IMC based PI Controller for a Coupled Tank Process

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***Abstract* — The objective of this paper is to develop the Internal Model Control (IMC) based PI Controller for a Single Input Single Output (SISO) system. The controller thus developed is implemented on Laboratory non- 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 Internal Model Control (IMC) based PI Controller 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 SISO process that exhibits nonlinear behaviour.**

***Index Terms* — Coupled tank system, IMC, PI controller, SISO.**

I INTRODUCTION

The controls of liquid level in multiple tanks and flow between the tanks are basic problems in the process industries. The process industries require liquid to be pumped and stored in the tanks and then pump it to another tank. Often the tanks are so coupled together that the levels interact and these must also be controlled. About 95% of process control loops are of PID or PI type. Since, its inception over eighty years ago, the proportional-integral-derivative (PID) control structure has remained the most commonly used single-input single-output (SISO) technique in industry, Primarily because it is one of the simplest [1]. Conventional PID controllers are of one-degree-of-freedom (1DoF) type. The degree of freedom of a control system is defined as the number of closed-loop transfer functions that can be adjusted independently. A conventional 1DoF PID controller can either perform servo tracking or disturbance rejection at a time [2]. However, tuning of PID controller parameters is a challenging task. Many authors have suggested different algorithms for tuning PID controller parameters. These include methods based on conventional Ziegler-Nichols (ZN) tuning method [3-6], Genetic Algorithm (GA) [7], Internal Model Control (IMC) [8-9], neural network fuzzy logic control (FLC) [10] etc. The conventional ZN parameter tuning method has a fixed structure of PID controller design and ZN tuning is applicable to only stable systems. Hence, these parameters may not provide satisfactory performance under transient conditions. Neural network based methods are especially useful for classification and function approximation problems which are tolerant of some imprecision having lots of training data available. Consequently, these tuning methods are less robust under momentary disturbances.

An alternative to this controller is the usage of Internal Model controller (IMC) which gives satisfactory performance for Conical Tank Interacting Level systems [1]. In this paper an Internal Model Controller is designed and implemented to Conical Interacting systems [2]. This controller uses the model of the process to run in parallel with the actual process [3]. The IMC design procedure is exactly same as the open loop control design procedure. Unlike the open loop control the IMC structure compensates for disturbances and model uncertainty.

The paper is organized as follows: The laboratory interacting coupled tank process setup chosen for the study is detailed first. The procedure involved in developing Internal Model Control (IMC) based PI Controller is presented. The simulation result analysis of the proposed controller is reported before providing the conclusion.

II PROCESS DESCRIPTION

The chosen process setup consists of pumps, motorized control valves, process tanks, overhead tanks, differential pressure transmitters, level transmitters and rotameters. In addition there are PID controllers, main and auxiliary switches to energize each equipment. Digital indicators are used to display the process variables. The schematic diagram of the chosen Interacting coupled tank system is illustrated in Fig. 1.

The mass balance equations of tank1 and tank2 are given in Equations 1 and 2. The rate of change of liquid volume in each tank is equal to the net flow of liquid into the tank. The volumetric inflow rate into the tank1 and tank2 are q_{in1} and q_{in2}. The volumetric flow rate from the tank1 and tank2 are q_{01} and q_{02}. Flow rate between tank1 and tank2 is q_{12}. The height of the liquid level is h_1 in tank1 and h_2 in tank2.

$$A_1 \frac{dh_1}{dt} = q_{in1} - q_{o1} - q_{12} \tag{1}$$

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

The system model can be formulated by ordinary differential equation using Bernoulli's law as shown in Equations 3 and 4.

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

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

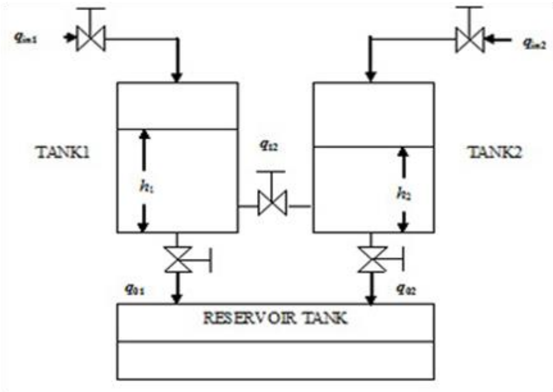

Fig. 1. The two tank liquid level system

The cross sectional area of tank1 and tank2 are A_1=A_2=1130.4cm^2, restriction areas in the outlet pipes of tank1 and tank2 are a_1=a_2= 3.9cm^2. Restriction area of interconnecting pipe is a_{12}=1.27cm^2 and g is the specific gravity. The maximum capacity of two tanks is 25cm. Height of the tank =30cm.

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

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

Convert above equation in form of $\frac{h_2(s)}{q_{in1}(s)}$

$$\frac{h_2(s)}{q_{in1}(s)} = \frac{R_2}{\tau_1\tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2)s + 1} \qquad (6)$$

Substituting the values, the complete transfer function is calculated as

$$\frac{h_2(s)}{q_{in1}(s)} = \frac{28.82}{29.6s^2 + 14.7s + 1} \qquad (7)$$

III IMC BASED PI CONTROLLER

A more comprehensive model based design method; Internal Model Control was developed by Morari and co-workers. The IMC method is based on the simplified block diagram as shown in Fig. 2.

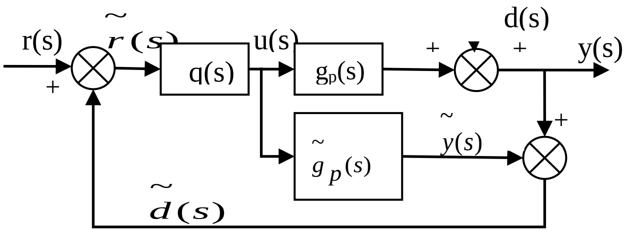

Fig. 2 Internal Model Control (IMC)

We have found that the IMC structure can be rearranged to the feedback control (FBC) structure, as shown in Figure 3. This reformulation is advantageous because we will find that a PID controller often results when the IMC design procedure is used. Also, the standard IMC block diagram cannot be used for unstable systems, so this feedback form must be used for those Cases.

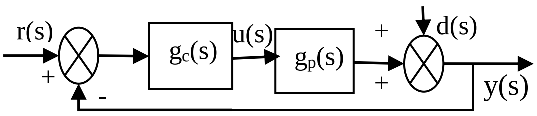

Fig 3. Standard Feedback Diagram Illustrating the Equivalence with Internal Model Control.

Step 1.Find the PID-equivalent to IMC for a second-order process,

$$\tilde{g}_p(s) = \frac{k_p}{(\tau_1 s+1)(\tau_2 s+1)} \quad (8)$$

Step 2. Find the IMC controller transfer function, q(s) - here we allow q(s) to be improper, because we wish to end up with a PID controller when we are

$$q(s) = \tilde{q}(s) f(s) = \tilde{g}_p^{-1}(s) f(s) \quad (9)$$

$$q(s) = \frac{(\tau_1 s+1)(\tau_2 s+1)}{k_p} \frac{1}{(\lambda s+1)} \quad (10)$$

where $\boldsymbol{\lambda}$ is the tuning parameter for PID controller (and also the IMC filter factor).
Step 3. Find the equivalent standard feedback controller using the transformation

$$g_c(s) = \frac{q(s)}{1-\tilde{g}_p(s)\, q(s)} \quad (11)$$

$$g_c(s) = \frac{\tau_1\tau_2 s^2 + (\tau_1+\tau_2)s+1}{K_p \lambda S} \quad (12)$$

Step 4. Rearrange equation (12) . Multiplying equation (12) by $(\tau_1+\tau_2)/(\tau_1+\tau_2)$, we find

$$g_c(s) = \frac{(\tau_1+\tau_2)}{K_p\lambda} \frac{\tau_1\tau_2 s^2 + (\tau_1+\tau_2)s+1}{(\tau_1+\tau_2)S} \quad (13)$$

Step 5. Sometimes this procedure results in a PID controller cascaded with a lag term (τ_F). The general PID form is given by

$$g_c(s) = K_c\left[\frac{\tau_I\tau_D s^2 + \tau_I s+1}{\tau_I S}\right]\left[\frac{1}{\tau_F S+1}\right] \quad (14)$$

Step 6. Comparing Equation (13) with Equation (14), we find K_c,T_I,T_D.

$$K_c = \frac{(\tau_1+\tau_2)}{K_p\lambda},\ T_I = (\tau_1+\tau_2),\ T_D = \frac{(\tau_1\tau_2)}{(\tau_1+\tau_2)} \quad (15)$$

Step7. We find K_p,τ_1,τ_2 values by comparing equation (7) with equation (8) and factorizing the equation (7),

$$\tilde{g}_p(s) = \frac{28.89}{(2.409s+1)(12.30s+1)} \quad (16)$$

K_c=0.5091, T_I=14.714

IV SIMULATION RESULTS

The simulation is carried out using MATLAB software for coupled Tank systems. Both servo and regulatory responses are obtained for the SISO process. The performance of IMC based PI Controller is shown in Fig 3(a), 3(b). Also set point tracking of servo response is obtained. Set point tracking of servo response for IMC controller based PI Controller is shown in Fig 4.

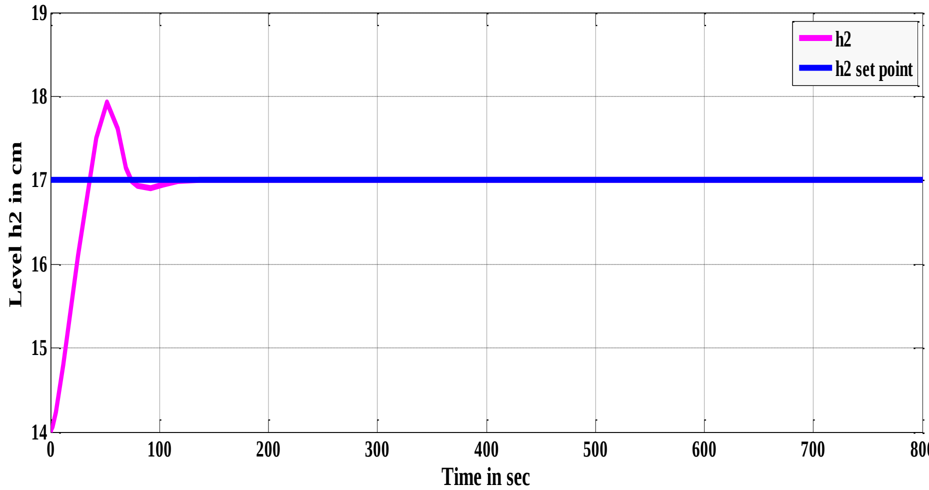

Fig. 3(a) Servo Response of Coupled Tank systems

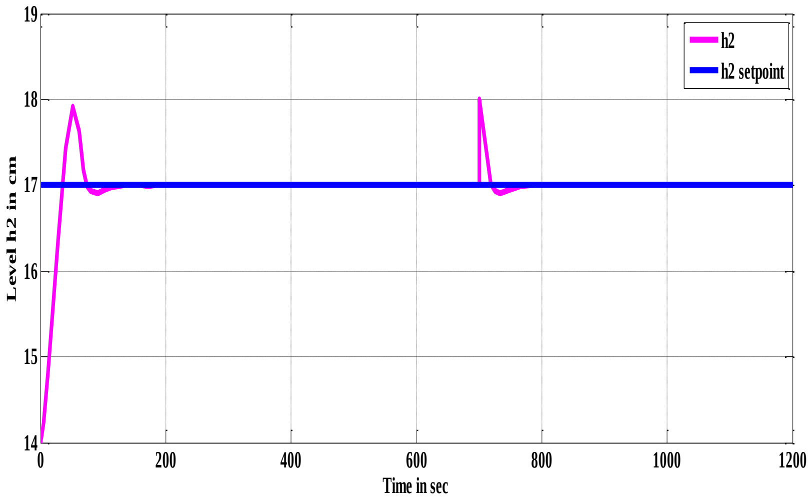

Fig. 3(b) Regulatory Response of Coupled Tank systems

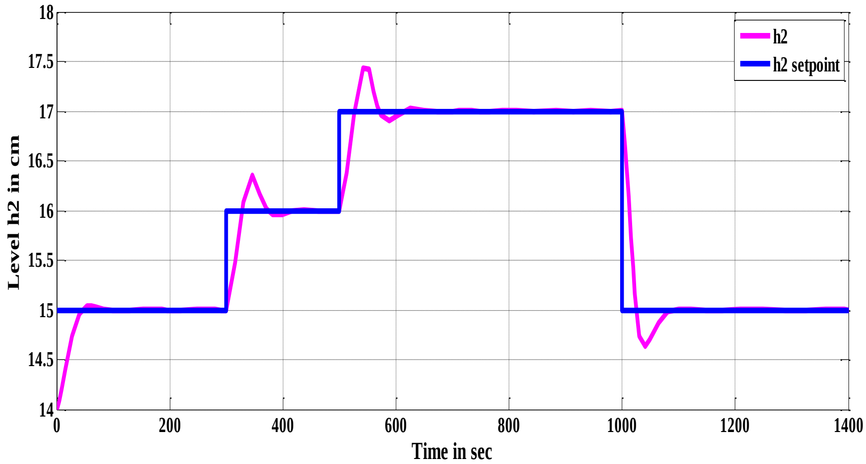

Fig. 4 Setpoint Tracking of Coupled Two Tank systems

V CONCLUSION

The performance of coupled tank process has been investigated using IMC based PI controller design. From the plots, it is clear that the overall system performance with PI based IMC is observed to have better tracking and disturbance rejection than that of the system with PI controller. The resulting performance could be improved by a better choice of the gain. This concludes that the Internal Model Control based PI controller is applicable for nonlinear coupled tank systems.

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