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Optimization of Input Weighting Factors for Model Predictive Controller

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1. Introduction

A model predictive control (MPC) method has been efficiently applied to APR-type reactor as a control bank controller for reactor power level and axial power distribution controls. MPC algorithm is to solve the optimization problem to minimize objective function over a future horizon. Normally, input weighting factors in objective function should be optimized to enhance the performance of controller. In this paper, input weighting factor has been determined by design of experiment (DOE) method.

2. Methods and Results

At present MPC is the most widely used multivariable control algorithm in the process industry. While MPC is suitable for almost any kind of problem, followings are its merits when applied to problem:

- A large number of manipulated variables (MV) and controlled variables (CV).
- Constraints imposed on both the MV and CV.
- Changing control objectives and/or equipment failure
- Time delays

2.1 Predictive Control Law and Model

The objective function (J) uses a quadratic function, shown in Equation (1).

$$J = \frac{1}{2}\sum_{j=1}^{N}\left(\hat{y}(t+j\,|\,t) - w(t+j)\right)^T Q\left(y(t+j\,|\,t) - w(t+j)\right) + \frac{1}{2}\sum_{j=1}^{M}\Delta u(t+j-1)^T R\Delta u(t+j-1), \quad (1)$$

subject to constraints

$$\begin{cases} \hat{y}(t+N+i) = w(t+N+i), & i = 1,\cdots,L \\ \Delta u(t+j-1) = 0, & j > M \quad (M < N) \end{cases}$$

where $\hat{y}(t+j\,|\,t)$ is an optimum j-step-ahead optimal prediction of the system output (power level) based on data up to time t. The vector, w, is a setpoint sequence for the output vector and Δu is a control input change (R5 control rod position change) between two neighboring time steps. N is the prediction horizon and M is the control horizon. Q and R input weight factors of $(\hat{y} - w)$ and Δu at certain future time intervals, respectively. There are two constraints. The first constraint, $\hat{y}(t+N+i) = w(t+N+i),\ i = 1,\cdots,L$, which makes the output follow the reference input beyond the prediction horizon, guarantees the stability of the controller. The second constraint, $\Delta u(t+j-1) = 0$ for $j > M$, means that there is no variation in the control signals after a certain interval $M < N$.[4]

The predictive control law uses an external input-output representation form, given by the polynomial relation that is described by the controlled auto-regressive and integrated moving average (CARIMA) model and the predicted outputs can be derived as a function of past values of inputs and outputs and of future control signals [3]:

$$A(q^{-1})\,y(t) = B(q^{-1})\Delta u(t-1) + C(q^{-1})\xi(t) \quad (2)$$

Where $y \in R^n$ is the output(n=the number of outputs), $\Delta u \in R^n$ is the control input change between two neighboring time steps(m=the number of inputs), $\xi \in R^n$ is a stochastic noise vector sequence with zero mean value, and q^{-1} is backward shift operator, $A(q^{-1})$ is monic matrix, $B(q^{-1})$ is n x m polynomial.

2.2 MV and CV

The number of outputs is two CVs and the outputs consist of the power level and the ASI. The number of inputs is also two MVs and the inputs are the axial positions of two types (regulating control banks and part-strength control banks) of control rod banks.

2.3 Optimization of input weighing factors

The weighting factors in objective function indicate Q (output weighting matrix) and R (input weighting matrix). In general, Q matrix treated as a unit matrix, while R matrix has to be determined to enhance the performance of controller. Due to MV is two variables, R matrix represented R1 and R2 for regulating bank and part strength control element assembly, respectively.

In order to make controller more sensitive response sequence, multiplier (M1) is applied to CV for output error.

2.4 D.O.E

DOE has been performed to design the optimal R1,R2,M1 weighting factors in Equation (1).

The numerical simulation was performed to the daily load-following operation of APR-type reactor which was performed numerically by KISPAC-1D code[5].

Statistics calculation is performed by MINITAB program that is widely used in statistic tool.

Table 1 shows variable range in DOE.

Table 1: Variable Range

Variable	Min.	Max
R1	**0.1**	**0.5**
R2	**0.1**	**0.5**
M1	**1**	**50**

Table 2 shows simulation results on Surface Reaction Values(SRV) with R1 and R2 ratio changes..

Table 2: Runs and Surface Reaction Value

Std Run	**Run**	**R1**	**R2**	**M1**	**SRV**
5	**1**	**0.1**	**0.1**	**50**	**0.03988**
6	**2**	**0.5**	**0.1**	**50**	**0.03856**
7	**3**	**0.1**	**0.5**	**50**	**0.03554**
3	**4**	**0.1**	**0.5**	**1**	**0.03554**
2	**5**	**0.5**	**0.1**	**1**	**0.13713**
1	**6**	**0.1**	**0.1**	**1**	**0.47754**
4	**7**	**0.5**	**0.5**	**1**	**0.76562**
8	**8**	**0.5**	**0.5**	**50**	**1.18064**

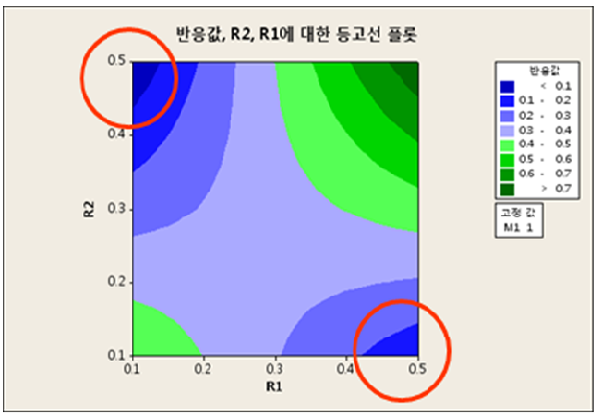

Fig. 1. Optimal Regions on R1 and R2.

Figure 1 shows DOE results by the numerical simulation for daily load-following operation at BOC of APR-type reactor. It was applied for simulation that a daily load cycle of a typical 100-50-100%, 2-6-2-14hr pattern. Optimal values of [R1: R2] are determined to be [0.5:0.1] or [0.1:0.5] for any values of M1. [R1:R2] ratio [0.5:0.1] is selected because regulating bank prefer to be prior to PSCEA .

4. Conclusion

Optimal input weighting values for R1 and R2 are determined by DOE in order to enhance the controller for APR-type reactor accommodate daily load follow operation. [R1:R2] values are determined by [0.5:0.1].

Optimal Input weighting factor is a key factor on performance of controller for APR-type reactor.

Reference

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