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A NEW DESIGN OF MULTIVARIABLE DECOUPLING INTERNAL MODEL CONTROLLER

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ABSTRACT

This paper is concerned with the design of multivariable decoupling internal model controller in industrial processes with large time delay characteristics, as well as linkages between controlling loops coupled. Some new results are obtained as follows: Design of multivariable decoupling internal model controller is realized by two step way that is decoupling device and controller, and they are separately designed. Decoupling control is based on system transfer function matrix and a diagonal matrix decoupled is equivalent to a system reference model. A foreword feedback control module is designed to remove minimum phase, then a high order low-pass filter is designed for filtering an error of actual output and model output. Equivalent model part integrated with the internal model controller is equivalent to IMC-PID controller by analytical method to simplify adjusting parameters of IMC. The dynamic characteristics, robustness of system and anti-interference performance under conditions of model mismatch and existing interference have been tested by experimental simulation. It is shown that the feasibility and the effectiveness of design of multivariable decoupling internal model controller proposed here.

Keywords: *Multivariable decoupling, Internal model controller, PID controller, Robustness*

1. INTRODUCTION

There is a general push to study real-time, multivariable on-line control since a production process control system is generally of multivariable, hysteresis and coupling characteristics. Compared with multivariable predictive control, internal model control (IMC) is received broad attention due to the following advantages: faster respond, strong robustness, anti-interference performance under conditions of model mismatch and existing interference, and so on [1-3]. But design of internal model controller is generally complex of compute-intensive so that we need to explore a new method of multivariable decoupling design of internal model controller.

Based on a model of multivariable decoupling internal model controller, a new approach two step way design of decoupling device and controller is put forward in this article. As long as diagonal element of system transfer function matrix is non-zero that almost all more variable system can meet this conditions, decoupling control can be realized as a system reference model based on a diagonal matrix decoupled, therefore, an internal model controller (IMC) can be changed into multiple mutual independent of single variable system[4-6]. A foreword feedback control module is designed to remove minimum phase, then a high order low-pass filter is designed for filtering an error of actual output and model output, in which only a filter time constant needs to be adjusted for a filter in multivariable decoupling internal model controller, that greatly simplifies adjusting parameters of IMC. Equivalent model part integrated with the internal model controller is equivalent to IMC-PID controller by analytical method. Internal model control based on PID controller (IMC-PID) not only maintained the characteristics of traditional PID control, but also has all the benefits of internal model control that is of good dynamic characteristics such as reliable robustness of system and strong anti-interference performance under conditions of model mismatch and existing interference.

2. A MULTIVARIABLE INTERNAL MODEL CONTROL SYSTEM AND DECOUPLING CONTROLLING

A multivariable internal model control is a control system introduced an internal model in which an internal model and actual object

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controlled is parallel formation, and the output feedback of the system is a feedback of disturbance estimated. A foreword feedback compensation proposed for removing out minimum phase of the model which take equivalent inverse of minimum phase part to make the system outputs track inputs change[7-9]. An error of actual output and model output is filtered by way of low-pass filter. Response of system and interference response can be separated so that a multivariable internal model control is of good controlling response performance.

A block diagram of a multivariable internal model control system is shown in Figure.1.

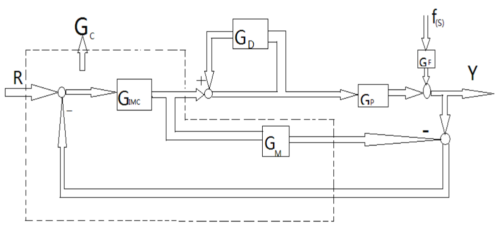

Figure. 1 A Block Diagram Of A Multivariable Internal Model Control System

Where R denotes reference input, G_{IMC} denotes internal model controller, G_D denotes foreword feedback compensation device , G_P denotes transfer function of actual process, G_M denotes equivalent system model of the actual process decoupled, $G_F(s)$ denotes interference channel transfer function matrix, G_C denotes system transfer function matrix , $f(s)$ denotes diagonal matrices interference input, $Y(s)$ denotes system output.

A multivariable controlling process is often more than one interaction between each control system which effect is known as association or coupling between control systems. A control system transfer function matrix is denoted control system association. Figure. 2 is a dual-input dual-output control system block diagram. System transfer function matrix is:

$$\begin{bmatrix} Y_1(S) \\ Y_2(S) \end{bmatrix} = \begin{bmatrix} G_{11}(S) & G_{12}(S) \\ G_{21}(S) & G_{22}(S) \end{bmatrix} \bullet \begin{bmatrix} U_1(S) \\ U_2(S) \end{bmatrix} \tag{1}$$

It is shown that if main diagonal element of system transfer function matrix $G_{12}(s)$ and $G_{21}(s)$ is non-zero, other elements are zero, two independent control systems, does not have association; if other elements gain is much smaller than main diagonal elements, it is weakly associated control system.

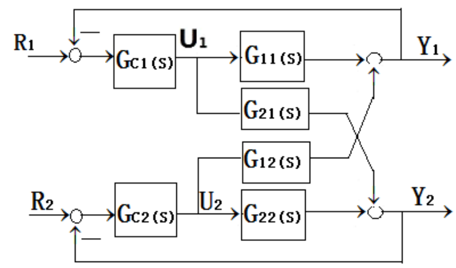

Figure. 2 A Block Diagram Of Dual-Input Dual-Output Control System

3. A IMPLEMENTATION OF MULTIVARIABLE DECOUPLING INTERNAL MODEL CONTROLLER

Basic procedure of design of multivariable decoupling internal model controller is realized by twp step way that is decoupling device and controller is separately designed.

Decoupling control: Design of decoupling control system will follow principle of self-determination and principle of coordinated tracking [10-12] and decoupling device simple and easy to implement. Assumes that several elements of decoupling device is 1.A foreword feedback control module or general instrument device can be used for implementation of lead and lag link structure. An implementation of decoupling device is shown in Figure. 3.

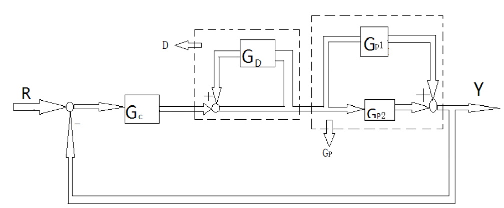

Figure. 3 A Decoupling Control Device

Where GP1 denotes a diagonal matrix of object controlled GP in which main diagonal elements are non-zero，other elements are zero; GP2 denotes a non-diagonal matrix of object controlled GP in which main diagonal elements are zero，other elements are non-zero.

$$G_p = G_{p1} + G_{p2} \tag{2}$$

Assumes that decoupling device transfer function is

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$$D_{11}(s) = D_{22}(s) = 1 \quad (3)$$

Then

$$D_{12}(s) = -\frac{G_{12}(s)}{G_{11}(s)} \quad (4)$$

$$D_{21}(s) = -\frac{G_{21}(s)}{G_{22}(s)} \quad (5)$$

Decoupling demand for

$$G(s)\ D(s) = diag[V_{ii}(s)] \quad (6)$$

$$D = [I - G_D]^{-1} \quad (7)$$

$$G_P \bullet D = (G_{P1} + G_{P2}) \bullet [I - G_D]^{-1} \quad (8)$$

Then

$$(G_{P1} + G_{P2}) \bullet [I - G_D]^{-1} = G_{P1} \quad (9)$$

A foreword feedback compensation is got

$$G_D = -G_{P1}^{-1} \bullet G_{P2} \quad (10)$$

That is

$$G_{Dij} = \begin{cases} -\frac{g_{ij}}{g_{ii}} & i != j \\ 0 & i = j \end{cases} \quad (11)$$

After decoupled, firstly, a foreword feedback compensation is proposed for removing out minimum phase of the model.

An equivalent system model of the actual process decoupled is expressed as

$$G_M = G_M^{+} + G_M^{-} \quad (12)$$

Where G_M^{-} denotes minimum phase part of G_M, G_M^{+} denotes Non-minimum phase part of G_M, which is zero point of at the right half-plane.

An internal model controller is expressed as

$$G_{IMC} = \frac{G_{M-}^{-1}}{(1+\alpha s)^n} \quad (13)$$

A high order filter is designed for filtering an error of actual output and model output as following.

$$T(s) = \frac{1}{(1+\alpha s)^n} \quad (14)$$

Where α is a adjustable filtering parameter, and n can be determined by simulation comparison.

Equivalent realization of PID controller for a Multivariable internal model controller is shown as Figure.4.

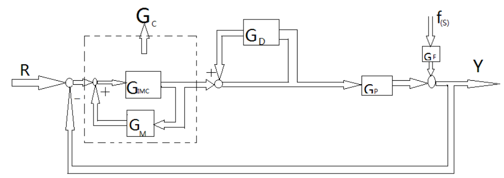

Figure. 4 A Block Diagram Of Equivalent Structures Of PID Controller For A Multivariable Internal Model Controller

Based on Fig 4,a system transfer function matrix of multivariable internal model controller is expressed as

$$G_C = \frac{G_{IMC}}{1 - G_M \bullet G_{IMC}} \quad (15)$$

Taking eq. (13) into eq. (15), a system transfer function matrix of multivariable internal model controller is expressed as

$$G_C = \frac{G_M^{-1}}{(1+\alpha s)^n - G_M} \quad (16)$$

A transfer function of an ideal-PID controller [13,14] is expressed as

$$H(s) = \frac{Y(s)}{E(s)} = K_p(1 + \frac{1}{T_I s} + T_D s) \quad (17)$$

Where K_p is a scale gain parameter, T_I is an integral time, and T_D is an differential time.

Based on an equivalent of PID controller, a system transfer function matrix is expressed as

$$G_C = K_C(1 + \frac{1}{T_I s} + T_D s) \quad (18)$$

Where taking n=1， then parameters of PID controller can be calculated as following

$$K_C = \frac{1}{K_P(\alpha + P)} \quad (19)$$

$$T_I = T_P + \frac{P^2}{2(\alpha + P)} \quad (20)$$

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$$T_D = \frac{P^2}{2(\alpha + P)}\left(1 - \frac{P}{3T_I}\right) \qquad (21)$$

4. AN EXPERIMENTAL SIMULATION OF MULTIVARIABLE DECOUPLING INTERNAL MODEL CONTROLLER

An experimental simulation is implemented based on Matlab Simulink software tool. A constitution of multivariable decoupling internal model controller is shown in Figure.5.

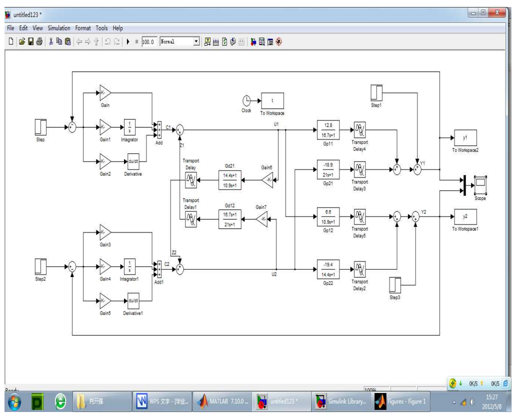

Figure. 5 A Constitution Of Multivariable Decoupling Internal Model Controller

Assumes that controlled object is

$$G_P = \begin{pmatrix} \frac{12.8e^{-s}}{16.7s+1} & \frac{-18.9e^{-3s}}{21s+1} \\ \frac{6.6e^{-7s}}{10.9s+1} & \frac{-19.4e^{-3s}}{14.4s+1} \end{pmatrix} = G_{P1} + G_{P2}$$

$$= \begin{pmatrix} \frac{12.8e^{-s}}{16.7s+1} & 0 \\ 0 & \frac{-19.4e^{-3s}}{14.4s+1} \end{pmatrix} + \begin{pmatrix} 0 & \frac{-18.9e^{-3s}}{21s+1} \\ \frac{6.6e^{-7s}}{10.9s+1} & 0 \end{pmatrix} \qquad (22)$$

A foreword feedback compensation is got

$$G_D = \begin{pmatrix} 0 & \frac{(16.7s+1)18.9e^{-2s}}{(21s+1)12.8} \\ \frac{6.6(14.4s+1)e^{-4s}}{19.4(10.9s+1)} & 0 \end{pmatrix} \qquad (23)$$

An equivalent system model of the actual process decoupled is got

$$G_M = G_{P1} = \begin{pmatrix} \frac{12.8e^{-s}}{16.7s+1} & 0 \\ 0 & \frac{-19.4e^{-3s}}{14.4s+1} \end{pmatrix} \qquad (24)$$

An inverse of equivalent system model is got

$$G_{M-}^{-1} = \begin{pmatrix} \frac{16.7s+1}{12.8} & 0 \\ 0 & \frac{14.4s+1}{-19.4} \end{pmatrix} \qquad (25)$$

Where taking n=1 , then internal model controller is expressed as

$$G_{IMC} = \begin{pmatrix} \frac{16.7S+1}{12.8(1+\alpha s)} & 0 \\ 0 & \frac{14.4s+1}{-19.4(1+\alpha_2 s)} \end{pmatrix} \qquad (26)$$

Where α is a adjustable filtering parameter, $\alpha = 3$ is got by a large number of simulation results. PID parameters are got as following table 1 shown.

Table 1 An Equivalent PID Parameters For IMC

	channel 1 $\alpha = 3$	channel 2 $\alpha = 3$
K_C	0.3286	-0.13015461
T_I	6.825	15.15
T_D	0.122524	0.700495
$\frac{K_C}{T_I}$	0.01953	-0.008591
$K_C T_D$	0.0402614	-0.0911726

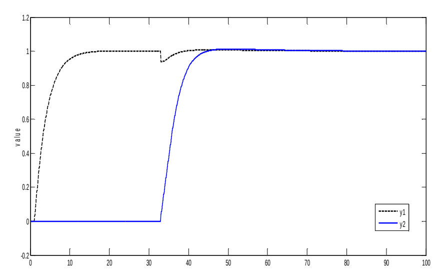

Figure.6 Dynamic Characteristics Of Multivariable Decoupling Internal Model Controller

Dynamic characteristics analysis of multivariable decoupling internal model controller system is shown Figure.6

For channel 1, input a step signal at t=0; channel 2, input a step signal at t=30. System dynamic response characteristics is shown that overshoot of the system have little, response time is very short,

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no mutual effects on outputs of channel 1 and channel 2 after decoupled .

Robustness of system is tested by way of increasing the model mismatch at model static gain 20%, increasing delay 20%, decreasing time constant 20%. System dynamic response is shown as Figure.7

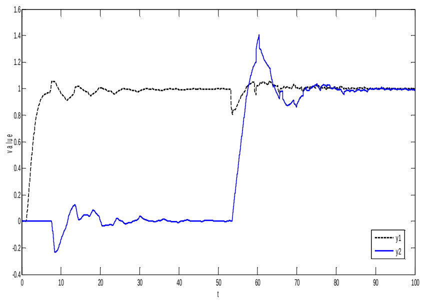

Figure.7 Dynamic Characteristics Of Multivariable Decoupling Internal Model Controller Under Model Mismatch

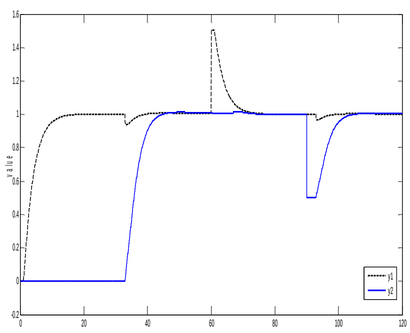

Figure.8 Dynamic Characteristics Of Multivariable Decoupling Internal Model Controller Under Signal Disturbance

System dynamic response characteristics is shown that overshoot modulation and mutual effects have little increase, but response time, errors of track and stability can meet with system robustness requirements.

An anti-interference performance is tested under conditions of delay closed-loop system. A step signal disturbance with amplitude of 0.5 is input at channel 1 and a step signal disturbance with amplitude of -0.5 is input at channel 2, step signal start at 60 and 90 seconds respectively. The model System dynamic response is shown as Figure.8

System dynamic response characteristics is shown that system output a certain extent of overshoot under step signal disturbances, but a stable output of the system is fast got and no mutual effects on outputs of channel 1 and channel 2.

5. CONCLUSIONS

This paper presents a new approach of design of multivariable decoupling internal model controller in industrial processes. A new design is proposed, a foreword feedback compensation to remove minimum phase and decoupling control is based on system transfer function matrix, a diagonal matrix decoupled can be equivalent to a system reference model. A high order low-pass filter is designed for filtering an error of actual output and model output which only adjust one parameter of the filter simply. Equivalent model part and internal model controller can be equivalent to IMC-PID controller by analytical method to simplify adjusting parameters of IMC. Good dynamic characteristics, Robustness of system and anti-interference performance show that this approach can significantly improve the designed of multivariable decoupling internal model controller.

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