. So we tuned the three control loops by trial and error(\( K_1 = 4 \), \( K_x = 50 \), \( K_y = 50 \), \( \tau_1 = \tau_2 = \tau_3 = 1 \)). As we expected, the reactor level oscillates heavily and manipulated action is very large as can be seen from Figure 4 which means that the control system has severe interactions.

2. **Modified Single Variable Control with Compensators**

Ochiai and Roark[12] suggested to modify the reactor level control system by making the flow rate of recycle 2 proportional to the reactor product flow by Loop 1, and to make the flow rate of the reactor product proportional to the flow rate of recycle 1 by Loop 2. With these two loops the interaction is reduced as compared to the multiloop single variable control. Figures 5 & 6 show the configuration and its block diagram of modified single variable control with compensators. From Figure 7, we can see that the oscillation of the reactor level is slightly reduced than that for multiloop single variable control. But yet we still have trouble tuning the control parameters. We tuned them by trial and error again(\( K_i = 4 \), \( K_x = -25 \), \( K_y = -30 \), \( \tau_1 = \tau_2 = \tau_3 = 1 \)).

3. **PI Control Combined with LQR**