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Control of Two Tank Conical Interacting Level System using Relay Auto Tuning

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Abstract

Objectives: The main objective of this work is to design a relay feedback based PI controller to maintain the level of two tank conical interacting level system (TTCILS) which is highly a non linear process. **Methods:** This technique is based on the observation that when the output lags behind the input by π radians, the closed loop system can oscillate with a period of Pu. It is a simple way to tune PI controllers that avoids trial and error process. **Findings:** A continuous cycling of controlled variable is generated from the relay feedback experiment. The important process information, ultimate gain and ultimate period can be extracted directly from the experiment. Model design and simulation is carried out in MATLAB/SIMULINK environment. **Conclusion:** The advantage of this method is that, it requires a single relay feedback test. Simulation studies prove that this technique has good tracking and disturbance rejection capability.

Keywords: Conical Interacting Level System, Mathematical Model, PI Controller, Relay Auto Tuning (RAT), Simulation Studies

1. Introduction

In most of the industries chemical processes present many challenging problems due to their nonlinear dynamic behaviour. Because of inherent non linearity, most of the chemical process industries are in need of traditional control techniques. One such non linear process taken up for study is Interacting Conical system.

Conical tanks are best suited for food process industries, concrete mixing industries, hydrometallurgical industries and waste water treatment industries. Its shape contributes to better drainage of solid mixtures, slurries and viscous liquids. To achieve a satisfactory performance using conical tanks, its controller design becomes a challenging task because of its non - linearity. This non - linearity arises due to its shape. It is broad at the end and becomes narrow in the lower end. The primary task of a controller is to maintain the process at the desired set point and to achieve optimum performance when facing various types of disturbances.

Astrom and Hagglund have developed an alternative to the continuous cycling method, called as relay auto tuning method. A simple experiment test is used to determine ultimate gain Ku and ultimate period P_u[1].

Many researchers have reported on relay auto tuning method. Relay based PID tuning is presented in Wilson[2]. Optimization of control parameters using improved relay tuning and Taguchi method is presented in Misal et al.[3]. Design of a tuner based on the approximate estimation of the critical point on the process frequency response from relay oscillations is presented in Khalore et al[4]. A modified relay tuning method for level control model is presented by Misal et al[5]. Control of Concentration in CSTR using PID controller based on relay feedback method is presented in Srinivasulu Raju[6]. Estimation of optimum control parameters using relay tuning method for a bioreactor is discussed in Misal[7]. Transfer function

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parameter identification by modified relay feedback is presented[8]. Also Misal et al.[9] discussed about the application of improved relay tuning for design of optimum PID control of SOPTD model. A PI controller is implemented for a level process using non contact sensor as discussed in Sai Vamsi et al[11].

The paper is organized as follows. In section 2 the two tank conical interacting system considered for simulation study has been discussed. In section 3, a relay auto tuning based PI controller has been explained. In section 4 simulation results of RAT based PI controller is discussed. Finally the paper ends with Conclusion in section 5.

2. Process Description

The two tank conical interacting system consists of two identical conical tanks (Tank 1 and Tank 2), two identical pumps that deliver the liquid flows Fin1 and Fin2 to Tank 1 and Tank 2 through the two control valves C_{V1} and C_{V2} respectively as shown in Figure 1. These two tanks are interconnected at the bottom through a manually controlled valve, M_{V12} with a valve coefficient β_{12}. F_{out1} and $F_{out\ 2}$ are the two output flows from Tank 1 and Tank 2 through manual control values M_{V1} andM_{V2} with valve coefficients β_1 and β_2 respectively.

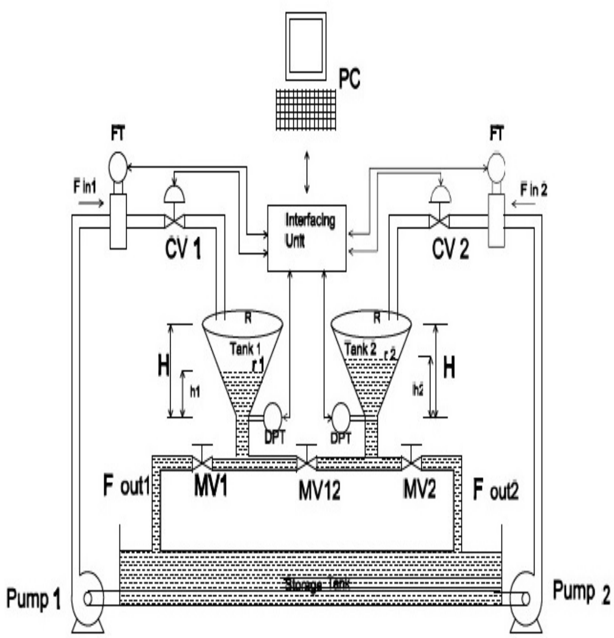


Figure 1. Schematic of TTCIS.

Table 1. Operating parameters of TTCIS

Parameter	Description	Nominal values
R	Top radius of conical tank	19.25cm
H	Maximum height of Tank 1 & Tank 2	73cm
F_{in1}& F_{in2}	Maximum inflow to Tank 1 & Tank 2	400 cm^3/sec
b_1	Valve coefficient of MV_1	35 cm^2/sec
b_{12}	Valve coefficient of MV_{12}	78.28 cm^2/ sec
b_2	Valve coefficient of MV_2	19.69 cm^2/ secs

The operating parameters of the interacting conical tank process is shown in Table 1.

In this work, TTCIS is considered as two inputs two output processes in which level h1 in Tank 1 and level h_2 in Tank 2 are considered as output variables and F_{in1} and F_{in2} are considered as manipulated variables. The mathematical model of two tank conical interacting system is given by Ravi et al[10].

$$\frac{dh_1}{dt} = \left[\frac{F_{in1} - h_1 \dfrac{dA(h_1)}{dt} - \beta_1\sqrt{h_1} - sign(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2|}}{\dfrac{1}{3}\pi R^2 \dfrac{h_1^2}{H^2}} \right] \tag{1}$$

$$\frac{dh_2}{dt} = \left[\frac{F_{in2} - \beta_2\sqrt{h_2} + sign(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2|} - h_2 d\dfrac{A(h_2)}{dt}}{\dfrac{1}{3}\pi R^2 \dfrac{h_2^2}{H^2}} \right] \tag{2}$$

where

$A(h_1)$ = Area of Tank 1 at h_1(cm^2)

$A(h_2)$ = Area of Tank 2 at h_2(cm^2)

h_1= Liquid level in Tank 1 (cm)

h_2= Liquid level in Tank 2 (cm)

The open loop responses of h_1 and h_2 are shown in Figure 2.

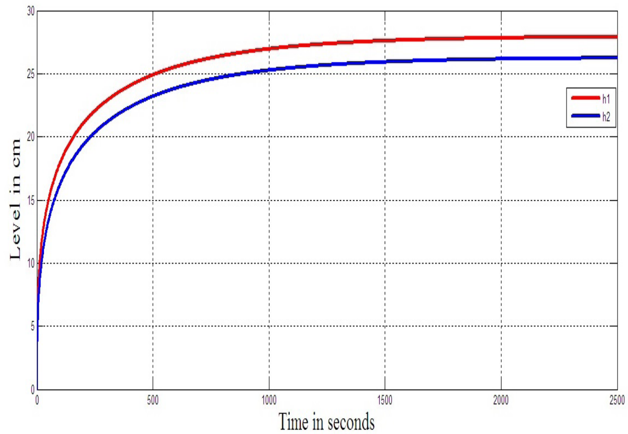


Figure 2. Open loop response of h_1 and h_2.

3. Relay Auto Tuning

For this test, the feedback controller is temporarily replaced by an on-off controller or relay. After the control loop is closed, the controlled variable exhibits a sustained oscillation that is characteristic of on-off control. The block diagram of relay feedback test and its output response is shown in Figure 3.

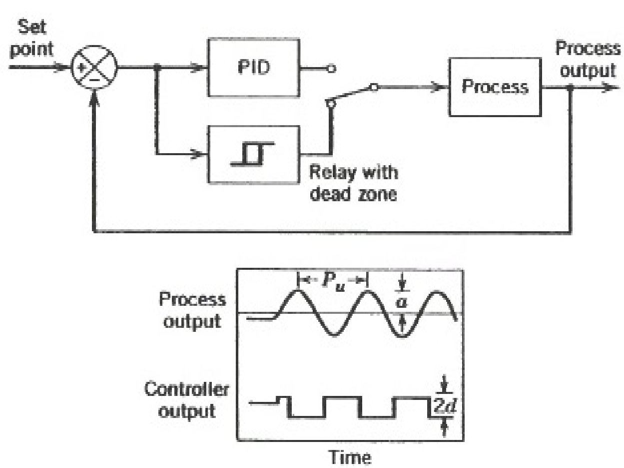


Figure 3. Block diagram of relay feedback test and its output response.

The ultimate gain and the ultimate period can easily be obtained from Figure 3.The ultimate period Pu is equal to the period of oscillation for the process output. The ultimate gain is given by equation (3).

$$K_u = 4h/\pi a \quad (3)$$

The relay auto tuning method has several important advantages compared to the continuous cycling method.

1. Only a single experiment test is required instead of trial and error procedure.
2. The amplitude of the process output 'a' can be restricted by adjusting relay amplitude d.
3. The process is not forced to a stability limit.
4. The experimental test is easily automated using commercial products.

4. Simulation Results

Simulation studies are carried out on TTCILS using MATLAB (R2010a) based on relay auto tuning. The tuning parameters obtained from relay auto tuning method are K_u = 22.75 and P_u = 0.2 sec. The simulation is carried out by considering the nominal values of h_1 and h_2 (h_1 = 28cm and h2 = 26cm). The relay and process response obtained from the application of this automatic tuning procedure is depicted in Figure 4 and 5.

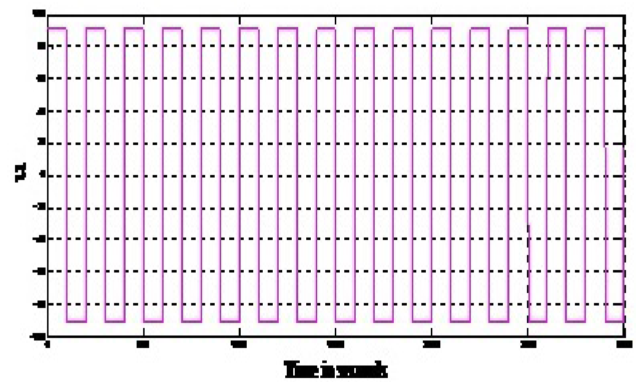


Figure 4. Relay response.

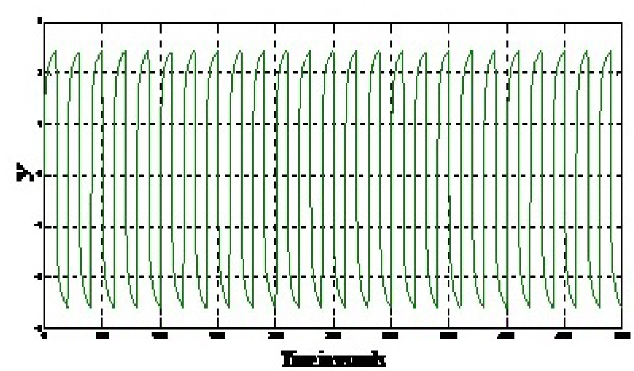
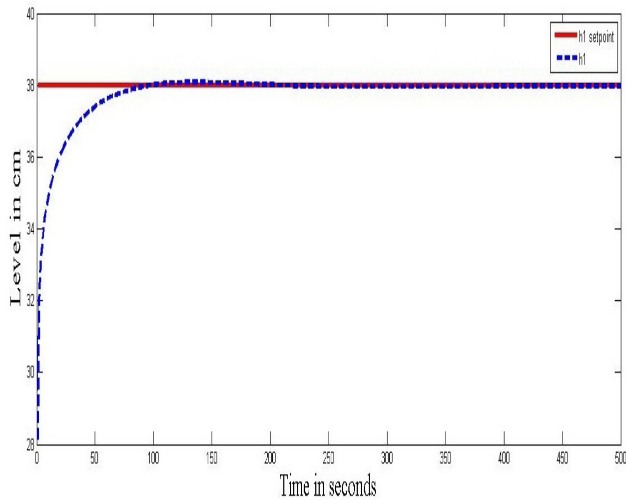


Figure 5. Process response.

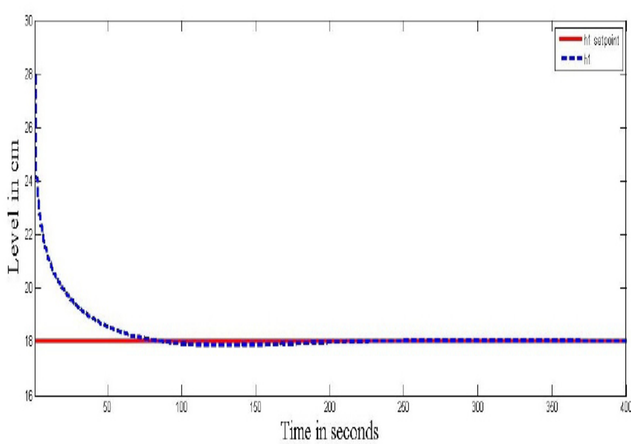
From the Figure 5 it is observed that the output exhibits the sustained oscillations. Also from the above process response K_u and P_u is calculated. These parameters are used to calculate the controller settings for tracking the change in set point.

The desired values of the controlled variables h_1 and h_2 are given as set points and their corresponding responses are obtained as shown below in Figure 6 (a) and (b) and 7(a) and (b).



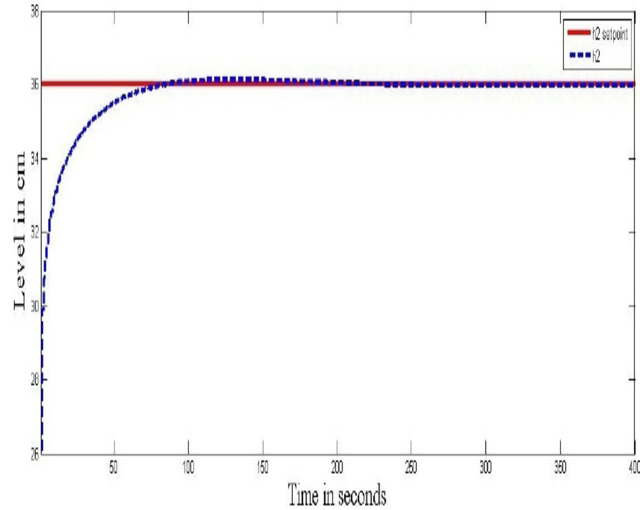
(a)

Figure 6. (a) Simulated response of h_1 = 38cm in TTCILS using RAT method.



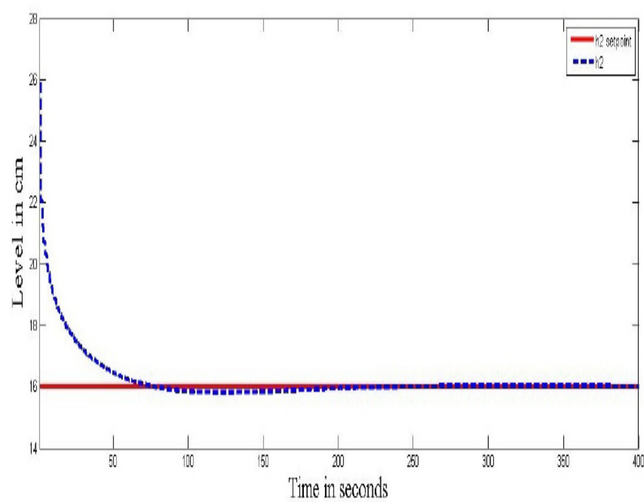
(b)

Figure 6. (b) Simulated response of h_1 = 18cm in TTCILS using RAT method.



(a)

Figure 7. (a) Simulated response of h_2 = 36cm in TTCILS using RAT method.



(b)

Figure 7. (b) Simulated response of h_2 = 16cm in TTCILS using RAT method.

4.1 Servo Performance

The set point variations are introduced for understanding the tracking capability of RAT controller as shown in Figure 8 and 9.

From the above responses, it can be concluded that the PI controller settings are able to track the set point for change in the inflow rate of TTCILS.

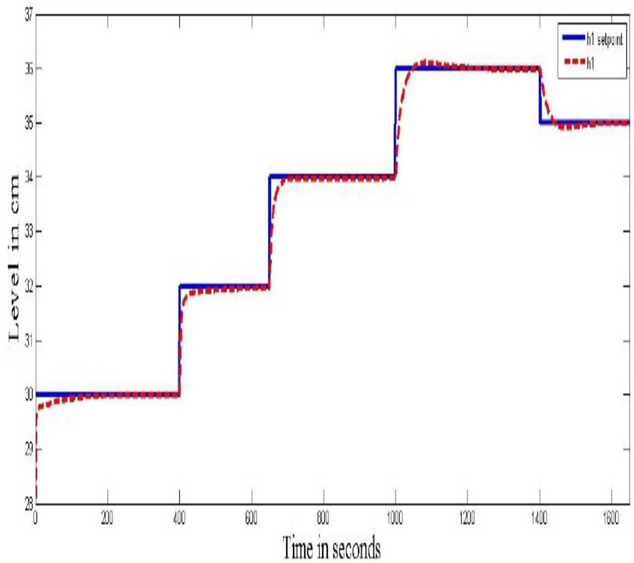


Figure 8. Set point tracking response of h_1 in TTCILS using RAT controller.

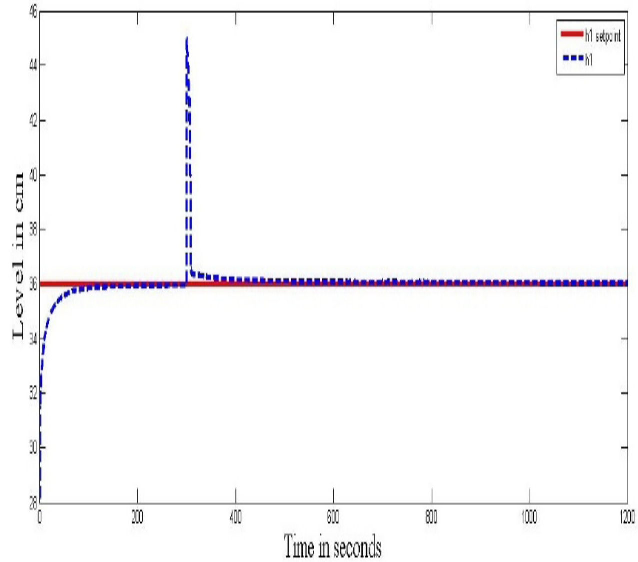


Figure 10. Regulatory response of h_1 in TTCILS using RAT controller.

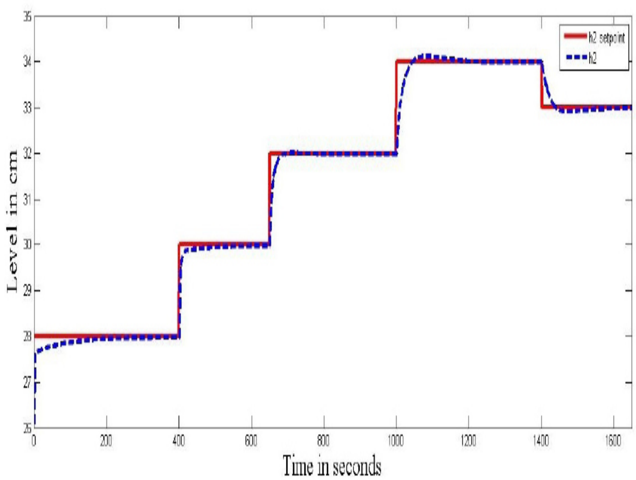


Figure 9. Set point tracking response of h_2 in TTCILS using RAT controller.

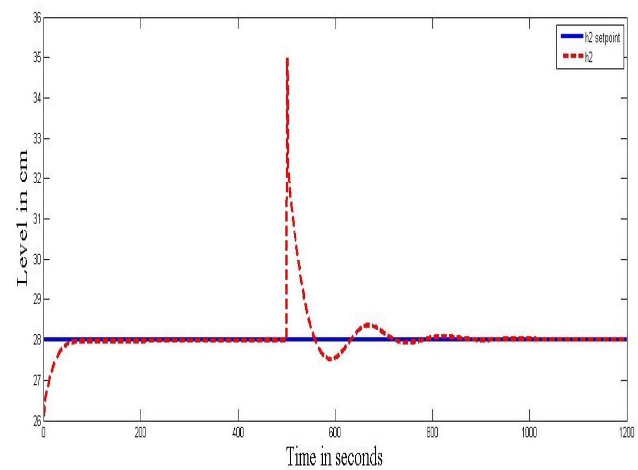


Figure 11. Regulatory response of h_2 in TTCILS using RAT controller.

4.2 Regulatory Performance

Simulation studies are also carried out to explain the disturbance rejection capability of RAT based PI controller. Figure 10 and 11 shows regulatory response of TTCILS using RAT controller.

From the above responses, it is clear that the RAT based PI controller is able to satisfy the servo response even in the presence of the disturbance occurred in the process. The disturbances are introduced at output levels of h_1 = 45cm and h_2 = 35cm.

5. Conclusion

In this study, a relay auto tuning PI controller for a two tank conical interacting level system is presented. By using this scheme, the parameters are optimally and robustly adjusted with respect to the system dynamics. This technique is found to be more effective than conventional tuning methods. The advantages of this method are the requirement of single relay feedback test and the PID parameters can be easily determined. This method of identification is simple and will be of much industrial use.

Servo and regulatory responses also reveals satisfactory results with the process.

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