All Sciences Proceedings
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3rd International Conference on Innovative Academic Studies

September 26-28, 2023 : Konya, Turkey

https://www.icias.net/

Development of PID Controller Tuned by using Ziegler Nichols Method for Controlling the Fluid Level in Coupled Tank System.

Danish Nouman *, Tanveer Hussain [2]

[1]Electrical/University of Engineering and Technology, Taxila, Pakistan
[2] Electrical /Teeside University, Middlesbrough, United Kingdom
*(danishnouman1@gmail.com)

Abstract – Coupled Tank system is largely used nowadays in chemical process industries. Tanks are used to transfer the fluids from one tank to the other. In this process, flow of fluids between tanks should be monitored because of the perfect mixing of chemicals in the tanks and to reach the optimal mixing of fluids. In this research paper, PID controller is used to control the fluid level between two tanks. Tuning constants of PID is tunned by using Ziegler Nichols method. All the work is done in Matlab environment. After applying the strategy, performance characteristics i.e., Settling Time (Ts), Rise Time (Tr), Overshoot (O.S) and Steady State Error (S.S.E) was checked and hence concludes that results of CTS system with ZN-PID controller was good and can be used in chemical Process industry.

Keywords – Coupled Tank System (Cts), Pıd Controller, Ziegler Nichols Method, Water Level Control

I. INTRODUCTION

Fluid level management is critical in many industrial process applications, especially in oil and gas organizations, waste-water treatment plants, and chemical industries [1]. Transferring fluid from one tank to the other tank is the main process of the chemical industries. Flow of fluids between tanks should be monitored because of the perfect mixing of chemicals in the tanks and to reach the optimal mixing of fluids. Fluid should be kept up at a particular level and it should be examined otherwise it will be a great loss for the industry. Controllers are used to examine the level of fluid in the tanks to get the optimal mixing of fluids. Different controllers have been proposed in the literature. In this research paper, PID with Zeigler Nichols tuning method is proposed for the coupled tank system.

II. METHODOLOGY

Methodology of this research is discussed below in detail.

A. Coupled Tank System (CTS)

As depicted in Fig 1, The Coupled Tank CTS-001 is a computer-controlled CTS that is used to manage liquid levels.

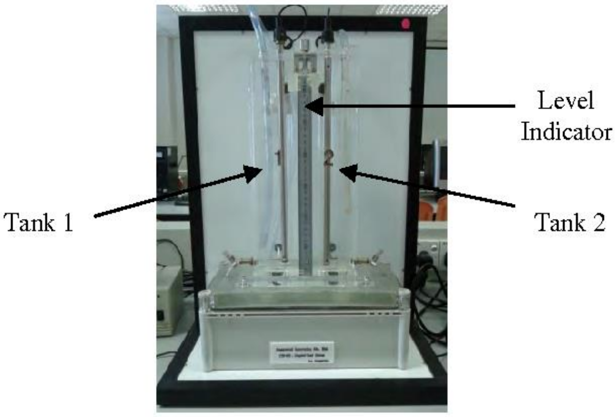


Fig 1: Coupled Tank System CTS-001

The idea of virtual instrumentation is presented in CTS-001. The requirement for customary committed user interfaces on singular instrumentation can be taken out by utilizing virtual instrumentation procedures [2]. Also, the PC can be utilized as the apparatus of interchange between the equipment and programming. Through the product investigation, it empowers to do the capacity of swaying and show the info and yield reaction. From the framework, it likewise can confirm the boundary of the model which can be gotten from the scientific displaying [3-7]. This yield reaction from the displaying capacity can be taken as the seat imprint to accomplish great reaction after executed it in the CTS. The exhibition can be handily observed in MATLAB simulation.

B. Mathematical Modelling

It is critical to know the mathematical representation of Coupled Tank System (CTS) behavior. The nonlinear powerful model is monitored in this framework, and the linearization technique is performed using the nonlinear model.

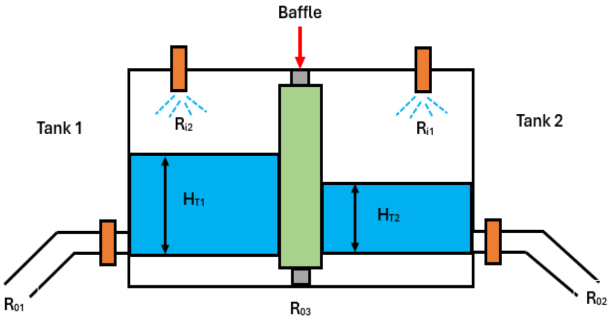


Fig 2: CTS Schematic Diagram

According to Fig. 2, H_{T1} and H_{T2} represent the liquid levels in Tanks 1 and 2. It is estimated for the corresponding outlet. In terms of fundamental mass parity, the rate of liquid volume progression in each tank approaches the net progression of liquid entering the tank. As a result, the conditions for Tank 1 and Tank 2 are as follows:

$$B_1 \frac{dH_{T1}}{dt} = R_{i1} - R_{01} - R_3 \tag{1}$$

$$B_2 \frac{dH_{T2}}{dt} = R_{i2} - R_{02} - R_3 \tag{2}$$

where:

H_T1, H_T2 = tank 1 and 2 fluid height
B1, B2 = of tank 1 and 2 cross-sectional area
R3 = tanks flow rate
R_{i1}, R_{i2} = tank 1 and 2 inward pump flow rate
R_{o1}, R_{o2} = tank 1 and 2 outward pump flow rate

Every outlet channel may be represented as a simple hole. Bernoulli's criterion for a constant, non-thick, incompressible stream demonstrates that the exit stream in each tank corresponds to the square foundation of the tank's head of water. As a result, the stream between the tanks equals the square root of the head differential. Thus:

$$R_{01} = \beta_1 \sqrt{H_{T1}} \tag{3}$$

$$R_{02} = \beta_2 \sqrt{H_{T2}} \tag{4}$$

$$R_3 = \beta_3 \sqrt{H_{T1} - H_{T2}} \tag{5}$$

where β_1, β_2, and β_3 are proportionality constants determined by the discharge coefficients, the cross-sectional area of each orifice, and the gravitational constant. The nonlinear state equations that characterize the system dynamics of the CTS apparatus are obtained by substituting (3), (4), and (5) into (1) and (2) are:

$$B_1 \frac{dH_{T1}}{dt} = R_{i1} - \beta_1 \sqrt{H_{T1}} - \beta_3 \sqrt{H_{T1} - H_{T2}} \tag{6}$$

$$B_2 \frac{dH_{T2}}{dt} = R_{i2} - \beta_2 \sqrt{H_{T2}} + \beta_3 \sqrt{H_{T1} - H_{T2}} \tag{7}$$

In the second order arrangement, the process variable is h_{t2}, the manipulated variable is r_1, and r_2 is assumed to be zero.

As illustrated in Fig 3, the block diagram of the second-order system may be reduced.

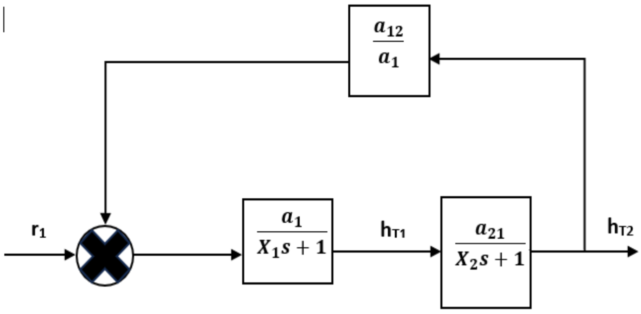


Fig 3: Second Order System Process for CTS

Thus, the nonlinear CTS can be obtained as:

$$\frac{h_{T2}s}{r_1 s} = \frac{a_1 a_2}{(X_1 s + 1)(X_2 s + 1) - a_{12} a_{21}} \tag{8}$$

$$= \frac{a_1 a_2}{X_1 X_2 s^2 + (X_1 + X_2)s + (1 - a_{12}a_{21})} \tag{9}$$

$$X_2 = \frac{B_2}{\left(\frac{\beta_2}{2\sqrt{H_{T2}}}\right) + \left(\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}\right)} \tag{10}$$

$$a_1 = \frac{1}{\left(\frac{\beta_1}{2\sqrt{H_{T1}}}\right) + \left(\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}\right)} \tag{11}$$

$$a_2 = \frac{1}{\left(\frac{\beta_2}{2\sqrt{H_{T2}}}\right) + \left(\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}\right)} \tag{12}$$

$$a_{12} = \frac{\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}}{\left(\frac{\beta_1}{2\sqrt{H_{T1}}}\right) + \left(\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}\right)} \tag{13}$$

$$a_{21} = \frac{\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}}{\left(\frac{\beta_2}{2\sqrt{H_{T2}}}\right) + \left(\frac{\beta_3}{2\sqrt{H_{T1} - H_{T2}}}\right)} \tag{14}$$

The plant's transfer function can be determined by inserting the parameter supplied by [2]. Table 1 displays the parameters that have been supplied.

Table 1: CTS different Parameters

Parameters	**Values**
H_{T1}	17 cm
H_{T2}	15 cm
β_1	10.78 cm^3/sec
β_2	11.03 cm$^{3/}$sec
β_3	11.03 cm^3/sec
B_1	cm^2
B_2	cm^2

After putting all the parameters in (9), (10), (11), (12), (13), & (14), we get the values as in Table 2:

Table 2: Parameter Values

X_1	X_2=6	a_1=0.2	a_2=0.2	a_{12}=0.7	a_{21}=0.7

By using the value that has been obtained from X_1, X_2, a_1, a_2, a_{12}, a_{21} and put it in equation the value of transfer function become [5]:

$$TF = \frac{(0.2)(0.2)}{(6)(6)s^2 + (6+6)s + [1 - (0.7)(0.7)]}$$

$$TF = \frac{0.04}{36s^2 + 12s + 0.51}$$

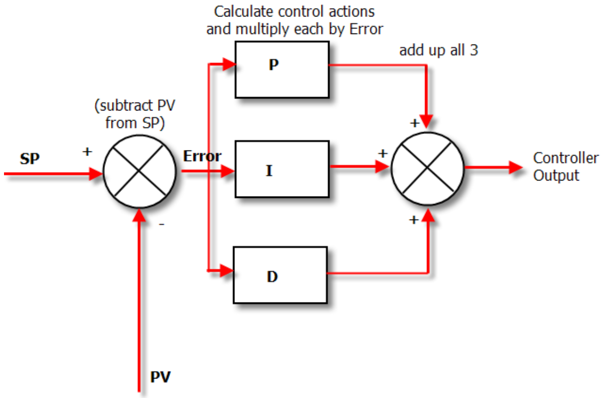


Fig 4: Block Diagram of PID Controller

C. Ziegler-Nichols (Z-N)

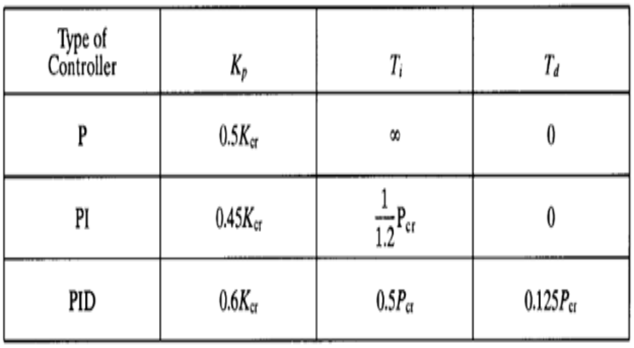
This method is used when you have a closed-loop control system with automatic control.

Here are the steps:

i) Set Kp, Ki, and Kd to zero (or very small values).
Increase Kp slowly.

ii) Gradually increases Kp until the system starts to oscillate continuously at a constant amplitude.
iii) Record the critical gain value (Ku) at which the sustained oscillations occur.
iv) Determine the oscillation period (Pu). Measure the time it takes for one complete cycle of oscillation at the critical gain Ku.
v) Then calculate the Kp, Ti and Td using the following table.

Table 3: Ziegler-Nichols Tuning Formula



Type of Controller	K_p	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

III. RESULTS

The simulation results of the control framework in connected tank are shown in the figures below.

A. System Response without Controller

Fig 5 which speaks to the framework reaction before including the controller, gives a few issues in the framework execution.

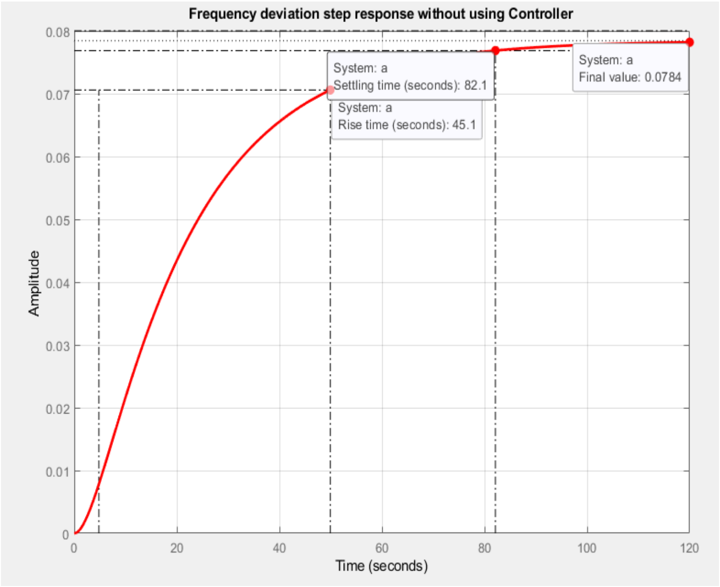


Fig: CTS without controller

As shown in figure 5, there is a series problem in its steady state final value. Rise time is 45.1 sec & settling time is 82.1 sec and steady state error is not zero. This is an unacceptable performance and should be altered.

B. System Response With Z-N PID Controller

Fig 6 shows the response of CTS with PID controller using Ziegler-Nichols method of tuning.

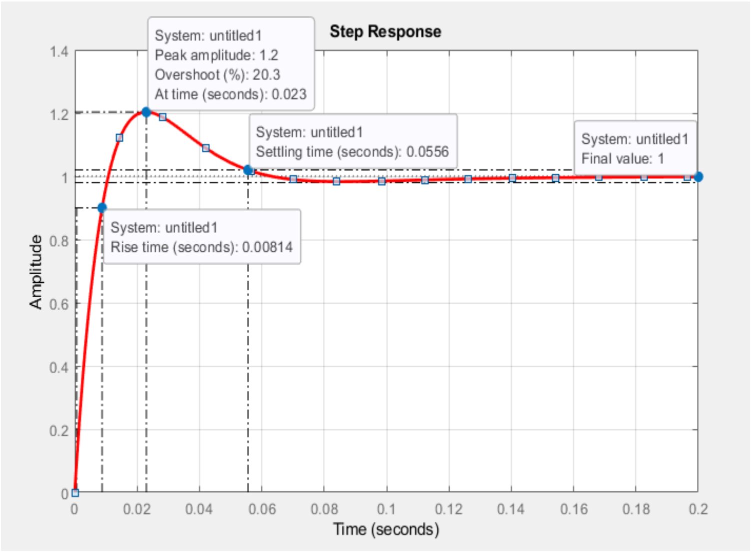


Fig 6: Response of CTS with Z-N PID Controller

Above Fig 6 shows the response of PID controller tuned by Ziegler Nichols (ZN) method.

The following table shows the responses of CTS system with and without controller.

Table 4: Response Characteristics of CTS with and without controller.

	Rise Time (Tr)	Settling Time (Ts)	Overshoot (O.S)	Steady State Error (S.S.E)
Without controller	45.1 sec		82.1 %	0.0784
With PID Z-N method	0.00814 sec	0.0556 sec	20.3 %	1

IV. DISCUSSION

By suing the Zeigler Nichols method, framework’s unique execution is appeared above in Fig 6, Kcr was set to be 3796371 when system response starts oscillating, and using this value, Pcr was taken out which was 0.1400. Without controller, system characteristics: rise time (Tr) was 45.1 sec, settling time was 82.1 sec and the steady state error (S.S.E) was 0.0784. These attributes are not wanted. We improved the attributes by including a controller in arrangement with the CTS plant. PID controller was utilized. We tuned the PID controller by utilizing Ziegler-Nichols strategy in MATLB environment. At the point when we tune the PID with Ziegler-Nichols technique, rise time (Tr) was 0.00814 sec, settling time (Ts) was 0.00556 sec, overshoot (O.S) was 20.3% and steady state error (S.S.E) was additionally decreased to 0 as appeared in Table 4. So, by using Z-N PID tunning method, response of CTS system is much better than the system without controller.

V. CONCLUSION

The transfer function of the two-tank framework has been found and scientifically demonstrated. The step response was used to evaluate the transfer function's performance characteristics, which included settling time, rising time, steady state error, and overshoot. In general, these features were both fair and unfair, such as steady state error, for example. A PID controller had been used to regulate the degree of the fluid. The Ziegler-Nichols technique can be used to optimize the settings of a PID controller. The coefficients of PID ought to be picked appropriately to get the necessary execution. After getting the results, the proposed tuning technique have good results of CTS system.

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