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Centralized controller design using state space concept

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Abstract: This paper presents a method for finding the controller parameters for a specific case of multi input multi output (MIMO) system. The focus of this paper is to obtain a simplified centralized PID tuning procedure using Falb's row by row decoupling (RRDP) concept. Controller settings for zero order, first order and second order systems with different closed loop specifications have been obtained. Suitable examples are discussed to demonstrate the simplicity and effectiveness of the proposed method.

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Keywords: Centralised control, multivariable control system, PID controller, decoupler, state feedback.

1. INTRODUCTION

A majority of industrial processes are multivariable in nature. The presence of interaction in such processes makes the task of control system design, challenging. Control design of processes such as distillation columns, Industrial scale polymerisation reactor etc., used in process industries, have gained considerable interest to control engineers. In multivariable processes, after conducting the pairing and interaction analysis, either decentralized or centralized control strategy is adopted.

The decentralized control scheme attempts to achieve closed loop diagonal performance by using pre-compensators such as decouplers. Decoupler based decentralized control scheme is preferred due to simplicity in design. Decoupling may be done using several different techniques. If the system cannot be decoupled, then other methods such as neural networks or model predictive control should be used to characterize the system.

Decoupling or non-interactive control has attracted considerable research attention since the 1960s when control engineers started to deal with multivariable systems. Classical and state space methods are two ways to decouple the system.

The classical decouplers reported in literature can be categorized into static and dynamic types. A static decoupler consists of a gain matrix and is simple to design. However they eliminate interaction only at steady state unlike dynamic decouplers. The dynamic decouplers reported in the literature are ideal decoupler, simplified decoupler, inverted decouplers etc. All the decouplers ensure a diagonal transfer function matrix. But they have problems like realisability issues, complex structure, being sensitive to modelling errors and few of them are not applicable for RHP transmission zeros.

From literatures it is seen that the state space framework provides better results in most of the cases. State space based decoupling problem can be categorised into two, namely, triangular decoupling problem(TDP) and row by row decoupling problem(RRDP).Compared with the row-by-row decoupling problem (RRDP), the TDP requires less restrictive conditions. Row by row decoupling problem was first introduced by Morgan et al. (1964). Falb and Wolovich (1967) first obtained the necessary and sufficient condition for decoupling. The integrator decoupled system introduced by them gained wide popularity in subsequent literatures. Further, Gilbert (1969) presented the results for integrator decoupled system in a canonical form. The canonical representation of Gilbert is simple compared to Falb's approach.

A unified framework consisting of integrator decoupled system evolved from Morgan (1964) can be used to develop a control law which provides complete decoupling with satisfactory subsystem dynamics. Further the resultant control law may not able to suppress the disturbance and track the set point in the presence of model mismatch. Centralized PI/PID control is desirable for such a case.

Truong Nguyen Luan Vu, Moonyong Lee (2010) applied the concept of effective open-loop transfer function (EOTF) to decompose the complex multi-loop control systems into a number of independent SISO loops in which dynamic interaction is taken into account. Using a model reduction technique, the individual controller of each loop is then independently designed by applying the internal model control (IMC)-based PID tuning approach, using Maclaurin's expansion.

V. Vijay Kumar, V.S.R. Rao, M. Chidambaram (2012) presented two methods of designing centralized control system for MIMO processes. The first method uses Relative

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Gain array (RGA) for approximation of the inverse of the process transfer function, whereas, the second method uses effective transfer function (ETF) derived from an relative normalized gain array (RNGA) and a relative average residence time array (RARTA) .Then controllers are designed based on direct synthesis method which are further reduced into standard PI form using Maclaurin series. Xiaoli Luan, Qiang Chen, Fei Liu (2014) proposed an ETF which is derived directly by exploiting the relationship between the equivalent closed-loop transfer function and the inverse of open-loop transfer function. Based on the obtained ETF, the full matrix controller is designed utilizing the existing IMC - PI tuning rules. Lieslehto J. (1996) has presented an n × n centralized proportional–integral–derivative (PID) controller based on IMC SISO design. Jatin K Pradhan and Arun Ghosh (2015) designed MIMO PID controller using linear quadratic regulator (LQR) approach. The controller provides good performance but decoupling was not achieved.

All these methods, based on classical control theory fails to provide satisfactory results in all cases, because of the approximations used in controller tuning.

The focus of this paper is to obtain a simplified centralized controller tuning procedure. An attempt is made using Falb's row by row decoupling (RRDP) concept. The procedure provides the centralised controller settings directly, without any approximations. Controller settings for zero order, first order and second order systems with different closed loop specifications have been obtained. Suitable examples are discussed to demonstrate the simplicity and effectiveness of the proposed method.

The following three sections illustrate the proposed approach in sufficient detail. Section 2 discuss about the problem formulation. The detailed control system design procedure is discussed in section 3. The results are validated using examples in section 4.

2. PROBLEM FORMULATION

Consider the multivariable feedback control system shown in Fig.1.

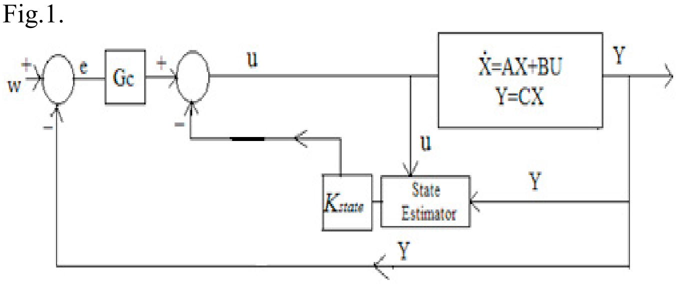

Fig.1.Proposed centralised control scheme for delay free system.

Let G be a square, n dimensional, non-singular, delay free and non RHP zero process transfer function matrix. Let G_c be a square, n dimensional, centralized controller. Let H be the desired closed loop transfer function matrix,

$$H(s)=\begin{bmatrix} H_{11}(s) & 0 & \cdots & 0 \\ 0 & H_{22}(s) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & H_{nn}(s) \end{bmatrix}$$

$H_{11}(s), H_{22}(s), \cdots, H_{nn}(s)$ is in the form of $\frac{1}{\lambda s+1}, \frac{2\lambda s+1}{(\lambda s+1)^2}$ & $\frac{\gamma s+1}{(\lambda s+1)^2}$

$$where \quad \gamma=\frac{2\lambda\tau-\lambda^2}{\tau} \tag{1}$$

The specifications recommended in IMC concept is considered as closed loop specification. The plant described by the state space model (A, B, C) with n input and n outputs is (assuming D=0)

$$\dot{x}(t)=Ax(t)+Bu(t) \\ y(t)=Cx(t) \tag{2}$$

where x ϵ R^m is the state, u ϵ R^n is the control input and y ϵ R^n is the measurement and A,B,C are real constant matrices of appropriate dimension.

The decoupling of linear multivariable system through the employment of constant gain state feedback, PD state feedback, constant gain output feedback and PD output feedback has been reported in the literature are the efficient tools.

To achieve decoupling, the following control which was originally proposed by Morgan et al. (1964) is used in most of the literatures.

$$u(t)= F\, x(t) +\Gamma\, \omega(t) \tag{3}$$

where F and Γ are real constant matrices are appropriate size. ω(t) is the set point. Falb and Wolovich (1967) gave necessary and sufficient conditions. Further, they described a class of control laws which decouples the system.

The above said control law is restated to obtain centralized PID control along with state feedback gain which is as follows,

$$u=K_{state}x+K_c e(t)+K_i\int e(t)+K_d\frac{d}{dt}e(t) \tag{4}$$

The second part of (4) is decomposed into two parts.

$$u=K_{state}x+\Gamma\Omega e$$

where Ω is the matrix which contains the values of integral and /or derivative time constants reported in SISO-IMC based PID tuning rule.

3. CONTROL SYSTEM DESIGN

The control system design consists of the following steps:

1. Using Falb's RRDP (Row by row decoupling problem) concept, find the structure of the integrator (the relative degree between numerator and denominator).
2. Once integrator structure is identified from step1, find the control law using Falb's concept. In most of the process, relative degree one is sufficient to control each loop. Hence, all the specifications

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