STUDY OF INTERACTING AND NON-INTERACTING WITH DISTURBANCE AND PID CONTROLLER DESIGN

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Abstract- A multi tank level control system includes both the example of interacting and non-interacting system. The main objective of this paper is to determine the mathematical model of interacting and non-interacting tank with disturbance and also design of PID controller. Based on procedure of mathematical modelling for tanks in interacting and non-interacting mode this paper is an extensive comparative experimental study liquid level controls.

Keywords: Interacting systems, non-interacting systems and PID controller.

I. INTRODUCTION

The first stage is in the development of any control and monitoring system is the identification of the system and mathematical modelling of the system. The present work is on the mathematical model for interacting and non-interacting tank process with disturbances. Disturbance is applied to second tank in each case (interacting and non-interacting tank [2]-[8].

Noninteracting Tank System: In Non-Interacting Tank system it consist of two tank as shown in the labview simulation diagram Fig.1. The pump supply the water flow, which is controlled by the pneumatic control valve having valve constant K. The output flow of the valve can be divided in to two part by the three way valve. The three way valve position can be determine by the constant γ. The (1- γ) portion of flow used as a disturbance to the lower tank and γ portion of flow to the upper tank. By using feedback control system we control the liquid level of the lower tank [7]-[5]-[2].

Interacting Tank System: Consider an interacting tank process, with one input and one output shown in the labview simulation diagram Fig.2. The objective is to control the water level of tank 2 i.e. h_2 with inlet water flow Q_{in}. Here Q_2 assumed as a disturbance variable. The Pump generate water flow, this flow rate can be controlled by the pneumatic control valve having gain K [6]-[3]. The output flow of the control valve be split in to two part by the three way control valve. The tank 1 flow rate can be $Q_1= K\gamma Q_{in}$ and tank 2 flow can be $Q_1= k(1-\gamma) Q_{in}$. The control objective is to maintain a level in tank2 by the varying inflow rate of tank1 in presence of disturbance flow to tank2 [1].

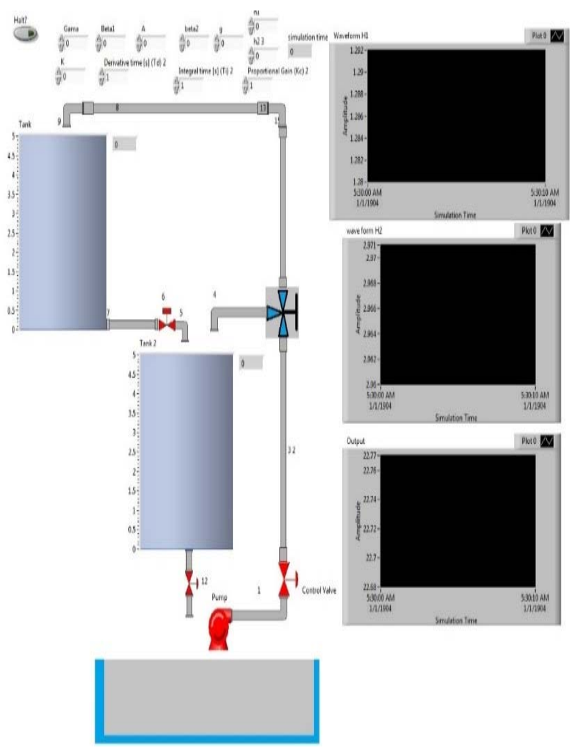

Fig.1

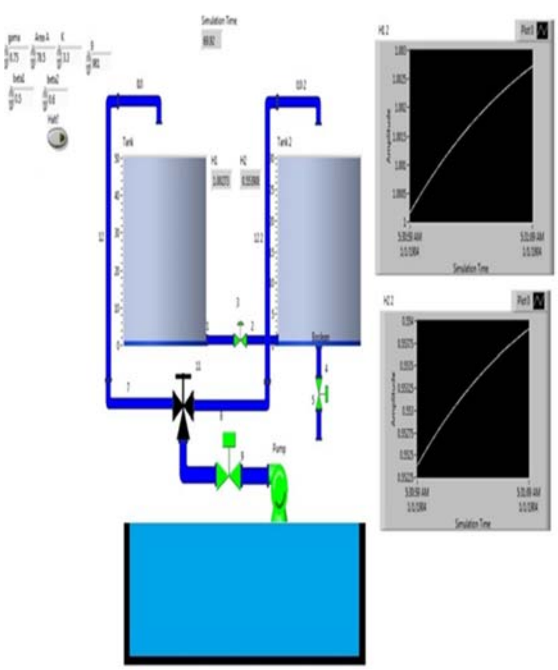

Fig.2

II. MATHEMATICAL MODELLING OF THE SYSTEM

The System Specification for both interacting and non-interacting tank is given in the table 1.

System Parameter	Non-Interacting Tank system (CGS unit)	Interacting Tank system (CGS unit)
Cross sectional area of tanks A(cm^2)	78.5 cm^2	78.5 cm^2
Outlet port cross sectional area (a cm^2)	1 cm^2	1 cm^2
Pneumatic Control valve constant(K cm^3/sec/bar)	3.2(cm^3/s/ Bar)	3.3(cm^3/sec/ Bar)
Ball Valve Coefficient	β_1=0.6, β_2=0.5	β_1=0.5, β_2=0.6
Three way valve coefficient	γ= 0.79	0.75
Pump Flow rate	138.89 cm^3/s (500lph)	138.89cm^3/s (500 lph)
Total height of the Tanks	10 cm	10 cm

Table 1

a. Mathematical Modelling of Non interacting Tank System:

Flow through control valve Q_{in}= KρgH cm^3/sec
Where,

K=Valve Constant (cm^3/s/Bar)
ρ= Density of water (gm/cm^3) =1 gm/cm^3
g= acceleration due to gravity (cm/sce^2)
H= Height of the liquid (cm)

Using mass balance equation we found the differential equations for the system

Tank 1

$$A\frac{dh_1}{dt} = KQ_{in}\gamma - \beta_1 a\sqrt{2gh_1}$$

Tank 2

$$A\frac{dh_2}{dt} = KQ_{in}(1\text{-}\gamma) + \beta_1 a\sqrt{2gh_1} - \beta_2 a\sqrt{2gh_2}$$

The system can be linearized around the operating point, The relation between steady state flow rate and height can be determine as;

$$\bar{h}_1 = \frac{(K\,Q'_{in}\,\gamma)^2}{\beta_1^2 a^2\, 2g} \quad \text{and} \quad \bar{h}_2 = \frac{(K\,Q'_{in})^2}{\beta_2^2 a^2\, 2g}$$

$\bar{h}_1$ = Steady State height of the Tank 1 and

$\bar{h}_2$ = Steady state height of the Tank 2

Q'_{in} = Steady state flow rate.

If Q'_{in} =10 lph then we obtain the calculated

$\bar{h}_1$ = 0.9048 cm and $\bar{h}_2$ =2.087 cm

The linearized differential Equations of the system

$$\frac{dh_1}{dt} = \{KQ_{in}\gamma - \frac{\beta_1 a\sqrt{2g}}{2\sqrt{\bar{h}_1}} h_1\}\ \frac{1}{A}$$

$$\frac{dh_2}{dt} = \{KQ_{in}(1\text{-}\gamma) + \frac{\beta_1 a\sqrt{2g}}{2\sqrt{\bar{h}_1}} h_1 - \frac{\beta_2 a\sqrt{2g}}{2\sqrt{\bar{h}_2}} h_2\}$$

$$\frac{1}{A}$$

Now the State space representation of the system

$$\begin{bmatrix} \bar{h}_1 \\ \bar{h}_2 \end{bmatrix} = \begin{bmatrix} -\left(\frac{\beta_1 a\sqrt{2g}}{2A\sqrt{\bar{h}_1}}\right) & 0 \\ \left(\frac{\beta_1 a\sqrt{2g}}{2A\sqrt{\bar{h}_1}}\right) & -\left(\frac{\beta_2 a\sqrt{2g}}{2A\sqrt{\bar{h}_2}}\right) \end{bmatrix} \begin{bmatrix} h_1(t) \\ h_2(t) \end{bmatrix}$$

$$+\begin{bmatrix} \frac{K\gamma}{A} \\ \frac{K(1-\lambda)}{A} \end{bmatrix} u_i$$

$$G(S) = C(sI - A)^{-1}B$$

Where ,

$$A = \begin{bmatrix} -0.1779 & 0 \\ 0.1779 & -0.0976 \end{bmatrix};$$

$$B = \begin{bmatrix} 0.0322 \\ 0.00856 \end{bmatrix}$$

The sensor output equation can be consider as,

$Y_1=h_1$ and $Y_2=h_2$

So,

$$\begin{bmatrix} \bar{h}_1 \\ \bar{h}_2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} h_1 \\ h_2 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Using Matlab Command ‘ss’ and ‘tf’ we determine the transfer function of the system,

$$G(s) = \frac{0.00856\,s + 0.007251}{s^2 + 0.2755\,s + 0.01736}$$

b. Mathematical Modelling of interacting Tank System:

Differential equations for the system,

Tank 1

$$A\frac{dh_1}{dt} = KQ_{in}\gamma - \beta_1\, a\ \sqrt{2g(h_1 - h_2)}$$

For Tank 2

$$A\frac{dh_2}{dt} = KQ_{in}(1\text{-}\gamma) + \beta_1\, a\ \sqrt{2g(h_1 - h_2)} - \beta_2 a$$

$$\sqrt{2gh_2}$$

The system can be linearized around the operating point, the relation between steady state flow rate and height can be determine as,

$$\bar{h}_1 = \frac{(K\,Q'_{in}\,\gamma)^2}{\beta_1^2 a^2\, 2g} + \frac{(K\,Q'_{in})^2}{\beta_2^2 a^2\, 2g} \quad \text{and} \quad \bar{h}_2 = \frac{(K\,Q'_{in})^2}{\beta_2^2 a^2\, 2g}$$

$\bar{h}_1$ = Steady State height of the Tank 1

$\bar{h}_2$ = Steady state height of the Tank 2

Q'_{in} = Steady state flow rate.

If Q'_{in} =6 lph then we obtain the calculated

$\bar{h}_1$ = 1.003cm and $\bar{h}_2$ =0.553 cm

Now the linearized differential equation of the system,

$$\frac{dh_1}{dt} = \{KQ_{in}\gamma - \frac{\beta_1 a\sqrt{2g}}{2\sqrt{(\bar{h}_1 - \bar{h}_2)}}(h_1 - h_2)\}\ \frac{1}{A}$$

$$\frac{dh_2}{dt} = \{KQ_{in}(1\text{-}\gamma) + \frac{\beta_1 a\sqrt{2g}}{2\sqrt{(\bar{h}_1 - \bar{h}_2)}}(h_1 - h_2)\} - \frac{\beta_2 a\sqrt{2g}}{2\sqrt{\bar{h}_2}} h_2\} \frac{1}{A}$$

Now the state space representation of the system,

$$\begin{bmatrix} \bar{h}_1 \\ \bar{h}_2 \end{bmatrix} = \begin{bmatrix} -\frac{\beta_1 a\sqrt{2g}}{2A\sqrt{\left(\bar{h1} - \bar{h2}\right)}} & \frac{\beta_1 a\sqrt{2g}}{2A\sqrt{\left(\bar{h1} - \bar{h2}\right)}} \\ \frac{\beta_1 a\sqrt{2g}}{2A\sqrt{\left(\bar{h1} - \bar{h2}\right)}} & -\left(\frac{\beta_2 a\sqrt{2g}}{2A\sqrt{\bar{h2}}} + \frac{\beta_1 a\sqrt{2g}}{2A\sqrt{\left(\bar{h1} - \bar{h2}\right)}}\right) \end{bmatrix} \begin{bmatrix} h1(t) \\ h2(t) \end{bmatrix}$$

$$+ \begin{bmatrix} \frac{K\gamma}{A} \\ \frac{K(1 - \lambda)}{A} \end{bmatrix} u_i$$

$$G(S) = C(sI - A)^{-1}B$$

Where ,

$$A = \begin{bmatrix} -0.2104 & 0.2104 \\ 0.2104 & -0.4379 \end{bmatrix};$$

$$B = \begin{bmatrix} 0.03153 \\ 0.010509 \end{bmatrix}$$

The sensor output equation can be consider as,

$Y_1 = h_1$ and $Y_2 = h_2$

So,

$$\begin{bmatrix} \bar{h}1 \\ \bar{h}2 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

Using Matlab Command ‘ss’ and ‘tf’ we determine the transfer function of the system,

$$G(s) = \frac{0.01051\, s + 0.008839}{s^2 + 0.6483\, s + 0.04787}$$

III. SIMULINK DESIGN OF THE SYSTEM

a. Non-Interacting System

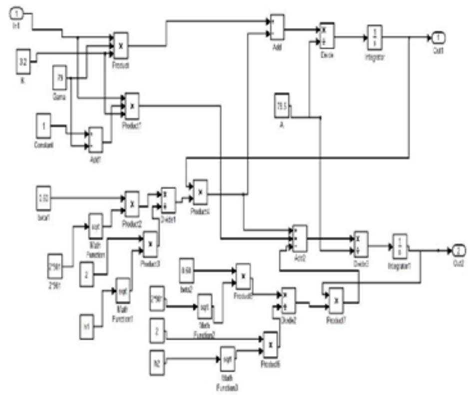

Fig.3 Non-Interacting Tank Syatem

a. Interacting System:

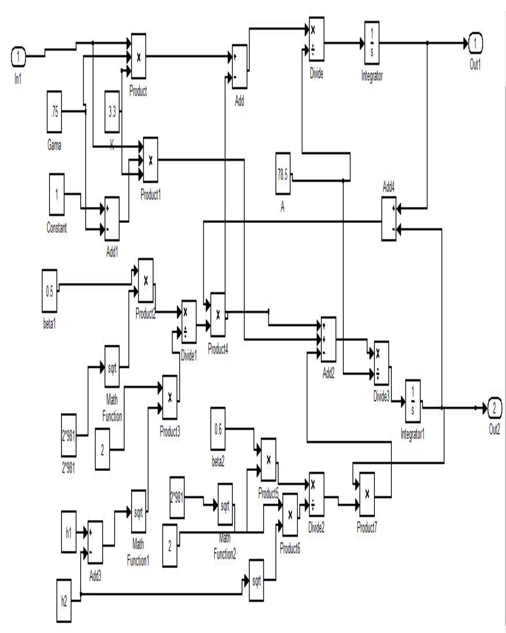

Fig.4 Interacting Tank System

IV.PID TUNING

The basic PID tuning method is Zeigler Nichols open loop response. For open loop tuning method we open the closed loop feedback. Then we apply the step signal in the and from the step response of the system then we determine the L and T value.

The steady state gain value represented by K.
The ‘a’ value can de determine a= (K*L)/T.
Zeigler-Nichols Tuning Formula;

Controller Type	Kp	Ti	Td
P	1/a		
PI	0.9/a	3L	
PID	1.2/a	2L	L/2

Table 2

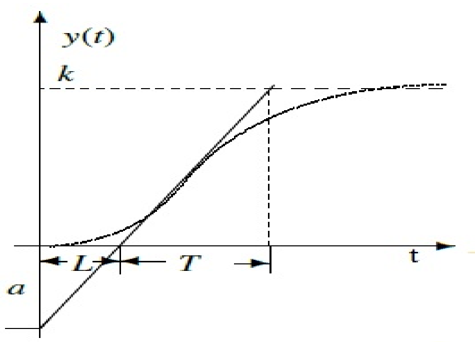

Fig.5

V. EXPERIMENTAL RESULT

a. Non-Interacting Tank System:

Open loop response of the system shown in Fig.6
Here,
K=.4177
L=1.132 sec
T=21.69 sec
A=0.02179
The calculated value for
PID controller is
Kp= 55; Ti=2.264
Td=.566

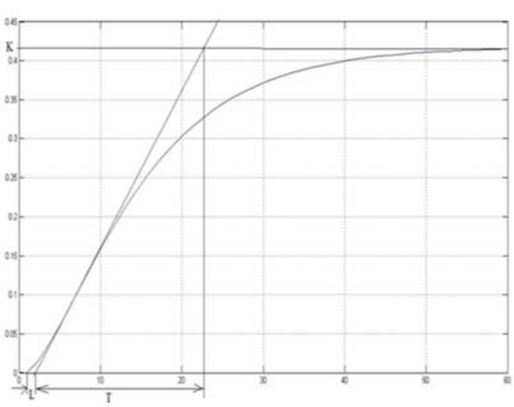

Fig.6

b. Closed Loop Response of the system:

Block Diagram of Closed Non-Interacting Tank System and step response of the system Shown below.

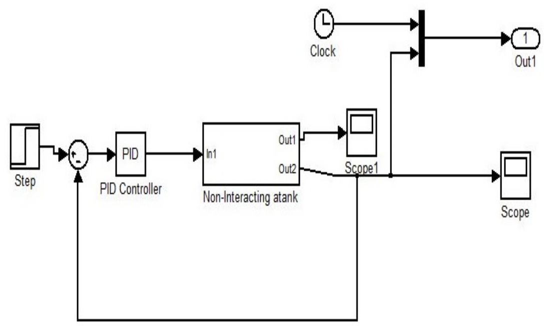

Fig.7 Closed loop Non-Interacting Tank system with PID controller.

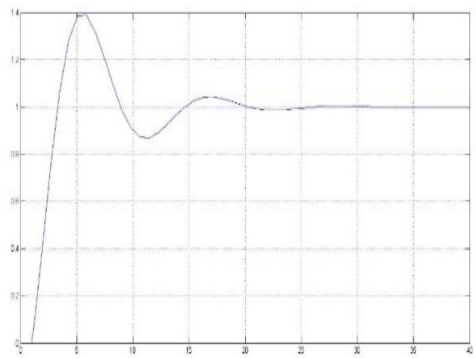

Fig.8 Step Response of the Non-Interacting Tank system with PID controller.

c. Interacting Tank System:

Open loop response of the system shown in Fig.9

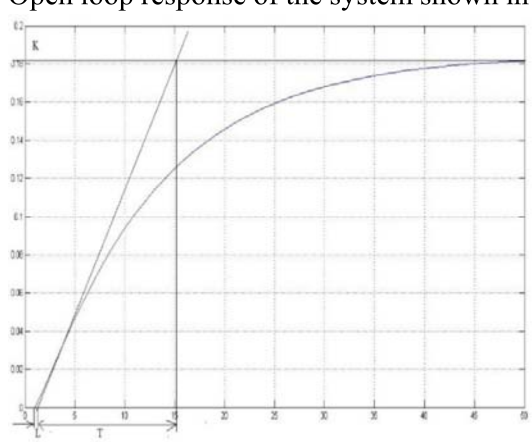

Fig.9

Here,
K=0.1846, L=0.377 sec, T=13.96 sec and A=0.004985
The calculated value for PID controller is
Kp= 200; Ti=0.754
Td=0.1885
The closed loop block diagram of the system is similar as the Non-Interacting tank system. The step response of the system with PID controller is shown in the figure 7.

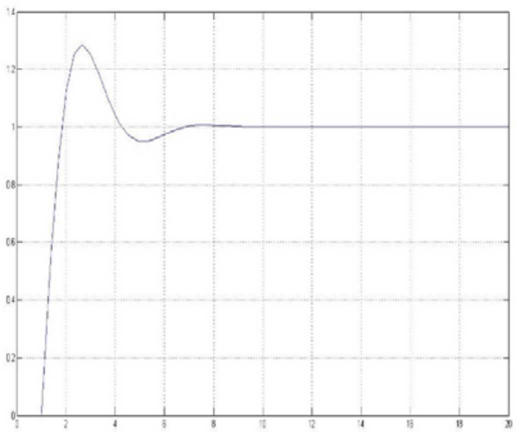

Fig.10 Step Response of the Non-Interacting Tank system with PID controller.

VI.CONCLUSION

From the experiment it is observed the without used of the PID controller both the system have large steady state error. The system have more error due to the disturbance input in both the systems. The Interacting tank system have high nonlinearity than the Non-interacting tank system because the flow out of the tank1 depends upon the height of the tank 2.There are several PID controller tuning method the Zeigler Nichols open loop tuning method is simple tuning method. The system with this PID controller eliminate the steady state error but have peak overshoot. The PID controller increase the rise time of the system and also settling time.

VII. REFERENCES

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