ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 3, March 2014

Comparison of Tuning Methods of PID Controllers for FOPTD System

K. Mohamed Hussain[1], R. Allwyn Rajendran Zepherin[2], M. Shantha Kumar[3]

UG Scholars, Department of Instrumentation and Control Engineering, Saranathan College of Engineering Trichy [1,2,3]

Abstract: Temperature Measurement is one of the major controlling parameter in Industries like Level, Flow, Pressure etc. One of such Temperature processes is taken in this paper and Modelling of the Process has been carried out and Transfer function of the Single Input Single Output (SISO) system. For the particular temperature process controller transfer function has been determined and control parameters such as Proportional Gain, Integral Time and Derivative time are identified. They are numerous methods of developing a Proportional Integral and Derivative (PID) Controller, amongst them some methods are adopted in this paper and Comparisons of Time Domain specifications of those controllers has been carried out and Performance Index metrics such as Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE), Mean Square Error (MSE) of those controllers are also compared. The Results are obtained from above comparisons and the optimum controller has been identified.

Keywords: PID controller, FOPTD, IAE, ITAE, ISE, MSE.

I. INTRODUCTION

Proportional Integral and Derivative (PID) Controllers are widely used in Process and Control Industries because of their simple design, easy to use and robustness characteristics. Ziegler and Nicoles introduced a PID controller during 1940s, it is the basic controller that is used in Industries and Research purposes till now. Some of the PID Controllers are mentioned in this paper with their characteristics. PID Controller is designed by obtaining the basic transfer function of a process. In this paper, the Transfer function of the Temperature process is determined. Using the Process Transfer function, the dead time, Gain, Time constant are calculated and hence by using those parameters controller parameters such as Proportional Gain, Integral Time, Derivative Time are determined and the Transfer function of the PID Controller has been obtained [1].

If Gc(S) is the Transfer function of PID Controller then,

$$Gc(S) = Kp\left[1 + \frac{1}{TIS} + TDS\right] = Kp + \frac{KI}{S} + KDS \ldots.. \quad (1)$$

Where,

K_P is the Proportional Gain
K_I is the Integral Gain
K_D is the Derivative Gain

The characteristics of PID Controller is that

- It can predict the future errors also and hence can provide better performance.
- It reduces offset which is a drawback of Proportional Controller.
- It has less overshoot compared to Proportional Integral Controller.
- It has faster response than Proportional Integral Controller.

The main disadvantage of a PID Controller is that they can only be used along with Proportional or Proportional Integral Controller.

This paper consists of the following sections:

Experimental Setup of the Temperature Process. In that, Determination of Process transfer function and identification of parameters such as Time constant, Dead time, Gain are done. Tuning methods of various PID Controllers. In that, ZN-II PID Controller, CHR PID Controller, TL PID Controller, IMC PID Controller, Damped Oscillation PID Controller, Modified ZN PID Controllers are used.

Minimum Error Criteria Tuning method. In that, the Performance Index metrics such as Integral Absolute Error (IAE), Integral Square Error (ISE), Integral Time Absolute Error (ITAE), Mean Square Error (MSE) methods are adopted.

Comparison and Result. In that, the comparisons of Time domain specification of the PID Controllers mentioned above are compared and Performance indices of error criteria are also compared. The result is obtained by those comparisons.

Analysis of Robustness. In that, the Process Control performance for the 20% decrease or increase in the Gain, Time constant, Dead time is determined and Transfer Function for the analysis is also obtained.

Conclusion. The Best Controller for the Process has been determined and characteristics are studied.

II. EXPERIMENTAL SETUP OF TEMPERATURE PROCESS

The Temperature Process consists of a heating tank system, with Solid Switch Relay (SSR). It has Rota meter to measure the Flow of the liquid(water). The type of control used here is SCADA. The temperature is sensed or detected by using a RTD PT 100. A transmitter which converts the process signal into 4-20 mA range output is used here. The Output detected is fed back to the controller and it is converted in terms of temperature rise or fall. Hence, the process can be controlled.

The following are the specifications for the Temperature Process:

Rota meter: 6-60 LPH
Process Tank: SS304, Capacity 0.5 lit, insulated
Type of Control: SCADA

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 3, March 2014

Control Unit: Digital indicating controller with RS 485 Communication

Communication: USB port using RS 485-USB converter

Temperature Sensor: Type RTD, PT 100

Heating Control: Proportional power controller(SSR), input 4-20mA D.C., Capacity 20 A

Overall dimensions: 400w*400D*330H mm

A step input is applied to solid state relay (SSR) and temperature of RTD (PT 100) is recorded in excel format. Stored data is used to plot open loop step response in MATLAB.

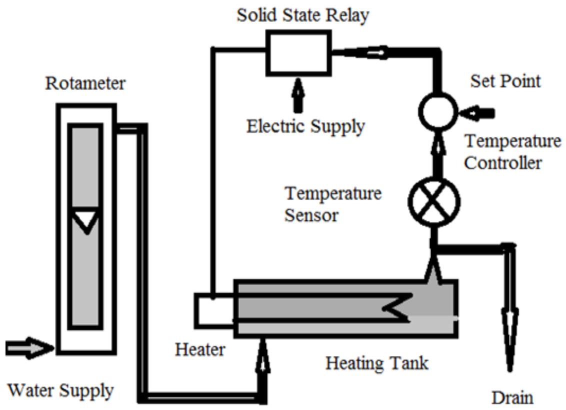


Fig.1 Experimental Setup for Heating Tank[2].

A. Determination of Process Transfer Function

The Process Transfer Function has been determined by the Experimental Process mentioned above. The Experiment is carried out and the response is taken until the steady state is reached without the use of the controller. The response of that process without controller will be a curve with some dead time and steady state time. By that, Gain of the process can be determined which is the ratio of output to the input, Time Constant can be calculated which is the time difference from dead time to steady state and Dead time (i.e) the time period for which the output is not responding to the input is also determined.

The Transfer Function of the Process will be of the form:

$$G(s) = \frac{kp\ e^{-tds}}{\tau s + 1}$$

Where,

$k_p$is steady state gain of system,

τ is time constant of system

$t_d$is dead time of system.

Hence, we obtain the First Order Plus Dead Time (FOPTD) Transfer Function form the above Temperature Process as,

$$Gp(s) = 2.2 * \frac{e^{-6s}}{40.484s+1} \ldots \quad (2)$$

Where,

$Gp(s)$ is the Process Transfer function.

(Water flow through Rota meter is kept at 40 LPH) [1]

B. Block Diagram of Closed Loop System With Controller

The Block Diagram of the Closed Loop system with Controller is shown in Fig.2

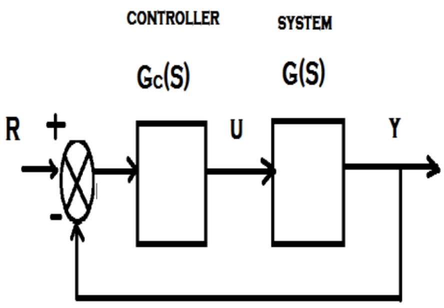


Fig.2A single loop controller configuration [1]

Where,

R is the input of the Plant.

Gc(S) is the Controller Transfer Function and

G(S) is the Process Transfer Function.

Y is the Desired Output obtained.

III. TUNING METHODS OF VARIOUS PID CONTROLLERS

PID controller transfer function is:

$$G(S) = Kc\left(1 + \frac{1}{\tau i s} + Td\right) \ldots \quad (2)$$

Where

k_c= proportional gain

T_I= Integral time

T_D= derivative time

A. Closed Loop Ziegler-Nichols Method

This method is a trial and error tuning method based on sustained oscillations that was first proposed by Ziegler and Nichols(1942) [14]. This method that is probably the most known and the most widely used method for tuning of PID controllers is also known as online or continuous cycling or ultimate gain tuning method. Having the ultimate gain and frequency (Ku and Pu) can be obtained, the controller parameters can be obtained. A ¼decay ratio has considered as design criterion for this method [4].

Proportional, integral and derivative constants are K_C=3.948 K_I=0.456 K_D=8.5425

The disadvantages of this technique are:

- It is time consuming because a trial and error procedure must be performed
- It forces the process into a condition of marginal stability that may lead to unstable operation or a hazardous situation due to set point changes or external disturbances.
- This method is not applicable for processes that are open loop unstable.
- Some simple processes do not have ultimate gain such as first order and second order processes without dead time [15].

B. Modified Ziegler-Nichols Methods

For some control loops the measure of oscillation, provide by ¼ decay ratio and the corresponding large overshoots for set point changes are undesirable therefore more conservative methods are often preferable such as modified Z-N settings [4].

Proportional, integral and derivative constants are K_C=2.1714 K_I=0.25 K_D=12.528

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 3, March 2014

C. Tyreus – Luyben Method

The Tyreus-Luyben procedure is quite similar to the Ziegler–Nichols method but the final controller settings are different. Also this method only proposes settings for PI and PID controllers. These settings that are based on ultimate gain and Like Z-N method this method is time consuming and forces the system to margin if instability [4].

Proportional, integral and derivative constants are K_C=2.05625 K_I=0.054 K_D=5.6485

D. Damped Oscillation Method

This method is used for solving problem of marginal stability. The process is characterized by finding the gain at which the process has a damping ratio of ¼. And the frequency of oscillation at this point, then similar the Ziegler-Nichols method these two parameters are used for finding the controller settings [4].

Gd = Proportional gain at decay ratio of ¼

Pd= Period of oscillation.

Proportional, integral and derivative constants are K_C=3.201 K_I=0.665 K_D=6.156

E. The C-H-R Method

This method that has proposed by Chien, Hrones and Reswich is a modification of open loop Ziegler and Nichols method. They proposed to use "quickest response without overshoot" or "quickest response with 20% overshoot" as design criterion. They also made the important observation that tuning for set point responses and load disturbance responses are different.

To tune the controller according to the CHR method the parameters of first order plus dead time model are determined in the same manner of the Z-N method [4,1].

Proportional, integral and derivative constants are K_C=3.6803 K_I=0.306 K_D=11.04

F. Internal Model Control (IMC)

Morari and his co-workers have developed an important new control system strategy that is called *Internal Model Control* or *IMC*. The IMC approach has two important advantages:

- It explicitly takes into account mode luncertainty and
- It allows the designer to trade-off control system performance against control system robustness to process changes and modelling errors [4].

Proportional, integral and derivative constants are K_C=3.084 K_I=0.071 K_D=1.723

IV. MINIMUM ERROR INTEGRAL CRITERIA TUNING METHODS

The shape of the complete closed loop response, from time t=0, until steady state has been reached, could be used for the formulation of a dynamic performance criterion. Unlike the simple criteria of this category are based on the entire response of the process.

The most often used are,

Integral of the Absolute Error (IAE) where

$$\mathbf{IAE}= \int_0^{\infty} | e(t) |.dt$$

Integral of the Square Error (ISE) where

$$\mathbf{ISE}= \int_0^{\infty} e^2(t).dt$$

Integral of the Time-Weighted Absolute Error (ITAE) where

$$\mathbf{ITAE}=\int_0^{\infty} t\,|e(t)|.dt$$

Integral of the Time-Weighted Square Error or Mean Square Error (MSE) where

$$\mathbf{MSE}=\int_0^{\infty} t.e^2(t).dt$$

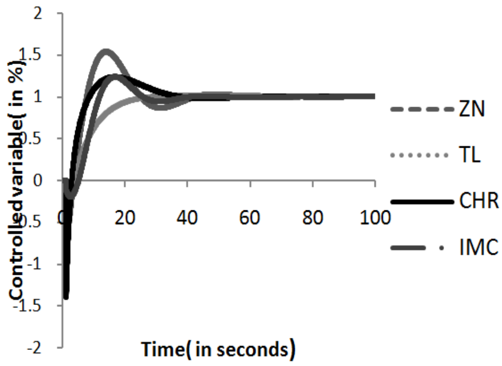
Where e(t) = Ysp(t) – Y(t) is the deviation (error) of the response from the desired set point.

V. COMPARISON AND RESULT

The Result of this paper is obtained by Comparing the Time Domain Specifications of the six PID Controllers mentioned above and Performance Index criteria IAE, ISE, ITAE, MSE. The time domain Specifications involve Settling time, Rise time, Peak time, Peak Overshoot. The Controller which has minimum Settling Time and Peak Overshoot and less Error will be considered as the Best Controller.

From the curves and controller time domain specifications the proposed controller for this method should be Chien, Hrones and Reswich method (C-H-R). From the performance index, ISE controller for Tyres Luyben method should be a suitable choice.

A. Comparison of PID Controllers (Time Domain)



B. Time domain specifications Comparisons

TABLE 1: The Comparisons of different PID controllers tuning methods are plotted below.

Controller	ZN controller	TL controller	CHR controller	IMC controller	DMP controller	MZN controller
Rise time (seconds)	5.4	8.1	4.5	30	7	4.8
Peak time (seconds)	14	40	17	44	16.25	27
Overshoot (%)	36.5	16.67	23.7	24.2	54.12	21.9
Settling time (seconds)	77	140	64	97	-	172

C. Performance index metrics Comparison

TABLE 2: The Comparison of different PID Controllers ITAE, IAE, ISE, MSE performance index are given below.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 3, March 2014

Controller Type	ZN controller	TL controller	CHR controller	IMC controller	DMP controller	MZN controller
ITAE	1456.1	638.76	884.08	800.90	888.98	1000.82
IAE	735.52	717.85	701.58	722.43	794.81	698.702
ISE	0.0177	3.5841	0.0032	0.0035	1.1375	0.0660
MSE (e-004)	3.7741	1.9986	3.7803	1.4150	5.7910	4.0648

VI. ANALYSIS OF ROBUSTNESS

The ability of the process to maintain stability though the parameters such as Gain, Time Constant, Dead time changed with 20% increase or decrease is known as Robustness. In this process, Gain k=2.2, Dead time td=6 sec and Time Constant Ꞁ = 40.484 sec. Let, these parameters be deviated as much as 20% from their values due to model uncertainty and external disturbance. Let, there is 20% increase in dead time and 20% decrease in gain and time constant. Therefore, new model is:

$$G(s) = 1.76 * \frac{e^{-7.2s}}{32.39S + 1}$$

VII. CONCLUSION

The PID Controller is tuned by sending Proportional band, Integral Time and Derivative time which are further converted into Proportional Gain (Kp), Integral Gain (Ki), Derivative Gain (Kd).By those values the Response is obtained using simulation done by MATLAB. The various results presented prove the betterness of Chien, Hrones and Reswich (CHR) tuned PID controller than remaining five methods. The responses obtained for the model validated reflect the effectiveness of CHR PID controller in terms of time domain specification. The performance indexmetrices of Chien, Hrones and Reswich (CHR) ISE error criteria is less than the other error criteria of remaining PID controllers. From the real time responses, the CHR method PID controller is suitable for this Heating tank system. The features of CHR illustrated in the work by considering the problem of designing a control system for a plantof a first order system with time delay and obtaining the possible results. The future scope of this work is aimed at providing a self-tuning PID controller with proposed algorithm so as to solve the complex issues for real time problems.

REFERENCES

[1] K. MohamedHussain, R.AllwynRajendranZepherin, M.Shantha Kumar, S.M. Giriraj Kumar International Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622, Vol. 4,Issue 2(Version 1), February 2014, pp.308-314

[2] A.R. Laware, V.S. Bandal and D.B. Talange, Real Time Temperature Control System Using PID Controller and Supervisory Control and Data Acquisition System (SCADA), International Journal of Application or Innovation in Engineering & Management (IJAIEM), 2013.

[3] Mohammad Shahrokhi and AlirezaZomorrodi, Comparison of PID Controller Tuning Methods, 2012.

[4] S.M. Giriraj Kumar, R. Ravishankar, T.K. Radha Krishnan, V. Dharmalingam and

[5] N. Anantharaman, Particle Swarm Optimization Technique Based Design of PI Controller for a Real time Non- Linear Process, Instrumentation Science and Technology, 2008.

[6] Manigandan, T.; Devarajan, N – Sivanandam. S. N. Design of PID Controller using reduced order model. Acad. Open Internet J. 2005,15.

[7] Gaing, Z. – L. A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System. IEEE Trans. Energy Conv., November 6 2002.

[8] Parsopoulos, K.E.; Vrahatis, M.N. Particle Swarm Optimizer in Noisy and Continuously Changing Environment; Indianapolis: IN,2001.

[9] Yoshida, H.; Kawata, K.; Fukuyana, Y.; Nakanishi, Y. A Particle Swarm Optimization for Reactive Power and Voltage Control Considering Voltage Stability. IEEE Intl. Conf. Intell. Syst. Applic. Pwr. Syst. (ISAP'99), Rio De Janeiro, April 4-8 1999.

[10] K. Ogata, "Modern Control Engineering", 3rd ed. Upper saddle River, NJ: Prentice- Hall 1997.

[11] Sung. S.W.; Lee, I-B.;Lee, J. Modified Proportional – Integral Derivative (PID) Controller and a new tuning method for the PID controller. Ind.Eng.Chem.Res.1995,34,4127-4132.

[12] Mehrdad Salami and Greg Cain, An adaptive PID controller based on Genetic algorithm processor, Genetic algorithms in engineering systems: Innovations and applications, 1214, September 1995, Conference publication No. 414, IEE 1995.

[13] K.J. Astrom and T. Haughland, "Automatic Tuning of PID Controllers", 1st ed. Research Triangle Park, NC: Instrum. Soc. Amer, 1995.

[14] Sundaresan, K. R., Krishnaswamy, R. R., Estimation of Time Delay, Time constant Parameters in Time, Frequency and Laplace Domains, Journal of Chemical Engineering., 56, 1978, p.257.

[15] Ziegler, J.G.; Nichols, N.B. Optimum settings for automatic controllers.Trans.Amer.Soc.Mech.Eng.1942,64,759-768