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De-Coupler Design for an Interacting Tanks System

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Abstract: *The dynamic behavior of two interacting system was studied by the introduction of a step change in inlet flow rate and with the development of the suitable mathematical model of this interacting system. This paper describes how the effect of the interaction of this interacting system is eliminated by the design of the suitable de-coupler for the system. This paper also includes the analysis of the interacting loops between the controlled variable that is liquid level and manipulated variable that is inlet flow rate by the help of relative gain array. The result exemplifies that the gain of each loop is reduced approximately half when the opposite loop is closed and the gain of other loop changes the sign when the opposite loop is closed. Thus the de-coupling method illustrate that it is one of the suitable method for the reduction of the interaction in the tanks system.*
Keywords: *interacting system, interacting loops, controlled variable, manipulated variable, relative gain array, de-coupler.*

I. Introduction

In most of the chemical industries the control of flow rate and the liquid levels in the tanks are two basic and major problems. Most of the time mixing treatment or the chemical operations are to be taken out in the tanks, but always the level of liquid in tanks must be controlled with the continuous regulation of flow rate between tanks. Thus we need to design the elements in such a way that the control over the variables will become easy.

Most industrial process control application involved a number of input and output variables which are often referred as MIMO system. The important examples of MIMO system includes heat exchangers, chemical reactors and distillation columns. It is more difficult to perform an operations on MIMO system than in SISO system. It is because of the interaction between the input and output variables.

The term interaction is often referred as Loading. The process is called as interacting if each input affects more than one output or a change in the output affects the other outputs, otherwise the process is called non interacting.

While designing two strongly interacting loops, we have to introduce the new element called ***Decoupler*** in the control system. The purpose of decoupler is to cancel the interaction effects between two loops and thus render two non interacting control loops. In another words, the main aim of the decoupling control system is to eliminate complicated loop interactions so that a change in one process variable will not cause corresponding changes in the other process variables.

RGA- Since its proposal by Bristol(1966), the relative gain technique has not only become a valuable tool for the selection of manipulated controlled variable pairings, but also used to predict the behavior of control responses. To fully appreciate the concepts of relative gain, the RGA will be constructed for a system represented by p-canonical structure. The RGA method indicated how the input should be coupled with the output to form loops with minimal interaction. A process with any controlled outputs and N manipulated variables, there are N! different ways to form the controlled loops. The RGA provides exactly such a methodology, whereby we select pairs of input and output variables in order to minimize the amount of interaction among the resulting loops.

In this paper, the dynamic behavior of an interacting two tanks system was studied both theoretically and experimentally. RGA is used as an interaction measurement and decoupling to design the loops.

II. Theory/Literature Survey

2.1 Notations and Standards

A_1 : Cross sectional area of tank 1, m^2
= 11.3097×10^{-3} m^2
A_2 : Cross sectional area of tank 2, m^2
= 11.3097×10^{-3} m^2
F : Volumetric flow rate, m^3/sec
R_1: Flow resistance in valve 1
= 10800 sec/m^2

R_2 : Flow resistance in valve 2
= 10800 sec/m^2
τ_1 : Time constant of tank 1
= 180 sec
τ_2 : Time constant of tank
= 95 sec
μ : Relative gain array

2.2 mathematical model

The important assumptions for the derivation of the mathematical model for the interacting two tanks system are:-

- The flow resistance is linear with the linear liquid level in the tanks.
- The tanks are of equal and uniform cross sectional area.
- The density of water remains constant which means that it is independent of time.

The interacting two tanks system is shown in the figure below.

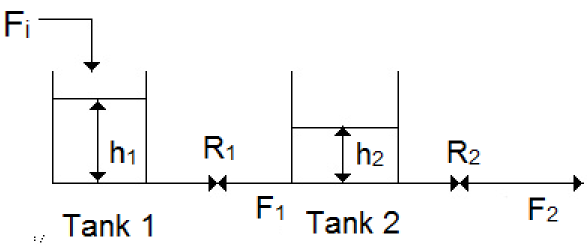

Fig1:-Interacting tanks system.

Applying the material balance in both of the tanks we get,
Accumulation = Mass flow in - Mass flow out   For 1st tank

$$A_1\frac{dh_1}{dt} = F_i - F_1 - - - - - - - - (i)$$

For 2nd tank

$$A_2\frac{dh_2}{dt} = F_1 - F_2 - - - - - - - - (ii)$$

By using assumptions,

$$F_1 = \frac{(h_1 - h_2)}{R_1} \quad \text{and} \quad F_2 = \frac{h_2}{R_2}$$

then equations (i) and (ii) become,

$$A_1R_1\frac{dh_1}{dt} + h_1 - h_2 = R_1F_1 - - - - - (iii)$$

$$A_2R_2\frac{dh_2}{dt} + \left(1 + \frac{R_2}{R_1}\right)h_2 - \frac{R_2}{R_1}h_1 = 0 - -(iv)$$

$$h_{1,s} - h_{2,s} = R_1F_{i,s} - - - -(V)$$

$$(1 + \frac{R_2}{R_1})h_{2,s} - \frac{R_2}{R_1}h_{1,s} = 0 - - - - - (vi)$$

then steady state equivalents of equations (iii) and (iv) are subtracting equation (v) from (iii) and (vi) from (v) and then introducing deviation variables we get,

$$A_1R_1\frac{dh'_1}{dt} + h'_1 - h'_2 = R_1F'_i - - - -(vii)$$

$$A_2R_2\frac{dh'_2}{dt} + \left(1 + \frac{R_2}{R_1}\right)h'_2 - \frac{R_2}{R_1}h'_1 = 0 .. (viii)$$

where,

$$h'_1 = h_1 - h_{1,s}$$
$$h'_2 = h_2 - h_{2,s}$$
$$F'_i = F_i - F_{i,s}$$

taking the Laplace transform of equations (vii) and (viii) and find

$$\bar{h}'_1(s) = \frac{(\tau_{p2}R_1)s + (R_1 + R_2)}{\tau_{p1}\tau_{p2}s^2 + (\tau_{p1} + \tau_{p2} + A_1R_2)s + 1}\bar{F}'_i(s) - - - - - - - - - - -(viii)$$

and,

$$\bar{h}'_2(s) = \frac{R_2}{\tau_{p1}\tau_{p2}s^2 + (\tau_{p1} + \tau_{p2} + A_1R_2)s + 1}\bar{F}'_i(s) - - - - - - - - - - - - -(ix)$$

2.3 Loop interaction

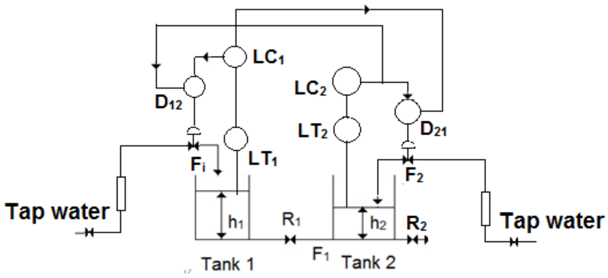

Fig2:-Interacting two tanks system

Let us consider a two tanks interacting system as shown in figure 2 having two manipulated variables F_i and F_2. Now we need to find the gain of each manipulated variable on each of the controlled variable. The four open loop system is shown in the figure 3 below

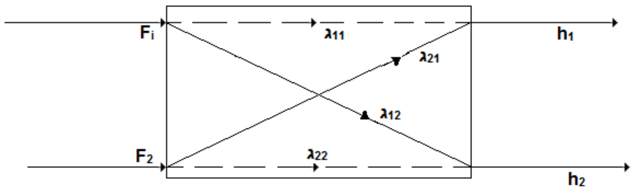

Fig3:- Schematic of interaction for controlled variable and manipulated variable

and given as

$$\lambda_{11} = [\frac{\Delta h_1}{\Delta F_i}]_{F_2} \quad \lambda_{12} = [\frac{\Delta h_1}{\Delta F_2}]_{F_i} - - - -(X)$$

$$\lambda_{21} = [\frac{\Delta h_2}{\Delta F_i}]_{F_2} \quad \lambda_{22} = [\frac{\Delta h_2}{\Delta F_2}]_{F_i} - - - (xi)$$

where,

λ_{ij} is the gain of ith controlled variable relating to the jth manipulated variable. The RGA provides exactly such a methodology whereby we select pairs of input and output variables in order to minimize the amount of interaction along the resulting loops. the major advantage of RGA is that it requires only the steady state process parameters that is steady state gains. Thus

$$\Delta h_1 = \lambda_{11}\Delta F_i + \lambda_{12}\Delta F_2 - - - - - (xii)$$

$$\Delta h_2 = \lambda_{21}\Delta F_i + \lambda_{22}\Delta F_2 - - - - - (xiii)$$

Now we need to introduce feedback system which connects F_2 with h_2, in order to determine the gain which connects F_i with h_i. According to figure 3, we get four closed steady state loops and hence four steady state gains is to be calculated from the four open loop gains. Thus the resulting formulae are:-

$$\bar{\lambda}_{11} = \frac{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}{\lambda_{22}}, \quad \bar{\lambda}_{12} = \frac{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}{-\lambda_{21}}$$

$$\bar{\lambda}_{21} = \frac{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}{-\lambda_{12}}, \quad \bar{\lambda}_{22} = \frac{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}{\lambda_{11}}$$

-------------------------(xiv)

According to the definition,

$$\mu_{ij} = \frac{\lambda_{ij}}{\bar{\lambda}_{ij}} - - - - - - (xv)$$

Thus,

$$\mu_{11} = \frac{\lambda_{11}\lambda_{22}}{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}, \quad \mu_{12} = \frac{-\lambda_{12}\lambda_{21}}{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}$$

$$\mu_{21} = \frac{-\lambda_{12}\lambda_{21}}{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}, \quad \mu_{22} = \frac{\lambda_{11}\lambda_{22}}{\lambda_{11}\lambda_{22} - \lambda_{12}\lambda_{21}}$$

--------------------------(xvi)

2.4 decoupling of interacting loops

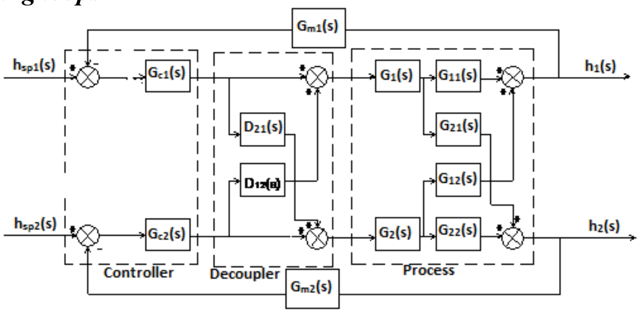

Fig 4:- block diagram of interacting tanks system with decoupler.

Now our main intention is to reduce or eliminate the interaction between the loops through the suitable design element what is called the Decoupler. Decoupling does change to each loop what the other loops were going to do anyway, this is one of the important characteristic of decouplers. In order to reduce this interaction between two tanks, two decoupler blocks having transfer functions $D_{12}(s)$ and $D_{21}(s)$ are installed in the system where decoupler $D_{12}(s)$ cancels the effect of manipulated variable $F_2(s)$ on controlled variable $h_1(s)$ and D_{21}9s) cancels the effect of manipulated variable $F_i(s)$ on controlled variable $h_2(s)$. Thus we get the design formulae for the decouplers are:-

$$D_{12}(s) = -\frac{G_2(s)G_{12}(s)}{G_1(s)G_{11}(s)} ----(\text{xvii})$$

$$D_{21}(s) = -\frac{G_1(s)G_{21}(s)}{G_2(s)G_{22}(s)} ----(\text{xviii})$$

III. Materials And Methods

3.1 experimental work

3.1.1 Description of Equipment

- Interacting two tanks - The interacting two tanks consists of two vessels arranging cascade having each of diameter 12×10^{-2} m, and hence the area 11.3097×10^{-3} m^2 respectively. Small narrow pipe with valve is connected between the two tanks.
- Water is supplied through stainless steel float rotameter having range 20-60 LPH with temperature condition of water at 27^0 C. The Rotameter has maximum capacity of 100 LPH.
- The control system consist of PID controller, control valve and pressure transmitter.

3.1.2 Experimental procedure

The inlet streams were given to the tanks and the valve in the inlet streams were adjusted to provide a suitable reading on the rotameter. After sometimes the liquid levels in two tanks are in steady state and system was left for stabilization. Then the following step were performed:-

- The inlet flow rate of the tank 1(F_i) was stepped up from 50 LPH to 60 LPH with constant inlet flow rate of tank 2(F_2) at 30 LPH by using the valve and the liquid levels in both tanks were recorded with respect to time.
- The inlet flow rate of the tank 2(F_2) was stepped up from 30 LPH to 40 LPH with constant inlet flow rate of tank 1(F_i) at 50 LPH by using the valve and the liquid levels in both tanks were recorded with respect to time.
- The inlet flow rate of the tank 1(F_i) was stepped down from 50 LPH to 40 LPH with constant inlet flow rate of tank 2(F_2) at 30 LPH by using the valve and the liquid levels in both tanks were recorded with respect to time.
- The inlet flow rate of the tank 2(F_2) was stepped down from 30 LPH to 20 LPH with constant inlet flow rate of tank 1(F_i) at 50 LPH by using the valve and the liquid levels in both tanks were recorded with respect to time.

IV. Result And Discussion

Relative gain array μ_{ij} is calculated from both experimental and theoretical final steady state condition with a step change in inlet flow rate of the two tanks and are found to be

$$\mu_{\text{theoretical}} = \begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}$$

$$\mu_{\text{experimental}} = \begin{bmatrix} 1.79 & -0.79 \\ -0.77 & 1.79 \end{bmatrix}$$

The theoretical relative gain $\mu_{11} = \mu_{22} = 2 = \frac{1}{0.5}$. It means the gain of each loop is cut in half when the other closed. Similarly the relative gain $\mu_{12} = \mu_{21} = -1 = \frac{1}{-1}$ indicates that the gain loop changes sign when the other loop is closed. Obviously last condition was undesirable. it is because of the fact that the action of the controller depends on the, whether the loop is opened or closed.
Now our main intention is to design the decoupler which is given by the equations (xvii) and (xviii). Thus we get,

$$D_{12} = \frac{-0.5}{180s+1} \qquad D_{21} = \frac{2}{95s+1}$$

Thus we can say that both the decouplers are simple gains. Decoupler $D_{12}(s)$ has a negative gain because its main intention is to keep the liquid level of tank $1(h_1)$, when the second inlet stream(F_2) changes. Similarly, Decoupler $D_{21}(s)$ has a positive gain because its main intention is to keep the liquid level of tank $2(h_2)$, when the first inlet stream(F_i) changes.

V. Conclusions

Thus from the above experiments, the following conclusions can be drawn:-

- The decoupler lessen the interaction of two interacting tanks system and the decoupler has same effect as it has before.
- Since the relative gain is $\mu_{11} = \mu_{22} = 2 = \frac{1}{0.5}$. It means that when the loop 1 is closed, the gain of loop 2 is cut into half.
- Since the relative gain is $\mu_{12} = \mu_{21} = -1 = \frac{1}{-1}$, it means that the action of controller depends on either the loop is open or close and it is undesirable one.

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References

[1] TrielWeiler J.O.," Application of The Robust Performance Number for Quantification of the Operability of the Quadruple-Tank Process", Brazilian Journal of Chemical Engineering, Vol. 19, Page No. 195-206.
[2] Zumberge J., Passino, K.M.," *A case study in Intelligent vs. Conventional Control for a process controlExperiment*", Journal of control Engineering practice, Vol. 6, No. 9, Page No. 1055-1075,1998.
[3] Esche S.K.," Tank Filling Of Liquid Level System", Stevens Institute of Technology, 2001,
[4] Stephanopoulos G.," *Chemical Process Control*", An Introduction to Theory and Practice", Prentice-Hall India, Inc.,1984, Page No. 487-508.
[5] Coughanowr R. Donald," *Process Systems Analysis and Control*" McGraw-Hill International Editions,Inc. 1965 Chemical Engineering Series, Page No. 82-86.
[6] Luyben L. William," *Process Modeling, Simulation, and Control for Chemical Engineers*", McGraw-HillInternational Editions1996,page No. 573-584.
[7] Edgar T. F. & Rueda L.," *Process Dynamic and Control Laboratory Experiments Carried Out OverThe Internet*", University of Texas, 2003.
[8] Ibrahim D.," *Microcontroller Based Applied Digital Control*", John Wiley & Son Ltd.,PageNo. 269-282, 2006.
[9] Henry J. & Nuttal E.," *Chemical Engineering Experimentation over the Internet*", AICHE/Labs, 2004.
[10] Douglas O. J., Desa," *Applied Technology and instrumentation for Process Control*", Taylor & Francis Books Inc., Page No, 71-75, 2005.
[11] E. P. Gatzke, E. S. Meadows, C. Wang, and F. J. Doyle," Model based control of a four tank system", Computer and Chemical Engineering, Vol. 24, Page No. 1503-1509, 2000.