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Performance Comparison Between Various Tuning Strategies: Ciancone, Cohen Coon & Ziegler- Nicholas Tuning Methods

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ABSTRACT

This paper, explains about the background study of the coupled tank and to model such tanks using Simulink blocks. It must explains, the coupled tanks are used to select the best tuning strategy for PID controller based on its performance and stability, and then the best tuning controller is obtained after comparing various tuning strategies like Ciancone, Cohen Coon & Ziegler- Nicholas tuning methods based on their performance in controlling the couple tanks.

The couple tank is then designed on Simulink as well and three different tuning methods for PI & PID controller calculations are implemented. The controller which gives best performance corresponding their tuning parameters which is obtained from various tuning method, and then selected.

Keywords: Ciancone, Cohen - Coon, Ziegler- Nicholas Tuning Methods, PI or PID Controller, Coupled Tank System and Matlab.

INTRODUCTION

The control of liquid level in tanks and flow between tanks is a basic problem in the process industries. The process industries require liquids to be pumped, stored in tanks, and then pumped to another tank. Tank level control systems are everywhere. The PI or PID controllers have been used heavily in the process industries, mostly concerned about improving its performance and efficiency without using other approaches.

Our lives are governed by level and flow control systems. For example, medical physiology involves many fluid bio-control systems. Bio-systems in our body are there to control the rate that blood flows around our body. Other bio-systems control the pressure and levels of moisture and chemicals in our body.

In Ciancone strategy, the proportional gain, the integral and derivative time are calculated from the the process reaction curve. Similarly, in Cohen Coon method, which is used to calculate the tuning constants using the parameters obtained from the process reaction curve. At last Ziegler – Nicholas method, the calculation of the tuning parameters in this case doesn't depend on the process reaction curve like the previous two method, it is derived from the bode plot of the transfer function which is calculated from the coupled tanks. In the figure of bode plot of the plant is used to define system stability.

This paper has four sections, section one tends a little bit of introduction of various control strategies, section two consists the designing of coupled tank system using Simulink/ Matlab, Third section explain results and fourth or last section consists conclusion.

COUPLED TANK SYSTEM

In coupled tank i.e. nonlinear system, the equations of flows in the coupled tank can be determined where the system states here are the liquid levels H_1 and H_2 in corresponding tanks.

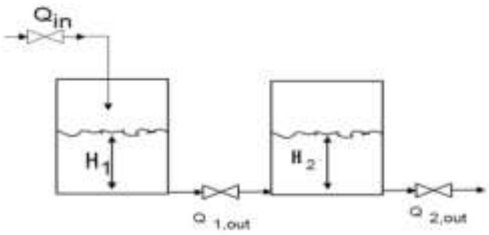


Fig. 1

Coupled Tank System

The mass balance for the first and second tank is respectively:

For Tank 1

$$\frac{A_1 dH_1}{dt} = Q_{in} - Q_{1,out} \qquad (1)$$

For Tank 2

$$\frac{A_2 dH_2}{dt} = Q_{1,out} - Q_{2,out} \qquad (2)$$

The flow out of the second tank is determined by the liquid head in that tank, i .e.

$$Q_{2,out} = k_2 \sqrt{H_2} \qquad (3)$$

However, because of the coupling between the two tanks, the flow out of the first tank is determined by the difference in levels of the two tanks, i.e. H1 □ H2.

$$Q_{1,out} = k_1 \sqrt{(H_1 - H_2)} \qquad (4)$$

Thus the final set of ODE's that describe system behaviour is given by:

$$\frac{dH_1}{dt} = \frac{\left(Q_{in} - k_1 \sqrt{(H_1 - H_2)}\right)}{A_1}$$

$$\frac{dH_2}{dt} = \frac{\left(k_1 \sqrt{(H_1 - H_2)} - k_2 \sqrt{H_2}\right)}{A_2}$$

Finally these can be written as:

$$\frac{A_1 dH_1}{dt} = Q_{in} - k_1 \sqrt{(H_1 - H_2)} \qquad (5)$$

$$\frac{A_2 dH_2}{dt} = k_1 \sqrt{(H_1 - H_2)} - k_2 \sqrt{H_2} \qquad (6)$$

These are called non-linear differential equations, which defines the non-linear behaviour of system. These are also using to obtaining simulink diagram for coupled tank system.

DESIGN OF COUPLED TANK SYSTEM USING SIMULINK

The coupled tank is constructed from the flow equation which is mentioned above.

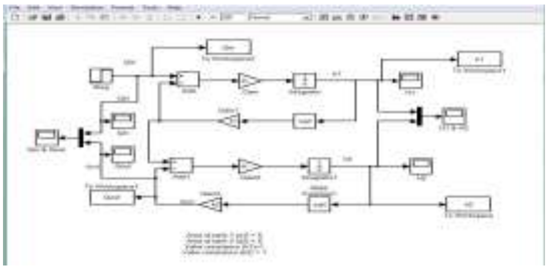


Fig. 2

Interacting Couple Tank Simulink Diagram

Fig. 2 shows the coupled tank with a step input (Qin) and the output is considered as the output flow (Qout).

The coupled tank system shown in fig. 2 consists parameters are:

A1 = 6cm2 = A2

k1 = 1cm5/2/s = k2

where,

A1, A2 = Cross Section areas

k1, k2 = Valve Resistances

DESIGNING / TUNING STRATEGIES: DETERMINING TUNING PARAMETERS FOR PI & PID CONTROLLER

Before determining tuning parameters for PI & PID Controller, we have to a little bit study of Process Reaction Curve of the plant, because this curve has play very important role in Ciancone and Cohn Cone methods. Without this these methods does not determine the tuning parameters for corresponding controllers.

Process Reaction Curve of the Plant:

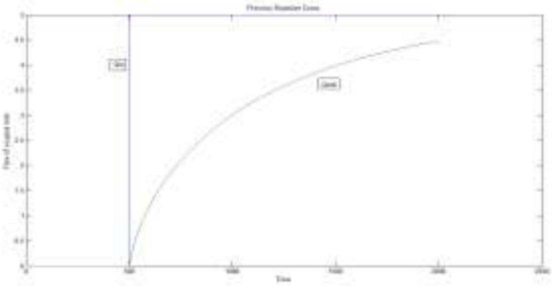


Fig. 3

Process Reaction Curve

Based on the relationship between the input and the output of the coupled tank shown in fig. 2, some parameters have been calculated using it such as process gain (Kc), dead time (θ) and time constant (τ). These parameters helped in determining the suitable controllers for the tank. This is also called "Process Reaction Curve".

Kc = 0.895, θ = 60 & τ = 498.

Using these values on three different approaches have been used to determine the suitable controllers which are Ciancone correlations, Cohen coon tuning correlations and Ziegler Nichols closed loop tuning correlations for PI and PID controllers.

Ciancone Correlations with PID Controller:

The proportional gain, the integral and derivative time are calculated from the parameters of the process reaction curve. The controller block is connected in series with the plant block as shown in the figure below:

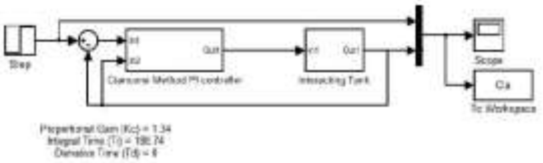
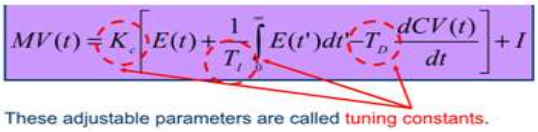


Fig. 4

Ciancone PID Block

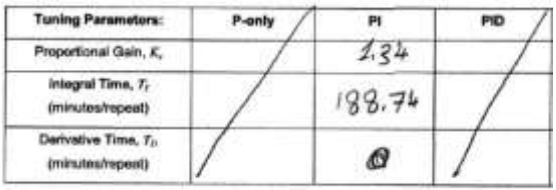
The Ciancone block is constructed from the PID formula where:



$$MV(t) = K_c\left[E(t) + \frac{1}{T_I}\int_0^t E(t')dt' - T_D\frac{dCV(t)}{dt}\right] + I$$

These adjustable parameters are called tuning constants.

Table 1 Tuning Parameters for Ciancone Method



Tuning Parameters:	P-only	PI	PID
Proportional Gain, K_c		1.34	
Integral Time, T_I (minutes/repeat)		188.74	
Derivative Time, T_D (minutes/repeat)		0	

The Ciancone block consists of the PID formula and the values of Kc, Ti and Td taken from above table1 & are added as shown below.

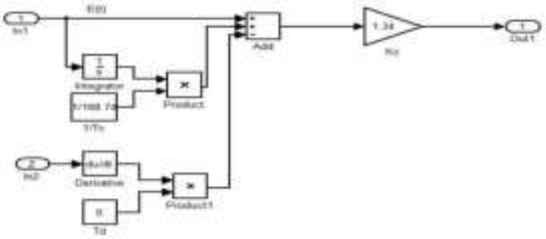


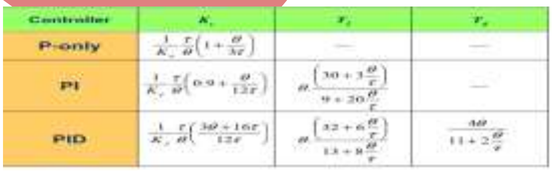
Fig. 5

Ciancone PID Block

Cohen Coon Tuning Correlations:

This is a second method which is used to calculate the tuning constants. The table below shows how to calculate them using the parameters obtained from the process reaction curve.

Table 2 Cohen Coon Calculations



Controller	K_c	T_I	T_D
P-only	$\frac{1}{K_p}\frac{\tau}{\theta}\left(1+\frac{\theta}{3\tau}\right)$	—	—
PI	$\frac{1}{K_p}\frac{\tau}{\theta}\left(0.9+\frac{\theta}{12\tau}\right)$	$\theta\frac{\left(30+3\frac{\theta}{\tau}\right)}{9+20\frac{\theta}{\tau}}$	—
PID	$\frac{1}{K_p}\frac{\tau}{\theta}\left(\frac{3\theta+16\tau}{12\tau}\right)$	$\theta\frac{\left(32+6\frac{\theta}{\tau}\right)}{13+8\frac{\theta}{\tau}}$	$\frac{4\theta}{11+2\frac{\theta}{\tau}}$

Similar to the Ciancone method, a Simulink block was constructed for the P, PI and PID controllers as shown.

Table 3 Tuning Parameters Cohen Coon Method

Controller	Kc	Ti	Td
P	9.646	---	---
PI	8.439	159.65	---
PID	12.64	140.6	21.33

By using the values as in table 3, we can obtained the simulink diagram.

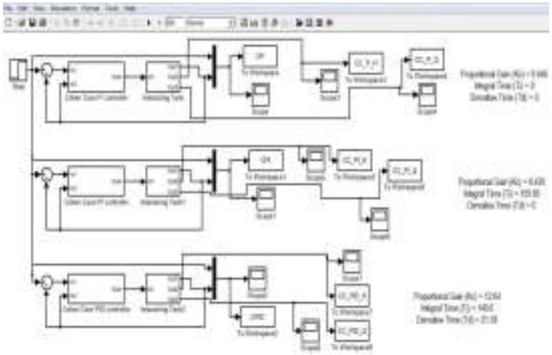


Fig. 6

Simulink Block for Cohen Coon Method

Since the PI and PID controllers showed better responses than the P controller, they will be discussed and analyzed.

Ziegler - Nicholas Closed Loop Method:

The third method which is used is the Ziegler- Nicholas. The calculation of the tuning parameters in this case doesn't depend on the process reaction curve like the previous two method, it is derived from the bode plot of the transfer function which is calculated from the coupled tanks.

In the figure below shows the bode plot of the plant. To ensure the stability of the system, we assume the phase degree to be -180, from that we can calculate the critical frequency (ωc) as well as the magnitude in decibel (ARC).

The ultimate gain (Ku) and the ultimate period (Pu) are then calculated using the following formulas:

$$K_u = \frac{1}{|G_{ol}(j\omega_c)|} = \frac{1}{AR_c} = \frac{1}{M} \qquad (7)$$

and

$$P_u = \frac{2\pi}{\omega_c} \qquad (8)$$

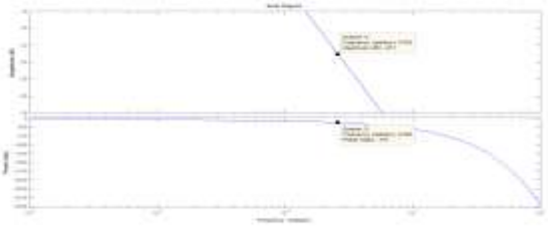


Fig. 7

Bode Plot of the Coupled Tank System

The simulink block is then constructed for the three controllers as shown in the previous methods. Since the performance of the PI and PID controllers showed better results than the P controller, they will be discussed only.

Table 4 Tuning Parameters for Z-N Method

Controller	Kc	Ti	Td
P	7.145	---	---
PI	6.495	161.11	---
PID	8.4	120.81	30.208

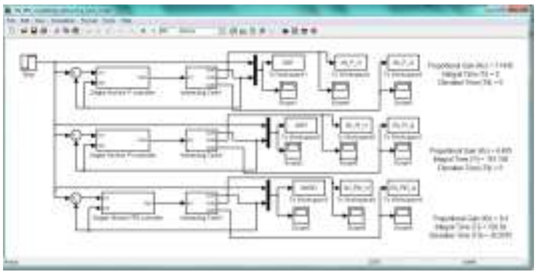


Fig. 8

Ziegler Nichols Closed Loop Method

Table 5 Ziegler Nicholas Closed Loop Calculations

Controller	K_c	T_i	T_d
P-only	$K_u/2$	–	–
PI	$K_u/2.2$	$P_u/1.2$	–
PID	$K_u/1.7$	$P_u/2.0$	$P_u/8$

SIMULATION RESULTS

Comparison between inputs of interacting coupled Tank & liquid level responses:

Fig. 9

Comparison Between for Tank1 Input & Tank1 Output

Fig. 10

Responses Comparison between Liquid Levels in Coupled Tank System

Fig. 9 shows the comparison of liquid input of tank 1 and input of tank 2 and fig. 10 shows the comparison response of Tank 1 & Tank 2 of coupled tank system without controller respectively.

Ciancone Method Responses:

The response of the levels with the Ciancone method showed a faster response than the original plant as well as for the input and output flow responses but the input flow experience a small overshoot.

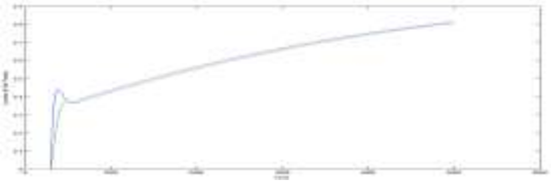


Fig. 11

Level of the tanks using Ciancone controller

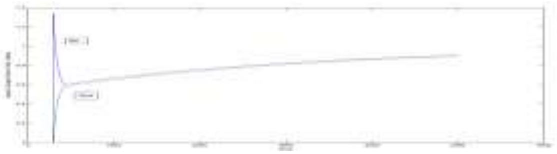


Fig. 12

Input & Output flow of Ciancone method

The response of the levels with the Ciancone method showed a faster response than the original plant as well as for the input and output flow

responses but the input flow experience a small overshoot.

Cohen Coon Method Responses:

Fig. 13

Level of the tanks of PI controller

Fig. 14

Flow of the PI Controller

The levels for the PI controller show better response than the Ciancone method and better settling time. The flow graph has also a fast response but Qin experience some overshoot at the beginning. This can be observed through the fig. 13 and 14.

In case of the PID controller, the levels have slower response than the PI controller while the input flow in this controller is very noisy and unstable which is unacceptable. The graphs for the levels and flow are shown as well.

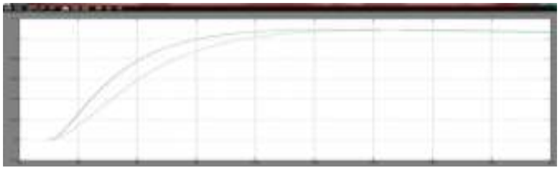


Fig. 15

Levels for PID Controller

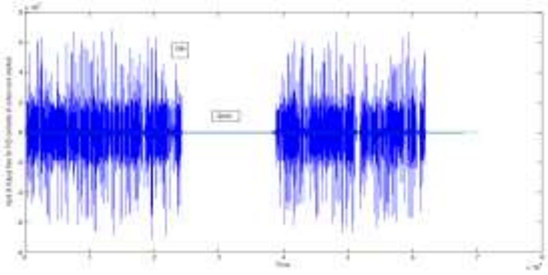


Fig. 16

Input & Output flow for the PID Controller

Ziegler – Nicholas Method Responses:

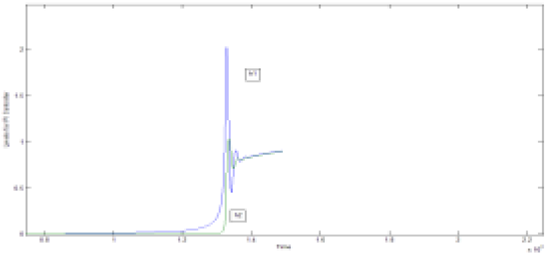


Fig. 17

Levels for the PI controller of ZN method

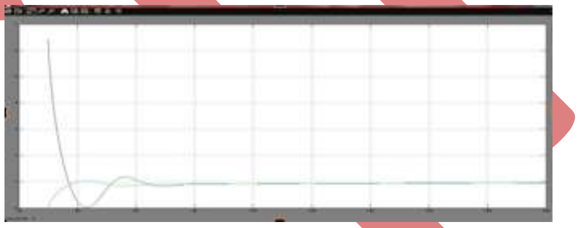


Fig.18

Flow for PI controller of ZN method

The graphs for the levels of the PI controller show similarities with the PI of the Cohen Coon method but its responses are slightly better. For the flow, the graphs are typical from the Cohen Coon method.

The PID controller shows the exact typical response with the Cohen Coon method for the levels as well as for the flow.

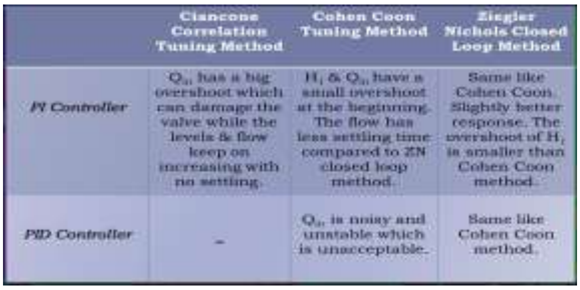
After discussing the performance of the controllers, the best controller is selected based on fast response, good settling time and low overshoot.

CONCLUSION

A model for a coupled tank system has been designed and several controllers have been tested (P, PI or PID controllers) and calculated by three different methods. The best controlled undergo fine tuning to get the best performance.

The table here summarizes or conclude the advantages and disadvantages of the controller used for the three methods. As shown, the Ciancone method has only PI controller where the other methods have PI and PID controllers.

Table 6 Comparison of performance between the three methods



	Ciancone Correlation Tuning Method	Cohen Coon Tuning Method	Ziegler Nichols Closed Loop Method
PI Controller	Q_{in} has a big overshoot which can damage the valve while the levels & flow keep on increasing with no setting.	H_1 & Q_{in} have a small overshoot at the beginning. The flow has less settling time compared to ZN closed loop method.	Same like Cohen Coon. Slightly better response. The overshoot of H_1 is smaller than Cohen Coon method.
PID Controller	-	Q_{in} is noisy and unstable which is unacceptable.	Same like Cohen Coon method.

After analyzing table 6, it was found that the PI controller of the Ziegler Nichols closed loop method is best controller with good performance.

h1 and Qin are observed to experience an overshoot in the controller so fine tuning was applied to the controller to enhance its performance.

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