RGA Based Decoupler Design for a Coupled Tank MIMO Process

C.Ravikumar, D.Sivakumar

***Abstract:** The objective of this paper is to develop the Relative Gain Array (RGA) based Decoupler design with PI Controller for a MIMO Process. The contrsoller thus developed is implemented on Laboratory interacting coupled tank process through simulation. This can be regarded as the relevant process control in petrol and chemical industries. These industries involve controlling the liquid level and the flow rate in the presence of nonlinearity and disturbance which justifies the use of PI Controller with Decoupler scheme. For this purpose, mathematical models are obtained for each of the input-output combinations using white box approach and the respective controllers are developed. A detailed analysis on the performance of the chosen process with these controllers is carried out. Simulation studies reveal the effectiveness of proposed controller for MIMO process that exhibits nonlinear behaviour.*

***Index Terms :** Interacting coupled tank system, Decoupler, RGA, PI controller, MIMO.*

I. INTRODUCTION

In process industries, the controls of liquid level in multiple tanks and flow between the tanks are basic problems. The process involves liquid to be pumped and deposited in the containers and later pumps it to different reservoir. The two tanks are connected in interacting manner so that the coupling will control the levels of the tank.

Most popular approach for industrial process control is classical Proportional Integral (PI) controller. In 1989, Japan electric Measuring Instruments Manufacturers Association conducted a survey [1] and concluded PID type control loops are used 90 percent in industries. Also survey by ender specified that manual mode is applied for 30 percent of the controller functions and 20 percent of the loops utilize factory tuning. It concludes that PID controller is used generally but tuned poorly. The poor tuning of controllers lead to mechanical wear related with unnecessary control activity, poor performance and outcome of poor quality products. Though, PID controller parameters tuning is a challenging task.

Furthermore different methods are proposed by researchers for tuning of PID controller parameters, which include Neural Network and Fuzzy Logic Control (FLC) [2], methods based on conventional Ziegler-Nichols (ZN) tuning method [3-5], Genetic Algorithm (GA) [7], Internal Model Control (IMC) [8-9], etc. The conventional ZN parameter tuning method is only applicable for stable systems of PID controller design. Therefore under transient conditions these parameters may not provide satisfactory performance. Classification and function approximation problems having lots of training data are tolerant of some imprecision, which use neural network based methods. These tuning methods are less robust under momentary disturbances.

The analysis of the interaction loops between the controlled variable (liquid level) and manipulated variable (input flow) was determined in this paper by implementing the relative gain array. This method specifies the coupling of input to output with least interface. Besides decoupling method is used to avoid the interaction effect thereby designing suitable decouplers for the system.[8] In the decoupling method, the liquid level of tank 1 is constant when the inlet flow of tank 2 changes and to keep the liquid level of tank 2 constant the inlet flow of tank 1 must be changed.

The paper is structured as follows: The interacting coupled tank process laboratory setup chosen for the study is explained first. Next, the procedure involved in developing decoupler design using RGA and PI Controller with decoupler is presented. In the third section simulation results on interacting coupled tank is given and a comparison study is made for closed loop PID controller response using with and without Decoupler. The final section concludes our approach of PID controller with Decoupler for MIMO process.

II. PROCESS DESCRIPTION

The block diagram of coupled tank liquid level system in interacting manner is shown in Fig 1.

Equations 1 and 2 represent the mass balance equations of tank1 and tank2. The total flow of liquid to tank1 is equal to the rate of change of liquid volume in each tank. q_{in1} and q_{in2} are the volumetric input to the tank1 and tank2. q_{01} and q_{02} are the volumetric flow rate from the tank1 and tank2. q_{12} is the flow rate between tank1 and tank2. $h1$ is the height of the liquid level in tank1 and h_2 in tank2.

Revised Manuscript Received on July 05, 2019

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$$A_1\frac{dh_1}{dt}=q_{in1}-q_{o1}-q_{12} \qquad (1)$$

$$A_2\frac{dh_2}{dt}=q_{in2}-q_{o2}+q_{12} \qquad (2)$$

Prototype of the coupled tank process is expressed using Bernoulli's equation are given in equations 3 and 4.

$$\frac{dh_1}{dt}=\frac{q_{in1}}{A_1}-\frac{a_1}{A_1}\sqrt{2gh_1}-\frac{a_{12}}{A_1}\sqrt{2g(h_1-h_2)} \qquad (3)$$

$$\frac{dh_2}{dt}=\frac{q_{in2}}{A_2}-\frac{a_2}{A_2}\sqrt{2gh_2}+\frac{a_{12}}{A_1}\sqrt{2g(h_1-h_2)} \qquad (4)$$

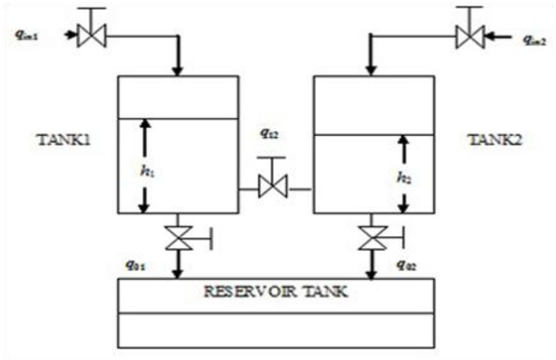

Fig. 1. Block diagram of liquid level process

A_1=A_2=1130.4cm^2 are the cross section area of tank1 and tank2, a_1=a_2= 3.9cm^2 are the control areas in the outlet pipes of tank1 and tank2. a_{12}=1.27cm^2 is the restriction area of interconnecting pipe. The full capacity of two tanks is 25cm. The control structure is designed and the characteristic equations are linearized by considering less changes in q_{in1}, q_{in2}, h_1 and h_2 [3].

The changes are considered with respect to minor operating conditions. The levels in both the tanks are brought to nominal condition initially by adjusting the hand valves. Nominal values of q_{in1}, q_{in2} are 26 and 20.75 litres per hour and for h_1 and h_2 are 12.5 and 12.1 cm respectively.

Rearranging equations (3) & (4) and then taking laplace transform on both sides, we get

$$h_1(s)=\frac{R_1}{\tau_1 s+1}\left[q_{in1}(s)-q_{12}(s)\right]$$
$$h_2(s)=\frac{R_2}{\tau_2 s+1}\left[q_{in2}(s)+q_{12}(s)\right] \qquad (5)$$

I. Multiloop Process

The two controlled outputs h_1 and h_2 with two manipulated inputs q_{in1} and q_{in2} are the four models which are crucial for multiloop controller strategy [5]. Equation 6 represents the perfect transfer function with flow rate as input and liquid level as output.

$$G_{11}(s)=\left(\frac{h_1}{q_{in1}}\right)_{q_{in2}};\quad G_{21}(s)=\left(\frac{h_2}{q_{in1}}\right)_{q_{in2}};$$
$$G_{12}(s)=\left(\frac{h_1}{q_{in2}}\right)_{q_{in1}};\quad G_{22}(s)=\left(\frac{h_2}{q_{in2}}\right)_{q_{in1}} \qquad (6)$$

The Transfer functions are formulated and represented in matrix form as follows:

$$G=\begin{bmatrix}G_{11} & G_{12}\\ G_{21} & G_{22}\end{bmatrix}=\begin{bmatrix}\frac{0.737}{61s+1} & \frac{0.583}{111s+1}\\ \frac{0.443}{106s+1} & \frac{0.633}{81s+1}\end{bmatrix} \qquad (7)$$

Fig. 2 represents the Multiloop interacting coupled tank process employed with G_{c1} and G_{c2} as PI controllers for tank1 and tank2.

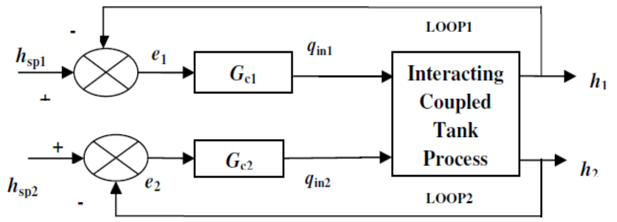

Fig. 2. Multiloop PI control system

A. Synthesis Method of Tuning

Synthesis method is implemented for controller parameter tuning. For the two first order processes G_{11} and G_{22} obtained from modeling. K_c and T_i represents proportional gain and integral time respectively. K_i denotes integral gain. τ_c is closed loop time constant of the process. Controller parameters are determined and tabulated in Table I.

Table I. Controller Parameters for PI Controller

Parameters	Controller	
	G_{c1}	G_{c2}
$K_c=\frac{\tau_p}{k_p\tau_c}$	2.357	2.579
$K_i=\frac{K_c}{T_i}$	0.038	0.032

III. DECOUPLER DESIGN USING RGA

The relative gain array can be defined as

$$\text{RGA},\Lambda=\begin{bmatrix}\lambda_{11} & \lambda_{12}\\ \lambda_{21} & \lambda_{22}\end{bmatrix} \qquad (8)$$

where

$$\lambda_{ij}=\frac{open\ loop\ gain\ between\ y_i and\ m_j}{closed\ loop\ gain\ between\ y_i and\ m_j}$$

For linearized steady-state model,

$$\overline{y_1}=G_{11}\overline{m_1}+G_{12}\overline{m_2}$$
$$\overline{y_2}=G_{21}\overline{m_1}+G_{22}\overline{m_2} \qquad (9)$$

Using equation (7),

Step1: If $\overline{m_1}=\frac{1}{s}$ and $\overline{m2}$=0 then

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$$\overline{y_1} = \frac{0.737}{61s+1}\cdot\frac{1}{s}$$

$\Delta y_1 = \lim_{s\to 0} s\overline{y_1} = 0.737$

$$\left(\frac{\Delta y_1}{\Delta m_1}\right)_{m_2} = \frac{0.737}{1} = 0.737 \qquad (10)$$

Step 2: Let us consider $\overline{y_2} = 0$ by varying m_2, and find the value of $\overline{m2}$.

$$\overline{m_2} = -\frac{0.443}{106s+1}\cdot\frac{81s+1}{0.633}\overline{m_1} \qquad (11)$$

Substitute $\overline{m2}$ values in $\overline{y_1}$ and then put $\overline{m_1} = \frac{1}{s}$

$$\overline{y_1} = \frac{1}{s}\left[\frac{0.737}{61s+1} - \left(\frac{0.583}{111s+1}\cdot\frac{0.443}{106s+1}\cdot\frac{81s+1}{0.633}\right)\right]$$

$\Delta y_1 = \lim_{s\to 0} s\overline{y_1} = 0.332$

$$\left(\frac{\Delta y_1}{\Delta m_1}\right)_{y_2} = \frac{0.332}{1} = 0.332 \qquad (12)$$

$$\lambda_{11} = \frac{\left(\frac{\Delta y_1}{\Delta m_1}\right)_{m_2}}{\left(\frac{\Delta y_1}{\Delta m_1}\right)_{y_2}} = \frac{0.737}{0.332} = 2.33$$

$\boldsymbol{\lambda}_{12} = 1 - \boldsymbol{\lambda}_{11} = -1.33$

$\boldsymbol{\lambda}_{12} = \boldsymbol{\lambda}_{21} = -1.33$

$\boldsymbol{\lambda}_{22} = 1 - \boldsymbol{\lambda}_{21} = 2.33$

Substitute $\boldsymbol{\lambda}$ values in equation (8), we get

$$\text{RGA},\Lambda = \begin{bmatrix} 2.33 & -1.33 \\ -1.33 & 2.33 \end{bmatrix} \qquad (13)$$

The important issue in MIMO process is the problem with control-loop interaction. When one manipulated input affects more than one controlled output, results in interaction. Decoupling is one of the approaches to handling this problem. Fig. 3 shows a simplified decoupling for a multivariable process.

Here the decoupling matrix is restricted with D11(s) = D22(s) =1 to the form

$$D(s) = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \qquad (14)$$

The structure of decoupler and its response is shown Equation (15)

$$Gp(s)D(s) = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix}\begin{bmatrix} 1 & D_{12} \\ D_{21} & 1 \end{bmatrix} \qquad (15)$$

$$Gp(s)D(s) = \begin{bmatrix} G_{11} & 0 \\ 0 & G_{22} \end{bmatrix} \qquad (16)$$

The solution for unknown are determined.

$$D_{12} = -\frac{G_{12}}{G_{11}} \text{ and } D_{21} = -\frac{G_{21}}{G_{22}} \qquad (17)$$

The control loop interaction is minimized by the effect of feed forward the synthetic inputs.

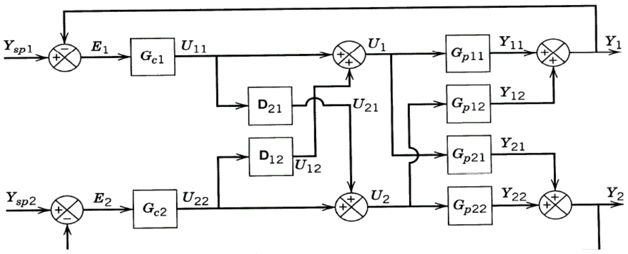

Fig. 3. Block diagram of MIMO PI controller with decoupler

IV. SIMULATION RESULTS

Fig 5(a), 5(b), 5(c) show the servo and regulatory responses of PI Controller without Decoupler.

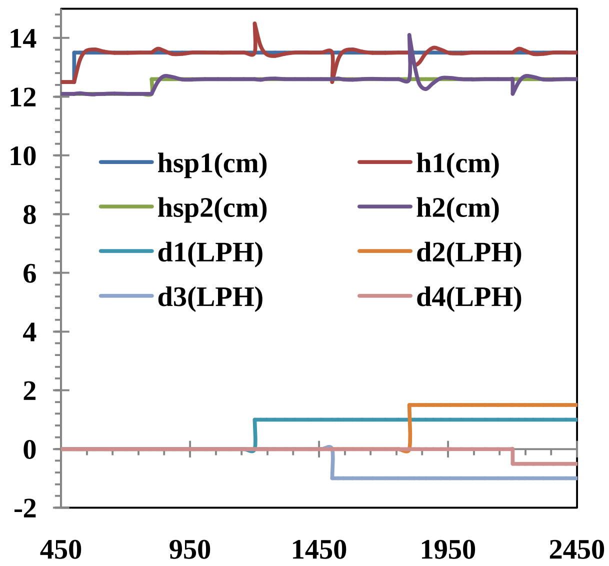

Fig.5(a) Serv oand Regulatory Response of PI Controller without D

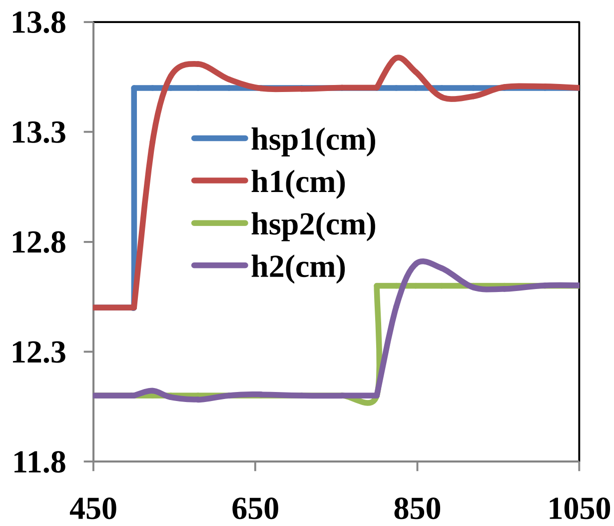

Fig. 5(b) Servo Response of PI Controller without D

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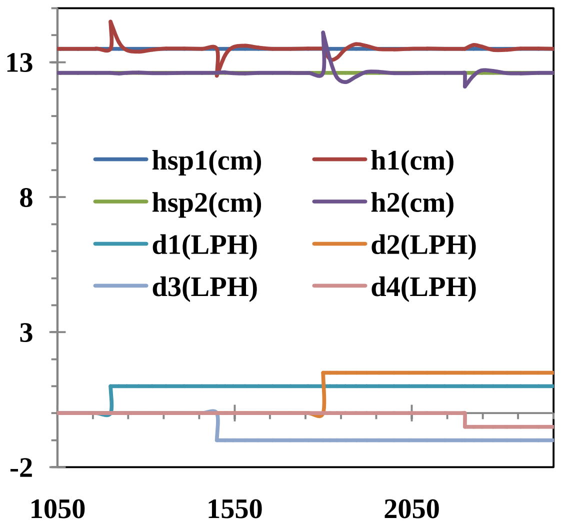

Fig. 5(c) Regulatory Response of PI Controller without D

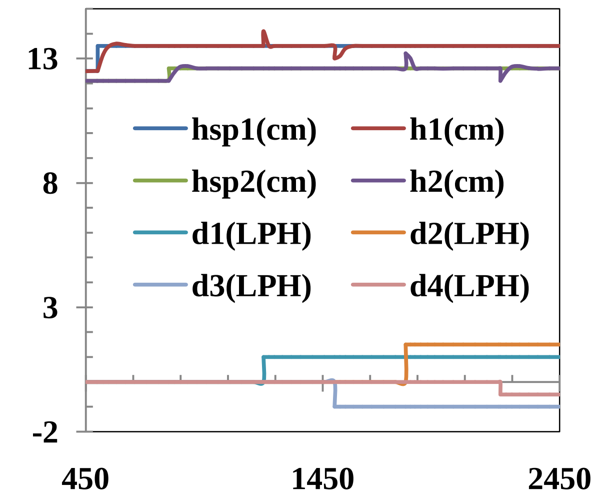

Fig. 6(a) Servo and Regulatory Response of PI controller with D

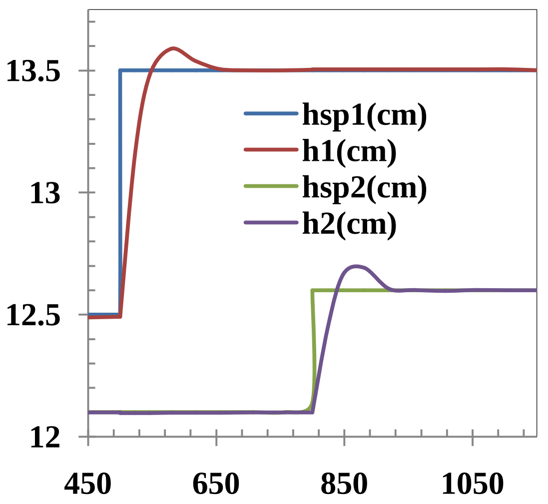

Fig. 6(b) Servo Response of PI controller with D

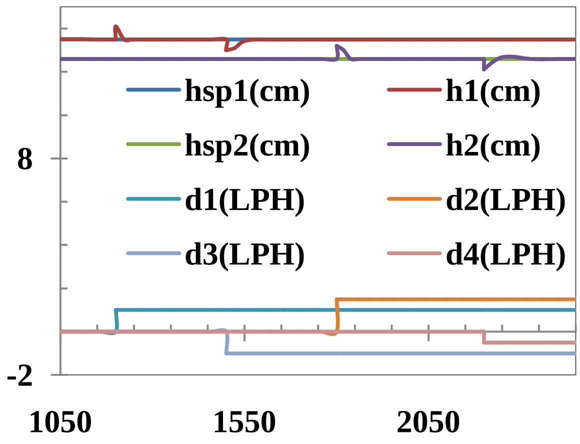

Fig. 6(c) Regulatory Response of PI Controller with D

V. CONCLUSION

The performance of coupled tank MIMO process has been investigated using RGA based PI controller with decoupler design. Interaction effects are projected for both servo tracking and load disturbance rejection. From the plots, it is clear that the overall system performance with PI with D is observed to have no interaction occurs than that of the system with PI controller. The resulting performance could be improved by a better choice of the tuning parameters. This concludes that the PI controller with decoupler design using RGA is applicable for nonlinear coupled tank systems.

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