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Abstract - **Temperature controllers are needed in any situation requiring a given temperature be kept stable. This can be in a situation where an object is required to be heated, cooled or both and to remain at the desired temperature, regardless of the changing environment around it. The purpose of this study is to compare the performance of three controller tuning methods for an air oven temperature control system. The controller parameters, response rate and dead time are determined by using Reformulated Tangent Method in open- loop test. Then, the optimum Proportional-Integral-Derivative value are determined by using Ziegler-Nichols, Chien et al. and Takahashi tuning methods. The performance of each tuning rule is analyzed in the closed-loop characteristics such as percent overshoot, setting time, rise time and integral absolute error. The fine tuning technique was implemented to improve the result which the value of Proportional-Integral-Derivative gains were tuned. The result presented that the Ziegler-Nichols tuning method give better performance compared to Chien et al. and Takahashi tuning methods.**

Key Words: Temperature Control, Reformulated Tangent Method, Open-Loop Test, PID Tuning, Fine Tuning

I. INTRODUCTION

More than 90% of industrial use Proportional-Integral-Derivative (PID) controller on process control field. In general, the temperature controls usually use in industrial control systems are uniform velocity temperature control mode and constant-temperature heating mode. PID controller is better compared to P and PI controller for temperature control by increasing the accuracy [1].

But, nowadays a lot of improvement from conventional PID control method to more sophisticated control method in order to get the best performance. The controller used such as fuzzy based intelligent controller for industrial furnace temperature system [2] and self-tuning fuzzy controller for water flow rate control [3], steam curing system [4], and fluidized bed combustor control [5]. In [6, 7], a combination of fuzzy control with conventional PID had improved the performance of the temperature control systems with smaller overshoot, better accuracy and stability.

Various types of controller tuning method used to achieve the optimum response such as Ziegler Nichols, Takahashi, Chien et al, Cohen-coon and Chien-Hrones-Reswick. Another method is the Genetic Algorithm (GA) optimization technique, pole-placement method and Particle Swarm Optimization (PSO) [8, 9]. GA-Adaptive Neuro Fuzzy Inference System (GA-ANFIS) was the best method to water bath temperature control system [10]. Tuning method using Tyreus-Luben had better in rise time, settling time, delay time and less overshoot compared to Modified Ziegler-Nichols and approximate to Ziegler-Nichols methods [2]. The optimum tuning of temperature process control for overdamped process response was found by using fine tuning method [11]. This paper presents the comparison of three classical PID tuning methods ZN, Chien and Takahashi by analyzes the closed loop response performance based on rise time (Tr), settling time (Ts), percent overshoot (%OS) and integral absolute error (IAE). The objective of this work is to achieve the best optimum PID performance.

There are a lot of methods have been used by researchers to control the temperature control system in the industry. The several methods used are integrated method of intelligent decoupling control for regenerative pusher-type furnace temperature control system, recurrent Neural Network (NN) to estimate zone temperature [12]. A step response identification method was implemented to obtain an integrating model for heating-up control design that apply to barrel temperature control of injection-molding machine. This method caused no overheating using internal- model-control (IMC) [4]. Increase or decrease scaling factors affected the temperature control of shell and tube exchanger system [13].

By using simplest tangent method technique, Reformulated Tangent Method (RTM) transforms the process response rate into trigonometric function to get the optimum PID [14, 15]. It analyzes the open-loop test response by reducing the analyzing steps to get the reaction rate and improves in data extraction speed. The various classical PID controller tuning methods such as Ziegler-Nichols (ZN), Chien-Hrones-Reswick (CHR) and Chien et al. (Chien) were proposed to control the air pressure control by using RTM for open-loop test. It presented that ZN has the best rise times, settling times and smaller IAE [16]. While in [17], Cohen-Coon (CC) tuning method showed the best performance for air temperature oven control system using RTM in open-loop test as compared to ZN and CHR methods. In this paper, thermocouple sensor has been used for temperature measurement instead of RTD.

The objective of this paper is to analyze the performance of an air temperature oven control system by using RTD as a temperature sensor. RTM technique has been used in open-

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loop test followed by three PID tuning methods in closed-loop test. The best performance in closed-loop test has been selected for fine tuning technique.

I. AIR TEMPERATURE OVEN SYSTEM

The air temperature oven is a simple temperature control system where temperature in a chamber is controlled to the desired temperature set via a controller. It is a single loop controller that receives signals from thermocouple (TC) or resistance temperature detector (RTD) PT100 and controls the heater power through a selector with continuous output current control. The control panel is connecting to a Distributed Control System (DCS) via the Human Interface Station (HIS). Figure 1 shows the model of the air temperature oven control system desktop.

Figure 1: Air temperature oven system

This project had been extended by using RTD as a temperature sensor as suggested in [17]. The controller functions, parameter setting, trending, setpoint adjustment, push button and selector switch operate from HIS computer terminal. The operating condition of the oven heating system such as the oven operating temperature range and disturbance need were selected. The schematic diagram of the air temperature oven control system is shown in Figure 2.

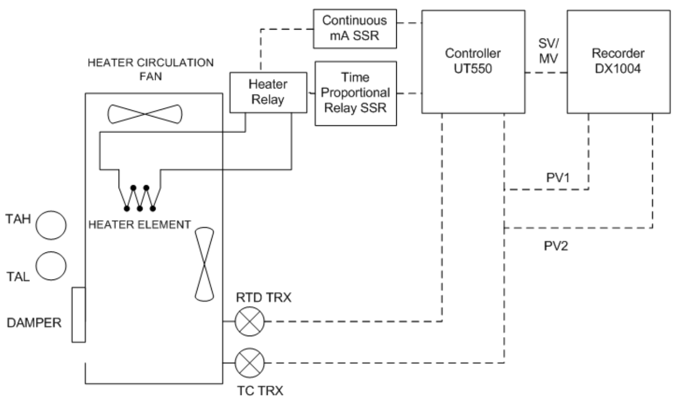

Figure 2: Schematic diagram for air temperature oven control system

II. REFORMULATED TANGENT METHOD

To stabilize the temperature, the open-loop test was performed. For open-loop test, manual mode is used. To determine the controller parameters, the simple loop test has been performed by using the Reformulated Tangent Method [14, 15]. Figure 3 shows the output response of the open-loop test for typical process [16, 17].

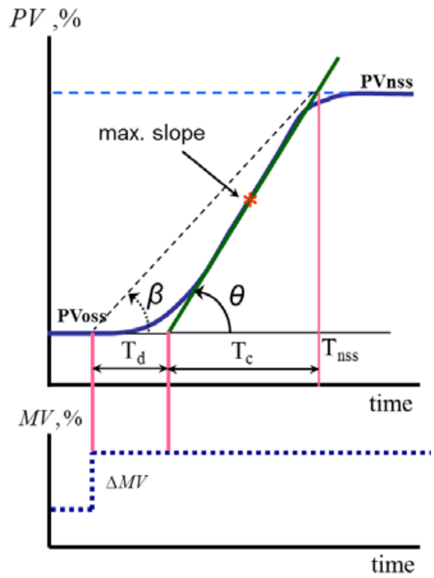

Figure 3: Transforming process rate into trigonometric form

Response rate, RR:

$$RR = \frac{(\frac{\Delta PV}{\Delta t})}{\Delta MV} \tag{1}$$

$$\frac{\Delta PV}{\Delta t} = \tan\theta \, \frac{a(\%\, length)}{b(\%\, length)} \tag{2}$$

Dead time, Td:

$$Td = b\left(\frac{time}{length}\right) X\, length \tag{3}$$

Where;

RR : reaction rate, 1/time
ΔPV : change in measurement, %
Δt : change in time, time
ΔMV : change in controller's output, %
a : scaling factor for y-axis, %/length
b : scaling factor for x-axis, time/length

III. PID CONTROL & TUNING

The general PID algorithms form of the Yokogawa CS3000 as in (14);

$$MV = \frac{100}{P}\left[E(t) + \frac{1}{I}\int E(t)dt + D\,\frac{dE(t)}{dt}\right] \qquad (5)$$

Where:

MV : Manipulated Variable
E(t) : Error
P : Proportional Band
I : Reset Time, Second
D : Derivative Time, Seconds

Basically, the performance of the PID controller is dependent to the adjustment of the proportional, integral and derivative actions which known as tuning. Table I shows three tuning methods that are used in this work.

TABLE I: TUNING METHOD

Method	PB, %	I	D
ZN	83.3 Td R_R	2.0 Td	0.5 Td
Chien	105 Td R_R	1.35 Td	0.47 Td
Takahashi	77 Td R_R	2.2 Td	0.45 Td

IV. METHODOLOGY

Firstly, the simple open-loop test was performed to determine the value of RR and Td by using RTM. In addition to that, the desired temperature was set to 45°C. The response curve from the open-loop test was then analyzed using the RTM to obtain the related process information.

In the second phase, the value of PB, I and D were calculated using three tuning methods as in Table I. Then the experiment was done with set point change operation in automatic mode or closed-loop of DCS. From the closed-loop response curve, the value of T_r, T_s, %OS and IAE were analyzed.

Finally, the best performance among the three tuning methods was selected to implement the fine tuning technique in order to get the best overdamped response in term of T_r, T_s, %OS and IAE.

V. RESULTS AND DISCUSSION

A. Open-Loop Test : Reformulated Tangent Method

Figure 4 presents the self-regulating output response of the open - loop test. A manipulated variable (MV) change performance was set from 30% to 45% which is Δ15%.

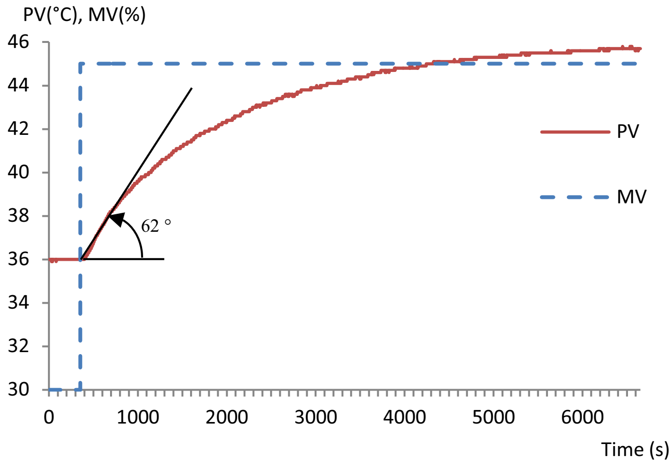

Figure 4: Open-loop result of ΔMV 15%

As can be seen, Figure 4 above shows that the old steady state was stabled at 36 °C before a load change was applied in the process. About two hours time was needed to reach a new steady state, 45 °C.

$$\frac{\Delta PV}{\Delta t} = \tan 62^{\,0}\,\frac{\frac{1\%}{11.4}mm}{\frac{200s}{10.4}mm} = 0.0858\ \%/s$$

The reaction rate, RR is

$$RR = \frac{0.08579\ \%/sec}{15\%} = 0.000572/s$$

The dead time, Td is

$$Td = \frac{200\ s}{10.4\ mm}(2.8\ mm) = 53.83\ s$$

B. Closed-Loop Test : PID Tuning

The value of proportional band, integral time and derivative time were determined by using three tuning methods as in Table I.

Table II below provided the PID values that used for closed-loop tuning method.

TABLE II: PID VALUE OF THREE TUNING METHODS

Tuning Method	PB (%)	I (s)	D (s)
ZN	2.565	107.660	26.915
Chien	3.233	72.671	25.300
Takahashi	2.371	118.426	24.224

Figure 5 below illustrates the output result for ZN, Chien and Takahashi response when SV is set to 55 °C.

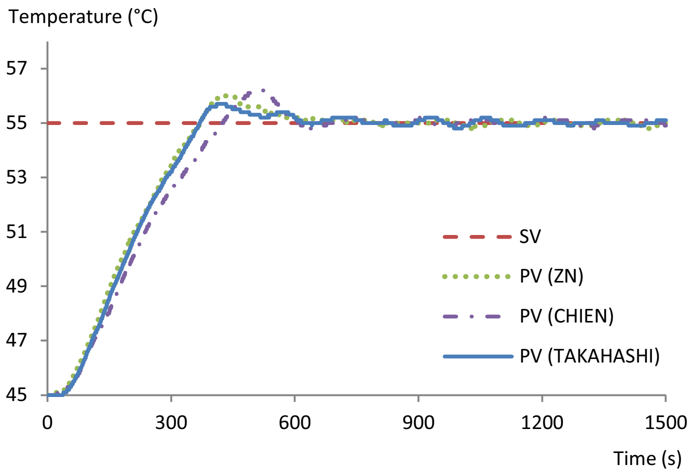

Figure 5: Closed-loop result for three tuning methods

In time response specifications, Figure 5 indicates that ZN was achieved rise times, setting times and IAE of 368 s, 804 s and 2000 respectively with 1.0 % overshoot. Followed by Takahashi, the rise time and settling time were 368 s and 817 s respectively, with 0.7 % overshoot and IAE of 2400. While for Chien the rise time was 422 s, settling time was 812s, IAE was 2100 with 1.2 % overshoot. The analysis of ZN and Takahashi revealed both responses were approximate with the same value of rise time. Takahashi performed the smallest percent overshoot, but higher on settling time and IAE as compared to ZN. Table III shows the corresponding rise time, settling time, %OS and IAE for closed-loop system between these three tuning methods.

TABLE III: CONTROL PERFORMANCES FOR DIFFERENT TUNING METHODS

Tuning method	Tr (s)	Ts (s)	% OS	IAE
ZN	368	804	1.0	2000
Chien	422	812	1.2	2400
Takahashi	368	817	0.7	2100

C. *Fine Tuning*

In this study, fine tuning technique was selected for ZN closed-loop test by using the multiplication factor of 2^n as shown in Table IV. The 2^5 factor was used for PB for the first and second fine tuning and 2^6 for the third fine tuning. While for I and D value, 2^2 factor for the first and third fine tuning and the second fine tuning used multiplication factor of 2^3.

TABLE IV: ZN PID VALUE BEFORE AND AFTER FINE TUNING

ZN tuning method	PB (%)	I (s)	D (s)
Before Fine Tuning	2.565	107.660	26.915
1st Fine Tuning	82.080	430.640	107.660
2nd Fine Tuning	82.080	861.280	215.320
3rd Fine Tuning	164.160	430.640	107.660

Figure 6 compares the result of the ZN tuning method before and after fine tuning has been done.

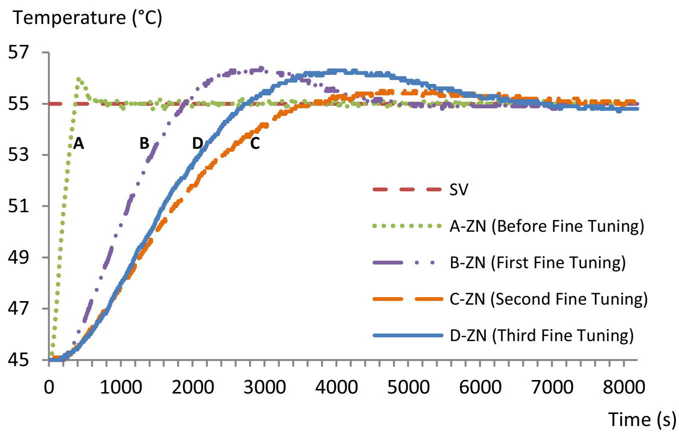

Figure 6: Fine tuning of ZN output response

Based on Figure 6, all the three fine tuning performances of ZN had increased in rise time, settling time and IAE as compared to the closed-loop test before fine tuning. Except for the percent overshoot, the second fine tuning reduced it by 0.5 % compared to 1.0 % before fine tuning. In comparison to the first fine tuning, using the same value of I and D but higher value of PB in the third fine tuning, the percent overshoot decreased by 0.1 %.

However, for the second fine tuning, the higher value of I and D decreased the percent overshoot from 1.4 % for the first fine tuning to 0.5 %. In addition, the higher value of PB and lower value of I and D produced lower rise time and settling time in the third fine tuning as compared to the second fine tuning. Table V summarizes the performance before fine tuning with the three fine tuning methods.

TABLE V: ZN COMPARISON FOR FINE TUNING

ZN tuning method	Tr (s)	Ts (s)	% OS	IAE
Before Fine Tuning	368	804	1.0	2000
1st Fine Tuning	1867	5440	1.4	12600
2nd Fine Tuning	3609	7255	0.5	17350
3rd Fine Tuning	2707	6933	1.3	17800

VI. CONCLUSION

The analysis of various tuning methods for air temperature oven control system were discussed. The open-loop test response was analyzed by using Reformulated Tangent Method. The performances of three classical tuning methods which are ZN, Chien and Takahashi controllers were analyzed in terms of time response specifications. For closed-loop system, the performance of ZN method and the Takahashi method were approximate to each other, but ZN method was better in stability than Takahashi. In fine tuning technique, the larger the factor of fine tuning, the response went toward overdamped response, but produced higher rise time, settling time and IAE.

In the future work, it is suggested to proceed with the comparison amongst various open-loop test response curve calculation method such as tangent method, ultimate gain and process reaction curve methods, hence this project used RTM only. In addition, the performance comparison analysis between RTD and thermocouple sensors using the same open-loop test and PID values can be done using the same MV and setpoint change. Furthermore, various load changes of MV and setpoint change value in open-loop and closed-loop test respectively can be used to compare the performances. For fine tuning, another n multiplication factor value can be implemented to improve the closed-loop test performance.

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