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OPTIMAL PI TUNING RULES FOR LIQUID FLOW PROCESS CONTROL SYSTEM USING COHEN-COON'S (C-C), ZIEGLER-NICHOLS'S (Z-N) AND TAKAHASHI'S TUNING METHOD

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Abstract

The purpose of this paper is to find the optimum PI controller tuning method and tuning rule for bench scale flow system. In this paper highlighted tuning method using Ziegler-Nichols (Z-N), Cohen-Coon (C-C) and Takahashi in order to find which one is best tuning method for Liquid Flow Process Control Training System Model SE270-1. The control system for this bench scale model not yet been studied in detailed since its usage only restricted to educational purpose. Hence, two type of controller such as P and PI, two PI tuning rules and three tuning methods were analyzed based on overshoot, settling time and rise time. Open loop test has been performed by using tangent method and reformulated tangent method. The open loop test was used to calculate the Response Rate (RR), Dead Time (Td) and Constant Time (Tc) where the value was used in tuning method. Three performance tests are done using three different gain values which were PI and PI multiply by four. PI controller with Takahashi tuning method with gain value multiply by four is choose as best controller, the response obtained is stable and robust with no oscillation, no overshot and short rise time and settling time.

Keywords: Takahashi; PI controller; Fine Tuning; Flow control;

1.0 INTRODUCTION

Chemical industry consists of highly dynamic process and very difficult to handle without interrupting the goal (i.e. a quality product with economically optimum operation) due to complex network of chemical processes [1]. Flow system is very significance in making contribution on quality of product in industries. Its function to transfer fluid such as gases or liquid from one side to another side [2]. In this paper, flow control for Liquid Flow Process Control Training System Model SE270-1 is studied. This system simulates the water flow process control system. Three most popular controller modes are proportional only (P), Proportional + integral (PI) and proportional + integral + derivative (PID). The controller calculated an error value as the difference between a desired set point (SP) and measured process variable (PV) and applies a correction based on proportional (P), integral (I), and derivative (D) terms [3]. It has been founded that Derivative (D) can degrade the stability of the system when there is a time delay where the system will oscillate and never reach their steady state in feedback open loop. Meanwhile, Proportional (P) modes can only ensure the error value is eliminated [4]. Hence, for this system (PI) mode use as a controller to obtain fast response.

By using non suitable value for P, I and D in control system, the pilot plant system will operate under unstable condition above and below the set point [5]. It also difficult to achieve the accurate values and optimum parameter in controller tuning [6]. The optimum gain values for the pilot plant system not yet been identify. Hence, this study focuses on finding the optimum PI controller tuning for this pilot plant system and this finding can be used for future research or project. There are few tuning rules for tuning method known as the Ziegler-Nichols method (Z-N), introduced by John G. Ziegler and Nathaniel B. Nichols of Taylor Instruments in 1942 [7] such as open loop technique and closed loop technique. Second well-known tuning method known as Cohen Coon (C-C), the technique is by looking at the system's response to manual step changes without controller operating initial values for PID [6]. Third, Takahashi tuning method, the tuning rules developed in the 1950s using analogue and mechanical controllers. Both tuning method which are Ziegler-Nichols and Cohen Coon are the famous tuning method commonly used in industry. In this paper, all the tuning method mention above will be studied and two tuning rules will be compared. In this paper, methodology section will be divided by three which are equipment set up, operability of the equipment and tuning method and followed by result and discussion section and conclusion section.

2.0 METHODOLOGY

i. Equipment set-up of Liquid Flow Process Control Training System Model SE270-1

The liquid flow process control model consists of water pump tank, centrifugal pump, level transmitter, control valve and microprocessor controller. The diagram for liquid flow process is shown in Fig 1. [8].

Fig. 1 Liquid Flow Process Control Training System Model SE270-1

ii. Operability of Liquid Flow Process Control Training System Model SE270-1

Basically, the system started with 90% water is filled in sump tank. Pump P-101 is turned on to pump out the water through the pipeline. Valve HV102 and HV103 is manually regulated until flow reading reach 100%. The flow control process is connected to panel/DCS for variables adjustment and graphical presentation. The water flow is adjusted to 60 LPM and the set point of the model is set to 50LPM. The process is stabilized first in auto mode. Then switch the controller to manual mode to adjust the manipulated variable (MV). The value of gain P and I is set to certain value and controller is set to auto mode [8]. The initial value for manipulated variable (MV) and process variable (PV) has been recorded. Then the value of manipulated variable changed, by increasing the value. Once the process variable (PV) has increased and stabilized, the response is recorded.

iii. Tuning Method

Based on the response, the value of response rate (RR), dead time (Td), time constant (Tc) was calculated as below:
Tangent Method [9]:

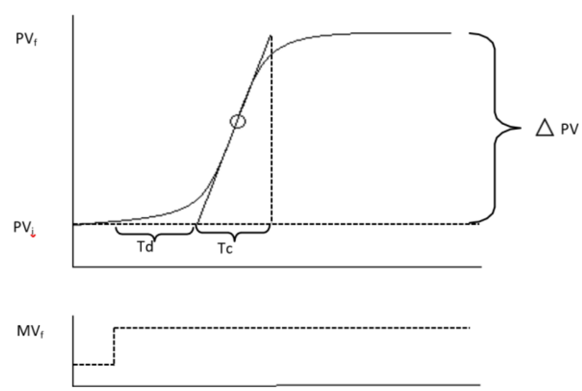

Fig. 2: Tangent method graph

Where

$$\Delta PV = PV_f - PV_I \quad (1)$$
$$\Delta MV = MV_f - MV_i \quad (2)$$

The response rate (RR) is calculated as follow,

$$RR = \frac{\Delta PV / \Delta t}{\Delta MV} \quad (3)$$

Reformulated Tangent Method [9]:

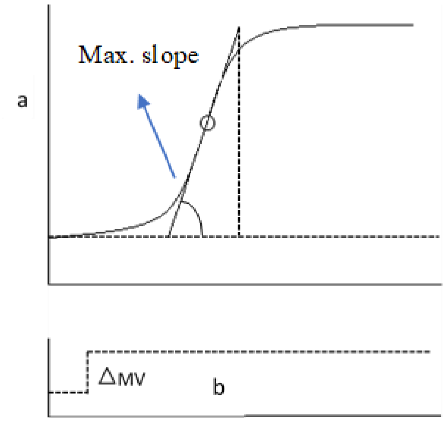

Fig. 3: Reformulated Tangent Method graph

$$RR = \frac{\tan\theta}{\Delta MV} \qquad (4)$$

The value of response rate (RR), dead time (Td) and time constant (Tc) was used. The tuning method that consist three tables which are Ziegler-Nichols (Z-N), Cohen-Coon (C-C), and Takahashi. The value of response rate (RR), dead time (Td) and time constant (Tc) will substitute in each tuning method listed in Table 1-4.

Table 1 Ziegler-Nichols Tuning Rules [9]

Mode	P	I	D
P	$100RRT_d$		
PI	$111.1RRT_d$	$3.33T_d$	
PID	$83.3RRT_d$	$2T_d$	$0.5T_d$

Table 2 Cohen Coon Tuning Rules [9]

Mode	P	I	D
P	$\frac{100}{1+\mu/3} RR\, T_d$		
PI	$\frac{100}{1+\mu/11} RR\, T_d$	$3.33\left[\frac{1+\mu/11}{1+11\mu/5}\right] Td$	
PID	$\frac{100}{1.35(1+\frac{\mu}{5})} RR\, T_d$	$2.5\left[\frac{1+\mu/5}{1+3\mu/5}\right] Td$	$\frac{0.37\, Td}{1+\mu/5}$

Table 3 Takahashi Tuning Rules [13]

Mode	P	I	D
P	$110RRT_d$		
PI	$110RRT_d$	$3.3T_d$	
PID	$77RRT_d$	$2.2T_d$	$0.45T_d$

3.0 RESULTS AND DISCUSSION

For the open loop test the response of the curve was analyzed by using two different methods which are Tangent Method (TM) and Reformulated Tangent Method (RTM) [12].

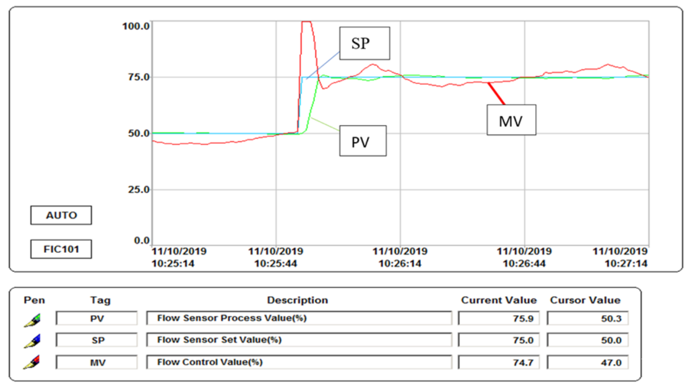

Fig. 4 Open Loop Test graph

Fig. 4 show the process curve of the MV from initial to final. Basically, the open loop test is depending on the change of MV. The first steady state for self-regulating process stabled at 50LPM. After the MV is increased the new steady state level reached at 75% LPM and it is stable condition.

Table 4 Open-Loop test result of RTM and TM

METHOD	RR(s)	Td(s)	Tc(s)
RTM	0.97	0.3	0.5
TM	1.70	0.3	0.5

Based on open loop test result as shown in Table 4, the value RR for TM method is higher compared to RTM. While the value of Td and Tc is same for the both methods. As a conclusion TM are more preferred to use because the RR value is high because small change of controller output gives faster process response rate. Flow control system are regarded fast loop that respond to change quickly [10].

Table 5 P values of three tuning method

TUNING METHOD	ZN	CC	TAKAHASHI
PB(%)	41.85	35.87	46.04

Table 5 shows the P value for ZN, CC and Takahashi rules tuning method by using tangent method and reformulated tangent method. The gain values obtained by TM method is used in closed loop response. The response obtained using those three methods are shown in Fig.4 -6.

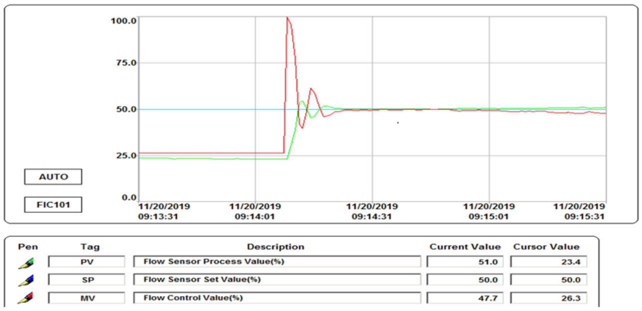

Fig. 5 ZN performance test for P value

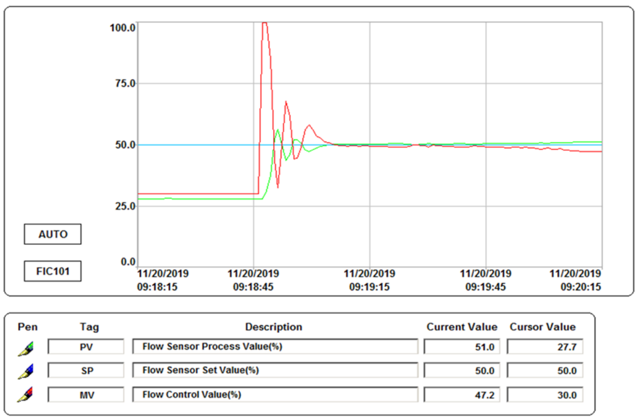

Fig. 6 CC performance test for P value

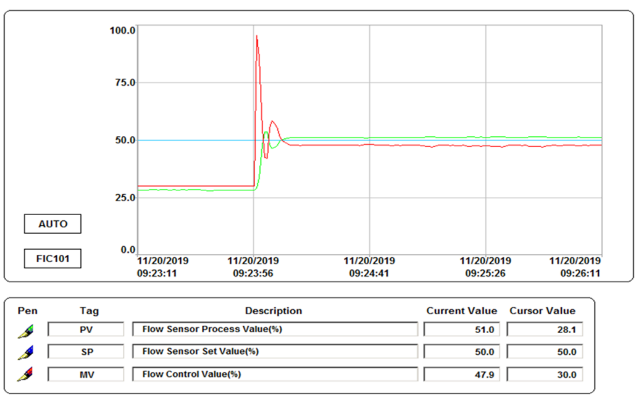

Fig. 7 Takahashi performance test for P value

From Fig. 5-7, the P controller successfully pushes the process variable nearly toward desired set point. However, response for P controller with Takahashi tuning method shows some error with an offset around 5% as shown in Fig. 7. Meanwhile, response for P controller with Z-N and C-C tuning method give no offset but a steady state error ± 2%. In order to overcome this problem PI controller is implemented since Integral controller function is to eliminate the steady state error and the responses are shown in Fig. 8-10 [13].

Table 6 PI values of three tuning method

TUNING METHOD	Z-N	C-C	Takahashi
PB(%)	16.67	14.22	16.50
I	1.00	0.45	0.99

Table 6 shows the PI gain values for ZN, CC and Takahashi tuning method using TM. The PI gain values used for closed loop tuning method based on RR, Td and Tc values obtained using TM. After the values of RR, Td and Tc substitute in tuning method the values of P and I was calculated.

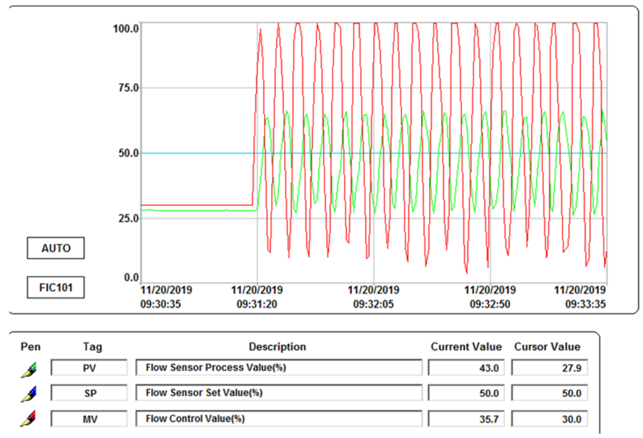

Fig. 8 ZN performance test for PI value

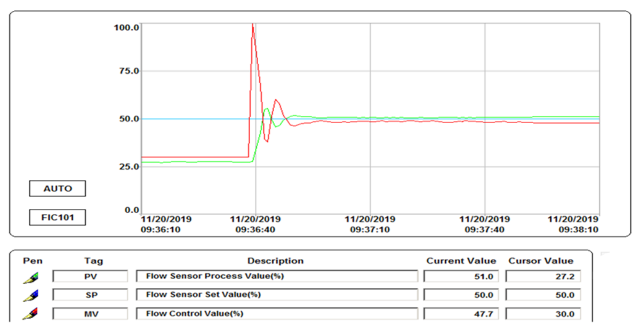

Fig. 9 CC performance test for PI value

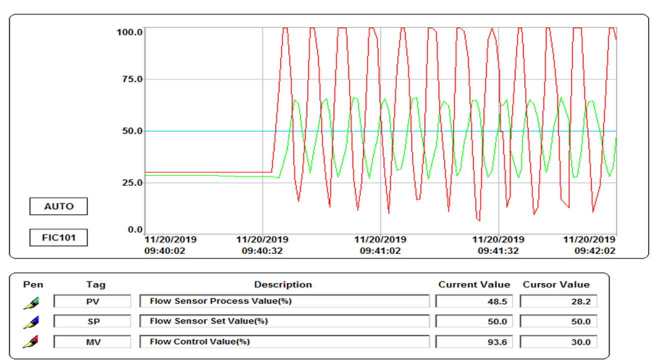

Fig. 10 Takahashi performance test for PI value

From the Fig. 8-10, the responses are recorded up to 3 minutes. From the response the C-C tuning method provide the best response with no oscillation and achieved desired set point successfully as shown in Fig. 9. Meanwhile, Z-N and Takahashi tuning method responses are oscillated from the start to the end. These shows that the gain values using by both tuning methods are not suitable for this system. In order to counter the problem above, the fine tuning must be performed by multiply the gain values by four is implemented to improve P and I gain values [9].

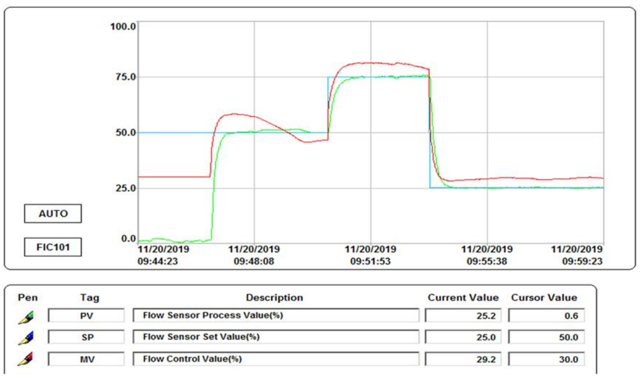

Fig. 11 (ZN) PI values multiplication by 4

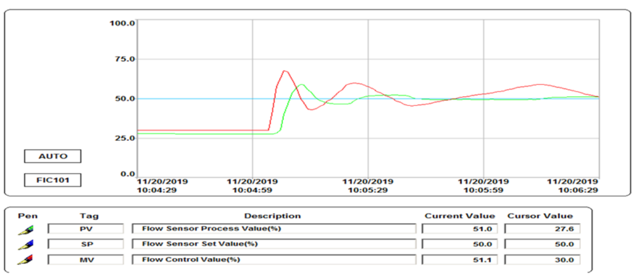

Fig. 12 (CC) PI values multiplication by 4

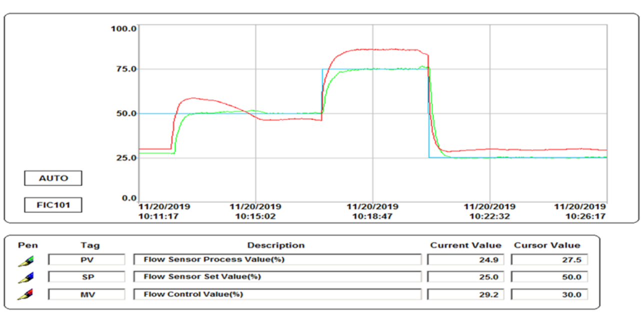

Fig. 13 (Takahashi) PI value multiplication by 4

From Fig. 11-13, the responses for all three tuning method obtained are improved as compared to previous tuning rules techniques. The responses obtained by Z-N tuning method and Takahashi tuning method achieved set point successfully with no overshoot and no offset as shown as Fig. 11 and Fig. 13. Meanwhile, the responses obtained by Takahashi tuning method shows shortest settling time (1.5 minutes) and rise time (1 minutes) as compared to Z-N and C-C tuning method. Slight overshot are appeared in C-C tuning method's response as shown in Fig. 11. Fig. 11 also shown, the rise time and settling time are higher compared to Z-N and Takahashi tuning method.

4.0 CONCLUSION

Two tuning method and three tuning rules is analyzed in order to obtain the best P and I gain values for the systems. Beforehand, response for P controller also taken. Based on the response, PI controller is more suitable due to its capability to eliminate the steady state error produced by P controller. Fine tuning is needed to increase the gain value of P or I by multiplying it with four to get a stable and robust responses. Based on the study, D value are not necessary in flow because PI controller is enough to stabilize the process and provide fast response. Among the two rules and three methods, the optimum tuning method and rules for flow system is tangent method using Takahashi with the gain value multiply by four. The multiplication of PI by factor four because the value of PI is too small and unable to control the system sufficiently. Takahashi tuning method able to ensure the response obtained for this flow system is stable and robust with lesser rise and settling time, no overshot and no offset. Advanced control tuning method such as IMC or MPC can be considered to improve the rise time and settling time for current method. Moreover, further study can be done to compare the performance of TM and RTM on a flow control system.

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References

[1] Sujit Anandrao Jagnade, Rohit Ashok Pandit, Arshad Ramesh Bagde, Modeling, Simulation and Control of Flow Tank System, International Journal of Science and Research, 4 (2015) 657-669.

[2] Saswat Sambit, Simulation and Flow Analysis Through a Straight Piped, Thesis of Bachelor of Technology in Civil Engineering, Department of Civil Engineering National Institute of Technology, Rourkela.

[3] L. Ntogramatzidis, Exact Tuning of PID Controllers in Control Feedback Design Exact Tuning of PID Controllers in Control Feedback Design, The International Federation of Automatic Control, 44 (2011)5759-5764.

[4] K. H. Ang, G. Chong, S. Member, and Y. Li, PID Control System Analysis, Design, and Technology, IEEE Transactions on Control Systems Technology,13 (2005) 559–576.

[5] Swaminathan Meenatchi Sudaram, Tathagata Dey, Empirical Model Identification and PID Controller Tuning For A Flow Process, International Journal of Pure and Applied Mathematics, 118 (2018)2015–2021.

[6] Mohd Fadzli Bin Mohd Noris, Comparison Between Ziegler-Nichols and Cohen-Coon Method For Controller Tunings, Thesis of Bachelor of Chemical Engineering Faculty of Chemical & Natural Resources Engineering University College of Engineering & Technology Malaysia.

[7] F. Haugen, "Article : Ziegler-Nichols ' Closed-Loop Method, (2010) 1–7.

[8] Worlddidac. Process Control Booklet 2014 (output) - Solteq. 2014.

[9] N. Hambali, A. Masngut, A. A. Ishak, and Z. Janin, Process Controllability for Flow Control System Using Ziegler-Nichols (ZN), Cohen-Coon (CC) and Chien-Hrones-Reswick (CHR) Tuning Methods, IEEE International Conference on Smart Instrumentation, Measurement and Applications, 2014.

[10] A. A. Ishak, Reformulation of The Tangent Method For PID Controller Tuning, Proceeding to TENCON2000, 2000.

[11] N. Hambali, M. Nazmi, and K. Zaki, Reformulated Tangent Method of Various PID Controller Tuning for Air Pressure Control, 2012 IEEE International Conference on Control System, Computing and Engineering, 2012.

[12] N. Hambali, A. Ab. Rahim Ang, A. A. Ishak, Zuriati Janin, Various PID Controller Tuning for Air Temperature Oven System, IEEE International Conference on Smart Instrumentation, Measurement and Applications, 2014.

[13] C. F. Beards., Engineering Vibration Analysis with Application to Control Systems, Elsevier Ltd, London, 1995.