Dynamic Resilience를 고려한 공정의 개선설계

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† 위 저자는 현재 LG화학 기술연구원에 소속되어 있음.

Process Retrofit Design Based On Dynamic Resilience

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INTRODUCTION

The control system was usually taken into consideration only after the design of the plant was completed and dynamic models were rarely used. However, in the last several years a number of useful results have been obtained pertaining to the assessment of alternative designs on the basis of their dynamic behaviours which affect the control performance of the systems. It is now widely recognised that wherever possible aspects of process control should be considered from the earliest stages of process design. In this manner any control difficulties which arise from properties of the process itself can be ironed out before they become expensive mistakes, and can be corrected even after they appear.

We use the terms "dynamic resilience" or "controllability" to describe the ability of the plant to move fast and smoothly from one operating condition to another (including start-up and shut-down) and to deal effectively with disturbances (Morari, 1983).

There are many approaches to the dynamic resilience of systems for the plant design. Most of them can be classified into two categories: Qualitative approach and quantitative approach. The former is usually concerned with so-called structural controllability and the latter with effective indices to determine how dynamically resilient or controllable processes are (Kwon and Yoon, 1995).

However, most of the studies have been concentrated on the selection of the best process configuration among various alternatives at the early stage of process design.

In this study, we suggest a effective method for process retrofit which can give us the information on the quantitative amount and the direction of design parameters to be changed to achieve appropriate dynamic resilience. The suggested method utilises condition number as a index, and is based on the techniques of singular value analysis of process transfer function matrix.

CONDITION NUMBER

The dynamic resilience of a process, the ease with which the process can be controlled to achieve a desired performance, may be investigated by resorting to properties of matrices describing the process. The transfer function matrix relating inputs to outputs in the frequency domain which characterise the dynamic behaviour of the process has been postulated and used in this study. One of the basic and most important tools of modern numerical analysis concerned with matrices is the singular value decomposition. We shall define the SVD here and make a few comments on its properties.

Theorem 1: Let $A \in C_r^{m\times n}$. Then there exist orthogonal [unitary] matrices $U \in C_r^{m\times m}$ and $V \in C_r^{n\times n}$ such that

$$A = U \Sigma V^H \tag{1}$$

where

$$\Sigma = \begin{pmatrix} S & 0 \\ 0 & 0 \end{pmatrix}$$

and $\Sigma = diag(\sigma_1, \sigma_2, \cdots, \sigma_r)$ with

$$\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_r \geq 0$$

The numbers $\sigma_1, \ldots, \sigma_r$ together with $\sigma_{r+1}=0, \ldots, \sigma_n=0$ are called the *singular values* of A and they are the positive square roots of the eigenvalues (which are non-negative) of A^HA. The columns of U are called the *left singular vectors* of A (the orthonormal eigenvectors of AA^H) while the columns of V are called the *right singular vectors* of A (the orthonormal eigenvectors of A^HA). If all the entries of the matrix A are real, then A^HA [A^TA] ≥ 0 and all the elements of the set $\{\sigma_i\}$ are positive real numbers.

The physical meaning of the singular value $\sigma_{\max}(G)$ of a transfer function matrix G for a process is the "magnitude" of the matrix, that is, the upper bound of the ratio of output vector to input vector.

"Condition number" is defined as the ratio of maximum to minimum singular value and used as a index for the direction of process gains. It has been shown that the condition number of the transfer function matrix of a system can be used as a measure of the sensitivity of its control performance to modelling error, and as such, is a measure of the dynamic resilience. CN quantifies the sensitivity for a process model or a process gain matrix. A minimum singular value indicates the minimum distance between the given matrix and the singular matrix, and thus determines invertibility of the matrix. A large CN means that it is very difficult to obtain an expected control performance regardless of the types of control systems used.

SENSITIVITY ANALYSIS OF SINGULAR VALUES

In order to organize a optimization problem for process retrofit in the aspect of dynamic resilience we need to express the changes of singular values properly in terms of process design parameters. An indication of the effect of parameter variations upon the singular values may be given by computing the sensitivity of each singular value with respect to these parameter variations (Freudenberg *et al.*, 1982). In this study we utilise the sensitivity of singular values devised by Freudenberg *et al.*. As is well known singular values are hardly expressed in terms of process design parameters analytically and thus nondifferentiable. They suggested the following theorem using mathematical properties of singular values.

Theorem 2: Let A be as in theorem 1. Then given p, the sensitivity of the singular values can be $\nabla \sigma_i(p; \Delta p)$ such that

$$\nabla \sigma_i(p; \Delta p) = Re \quad [u_i(p)^T \delta A(p; \Delta p) v_i(p)] \tag{2}$$

where $\delta A(p; \Delta p) = \sum_{i=1}^{m} \nabla_i A(p) \Delta p_i$ and $Re\ [M] = \frac{1}{2}\ [M+M^T]$

Since ΔP denotes the vector of the direction into which the design parameter P changes, the sensitivity in theorem 2 can deal with not only the change in one design parameter but the changes in multiple design parameters which may affect each other.

Now we define the relative sensitivity of singular values as follows.

$$\delta\sigma_i(p; \Delta p) = Re \quad [u_i(p)^T \delta A(p; \Delta p) v_i(p)] \ / \sigma_i(A) \tag{3}$$

With these sensitivities, the change of the CN and the singular values as the process design parameters differ can be easily predicted through computation.

RESULTS AND CONCLUSION

The suggested method is illustrated with a two-staged CSTR process and the others. It can be determined that how much and to which direction the process design parameters should be changed in order to meet the desirable dynamic resilience (a small CN) without computing an analytical solution of CN or singular values in terms of the process design parameters. The method would be very useful for a retrofit design of complex processes. The further study of screening out the dominant design parameters affecting dynamic resilience is required.

Acknowledgement – This study was supported in part by the Korea Science and Engineering Foundation (KOSEF).

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