Design and implementation of PID controller for the decoupled two input two output control process

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***Abstract*—The paper describes the procedure to decouple TITO (two input two output) system. The objective is to reduce the complications due to loop interaction in input and output variables and convert it into FOPDT (first order plus time delay) system. Then, for decoupled system PID controller is designed independently based on gain and phase margin algorithm. The performance of system is verified using simulation results.Frequency domain analysis is done using nyquist plot.**

Index Terms—*Decoupling technique.;Gain and Phase margin;simulation;TITO system.*

I. INTRODUCTION

Many processes in industry are multi input multi output system like chemical reactors, distillation process, and heat exchanger.In MIMO system complications are more due to loop interaction that creates difficulty in designing of controller,while regulating parameters of one controller affects another in multi loop.The interaction analyser techniques includes relative gain array(RGA),singular value decomposition(SVD),IMC interaction analysis,nyquist arrays [1]. The favourable input-output pairing is determined by using RGA analysis(Bristol 1966) for efficacious control scheme.If RGA is far from unity,it is required to use decoupler.After decoupling choose the pairing which are closest to unity.The probable variables combination is analysed by SVD of process gain matrix depending upon whether only steady state decoupling is desired or dynamic decoupling is desired.These plants are also have issues like high order systems,time delays in process,poor damping factor,non-linearity and time varying dynamics.Thus,to overcome this problem several decoupling techniques have been developed to tune MIMO system to independent SISO system and then decentralised PID controllers are designed[2].

Most of the industrial control schemes are equipped with PID controllers as they are simple to design and implement.Although there are several techniques to tune PID parameters, Gain and Phase margin is always preferred for robustness and stability [19].Phase margin is related to the damping of system.The most common PID design procedure is the Ziegler-Nichols[Z-N] method introduced in 1942[3].This was based on the identification of critical gain and critical frequency of the system and using those features PID coefficients are calculated. In 1971, Niederlinksi implemented Z-N method to MIMO system. Since, MIMO system have several critical points, this procedure becomes complex and time consuming. In 1984, Astrom and Hagglund suggested automatic tuning of simple regulators with specifications on phase and amplitude margin by use of relay in identification phase for SISO system [4].In 1986, Luyben proposed BLT (biggest log modulus) method simple method for tuning SISO controllers inmultivariable system [5].In 1990, Zgorzelski proposed replacing one controller by the relay and the rest by proportional controller whose values are adjusted in each of the experiments in iterative method until the desired critical points are obtained [6]. W., Zhou, J. R., & Tay, E. B. suggested using direct Nyquist array design of PID controllers [7].

In this paper,general class of TITO system is used as an example of MIMO system.In 1996 Shinskey explored the TITO processes decoupling,its design and approach [8]. In 1987 Gawthrop designedanauto-tuner that uses a feed-forward designfor regulatordesign [9].In 1995 Palmor proposed an automatic tuningstrategy for decentralised PID control for TITO plants using multiloop auto-tuner [10]. Ho, Lee, Xu, Zhou, and Tay in 2000, recommended autotuning a decoupling controller for TITO process [11].Tavakoli et al. (2006) proposed a decentralized PI/PID controller for TITO systems based on non-dimensional analysis [12], while an ideal decoupler for the controller designbased on exhaustive search is presented by Nordfeldt andHägglund under the constraints on robustness and sensitivityto measurement noise [13].In 2012,decentralized PI/PID controllers based on gain and phase margin specifications for TITO processes implemented by D.K. Maghade, B.M. Patre.[14]

This paper has following sections: section II describes the decoupling technique of TITO to SISO system.Section III is to find the FOPDT equivalent of the derived time delayed

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decoupled transfer function. In section IV the proposed algorithm is described for finding PID parameters. In section V simulation results and Nyquist plot are shown.

II. DECOUPLING

Consider the TITO process mathematical model in matrix form as shown below

$$G(s) = \begin{pmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{pmatrix} \quad (1)$$

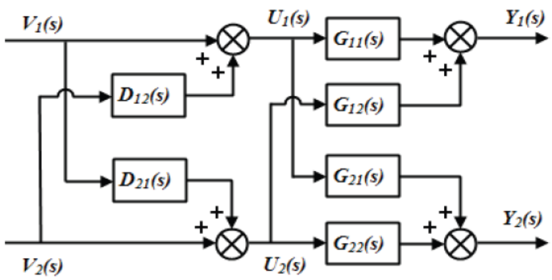

Fig.1. Decoupling representation

Consider decoupler matrix D(s) such that diagonal matrix T(s) is designed as

$$T(s) = G(s)\,D(s) \quad (2)$$

$$D(s) = \begin{pmatrix} D_{11}(s) & D_{12}(s) \\ D_{21}(s) & D_{22}(s) \end{pmatrix} \quad (3)$$

$$T(s) = \begin{pmatrix} T_1(s) & 0 \\ 0 & T_2(s) \end{pmatrix} \quad (4)$$

Fig .1 represents the TITO system design with decoupler. $V_1(s)$, V2(s) are the controller outputs, $Y_1(S)$,$Y_2(s)$ are the plant outputs.

$D_{12}(s)$ is to cancel effect of $U_2(s)$ on $Y_1(s)$

$D_{21}(s)$is to cancel effect of $U_1(s)$ on $Y_2(s)$

Thus, selecting decoupler matrix as

$$D(s) = \begin{pmatrix} 1 & \frac{-G_{12}(s)}{G_{11}(s)} \\ \frac{-G_{21}(s)}{G_{22}(s)} & 1 \end{pmatrix} \quad (5)$$

In case of time delay control process,

$$G(s) = \begin{pmatrix} g_{11}(s)e^{-\theta_{11}(s)} & g_{12}(s)e^{-\theta_{12}(s)} \\ g_{21}(s)e^{-\theta_{21}(s)} & g_{22}(s)e^{-\theta_{22}(s)} \end{pmatrix} \quad (6)$$

Thus, transfer function of decoupler matrix are derived as

$$D_{12}(s) = -\frac{g_{12}}{g_{11}} e^{-(\theta_{12}-\theta_{11})s} \quad (7)$$

$$D_{21}(s) = -\frac{g_{21}}{g_{22}} e^{-(\theta_{21}-\theta_{22})s} \quad (8)$$

The decoupler matrix D(s) will not be causal if

$$(\theta_{12} - \theta_{11}) \prec 0$$

$$(\theta_{21} - \theta_{22}) \prec 0 \quad (9)$$

Thus, decoupler cannot be realized and needs to be modified [15].If(θ_{21}-θ_{22}<0), then the first column of thedecoupler can be multiplied with a term $e^{-(\theta 21-\theta 22)}$,leads to causal$D_{21}$ without effecting decoupled system. Similarly, if (θ_{12}-θ_{11}< 0), the second column can be multiplied with $e^{-(\theta 12 - \theta 11)}$to ensure the causality of D_{12}.Using equation (1), (2), (6), the decoupled TITO system is represented by SISO system

$$T_1(s) = G_{11}(s) - \frac{G_{12}(s)G_{21}(s)}{G_{22}(s)} \quad (10)$$

$$T_2(s) = G_{22}(s) - \frac{G_{12}(s)G_{21}(s)}{G_{11}(s)} \quad (11)$$

III. FOPDT MODEL

The method to determine first order time delay model from the decoupled model is described in this section.The FOPDT model has three parameters –process gain (k_p),time constant(T), effective time delay (τ)[16].

$$H(s) = \frac{k_p e^{-\tau s}}{Ts+1} \quad (12)$$

Fitting Nyquist plots of high order and low order models at particular points was successfully used in Wang, Lee, Fung, Bi, and Zhang (1999).

Approximation of FOPDT [17] is done using following equations.

$$H(0) = I(0)$$
$$|H(jw_c)| = |I(jw_c)|$$
$$\angle\{H(jw_c)\} = \angle\{I(jw_c)\} \quad (13)$$

w_c= crossover frequency of the system is calculated using $\angle I(jw_c) = \pi$

FODPT parameters are calculated as follow

$$k_p = I(0) \quad (14)$$