International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Design and Implementation of Real Time Integer Order PID Controller for Infrared Heater

Vineet Shekher, Surya Deo Choudhary, Pankaj Kumar, Neel Kamal

Abstract: ***A modified technique is introduced to understand the design of Integer order PID controller. Due to simple tuning rules, conventional PID controller has the great success with the automatic tuning feature and tables that simplify their design. The Integer order PID controller show better robustness performance with the comparison of PID control's experimental to Heating control system (HIL). In Integer order control, design of simulation model of system can be designed straight forwardly with design specification based on frequency analysis which can be change continuously. The simulation analysis and real time results shows that Integer order PID controller is more effective way to enhance the system control performance.***

Index Terms: Integer order controller, Hardware in Loop, First Order plus Time delay

I. INTRODUCTION

The PID controllers are normally used controller in industrial application in industry. Now a day, various methods for tuning of PID controllers, the Ziegler-Nichols (Z-N) tuning method is accepted and broadly used for the determination of PID parameters. Compensated systems with controllers are tuned by Zeigler-Nichols method shows high overshoot with step input. The enhancing of integer order calculus to non-integer order cases is new by means of latest concept. The systematic studies made in the beginning by Liouville, Riemann, and Holmgren in middle of 19th century [1]. The common application of fractional order differentiation has been found in [2]. The concept of fractional order calculus attracts the attention of researchers in applied sciences as well as in engineering and examples found in [3] and [4]. Some applications such as automatic control are discussed in [5]. Fractional order control with integer order specification has adequate modeling and performs robust control performance with respect to classical PID control. The benefits of fractional order control in modeling and control design motivate interest in various applications of control application [6]. Some MATLAB tools of the fractional order dynamic system modeling and control can be found in [7]. Reference [8] shows fractional order PID controller by minimizing the integral of the error squares (ISE). Some numerical examples based on control application with fractional order were presented in [9].

Revised Manuscript Received on 30 July 2019.

* Correspondence Author
Vineet Shekher*, Associate Professor, EEE, Noida Institute of Engineering & Technology, Greater Noida (vshekher2407@gmail.com)
Surya Deo Choudhary, Assistant Professor, ECE, Noida Institute of Engineering & Technology, Greater Noida (suryadeo.bit@gmail.com)
Pankaj Kumar, Chief-IPP, Electricity and Water Authority, Bahrain (pankajkumar666@gmail.com)
Neel Kamal, Associate Professor, EEE, Noida Institute of Engineering & Technology, Greater Noida (drsaini25aug@gmail.com)

II. CONVENTIONAL PID CONTROLLER

The flexibility and robustness of the PID controller makes it widely applied in many applications. The generalized form of PID controller with control law is,

$$u(t) = K_p e(t) + K_i \int_0^t e(t) d(t) + K_d \frac{d}{dt} e(t) \qquad (1)$$

And Laplace transform of equation (1) is given as

$$U(s) = K_p \left(1 + \frac{1}{sT_i} + sT_d \right) \qquad (2)$$

Where, $K_i = \frac{K_p}{T_i}$ and $K_d = K_p T_d$

Where, *e(t)* is the error signal between the set point and actual output, *u(t)* is the controller output and K_p, K_i, K_d are the PID controller gains. A conventional PID controller directly operates on the error signal and it produces a high overshoot in the process response due to the proportional and derivative action. The integral square error (ISE) was chosen as the performance index for tuning of PID controller. The design of the PID controller is based on the determination of the optimum PID set gains (K_p, T_i, T_d) that minimize the integral of the square error (ISE). For designing of controller, ISE is more useful and appropriate because the range of error was large in most cases of controlling temperature. The integral square error is defined as,

$$ISE = \int_0^t e^2(t) dt \qquad (3)$$

III. GAIN AND PHASE MARGIN BASED IOPID CONTROLLER

The generalised form of a fractional order PID controller is PIλDμ Controller (Podlubny, 1999a), having an integrator of order λ and a differentiator of order μ. where λ and μ can be any real number.

Retrieval Number: B1576078219/19©BEIESP
DOI: 10.35940/ijrte.B1576.078219
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

$$\frac{U(s)}{E(s)} = C_{FOPID}(s) = K_p + \frac{K_i}{s} + K_d s^{\mu} \;,(\lambda,\mu > 0) \qquad (4)$$

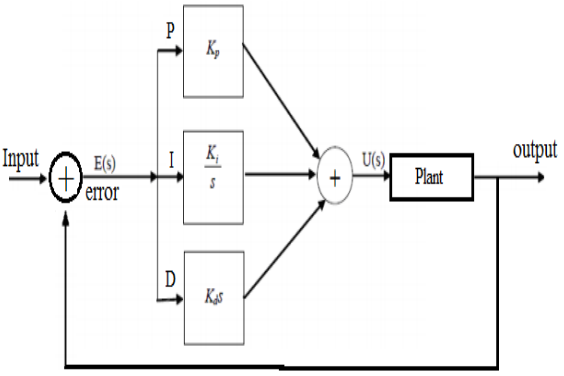


Figure.1(a). Block diagram of IO-PID Controller

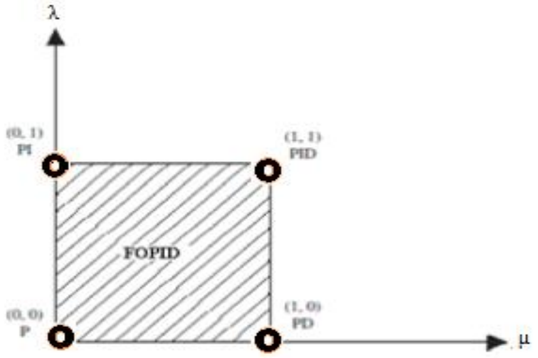


Figure.1(b). X-Y representation of FOPID parameters variation.

Fig. 1(a) is a block diagram representation of IOPID clearly, selecting λ=1 and μ=1, an integer order PID Controller can be recovered. The selections of λ=1, μ=0 and λ=0, μ=1 respectively Corresponds conventional PI and PD Controllers as shown in fig 1(b).

IV. PROCESS MODELLING

In this work, for the design of controllers, the Heating system is represented as FOPTD transfer function model. The recorded data is plotted beside with time to get the process reaction curve. From the process reaction curve obtained by experiment, the First Order (FO) model parameters are process gain K, process time constant T of the Ceramic IR heater temperature system are determined from Fig2.

The FOPTD transfer function model for the unstable heating system is denoted as:

$$G_{IR}(s) = \frac{[2.6770]e^{-46s}}{262s+1} \qquad (5)$$

V. CONVENTIONAL CONTROLLER MODELLING

Conventional ZN-PID controller tuning rules is the classical tuning method which is normally used. In the Ziegler-Nichols tuning method, the first step is to produce sustainable oscillations with a P-controller to get the “ultimate” gain (Kcr), corresponding “ultimate” period (Pcr). Ziegler and Nichols recommended the following ZN-PID tunings formulae are:

Table 1. Tuning rule for ZN-PID Controller.

Controller	Gain (Kp)	Integral Gain (Ki)	Derivative Gain (Kd)
PID	0.6 Kcr	2/Pcr	Pcr/8

By putting up the value of the transfer function of ceramic IR heater having K =2.6770 rad/sec, L=46 sec and T=262 sec in Table 4.3 for Zeigler Nichols closed loop then we calculate the value of Kp, Kiand Kdas 2.15, 0.027389 and 42.193, so the value of controller as:

$$C_{znc}(s) = 2.15 + \frac{0.027389}{s} + 42.193s \qquad (6)$$

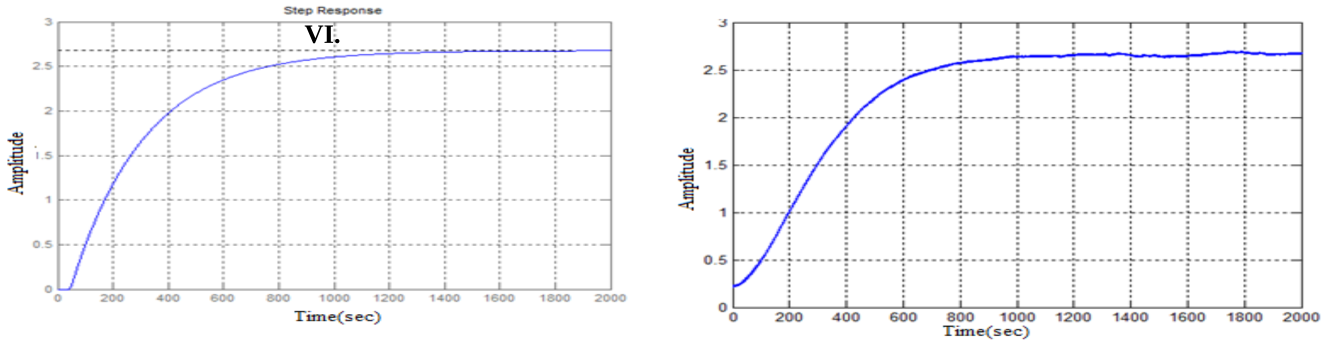


Figure. 2. Transfer function approximation using reaction curve method.

INTEGER ORDER BASED PID CONTROLLER

Design Specification for IOPID Controller

i. Phase Margin & Gain Crossover frequency

Phase and gain margin have always play important role for robustness. The phase margin is co-related to the damping of the system. The equations show the condition for the phase margin ϕ_m and gain crossover frequency ω_{cp} are:

$$|G(j\omega_{cp})| = |C(j\omega_{cp})P(j\omega_{cp})|_{dB} = 0 \ dB \tag{7}$$

$$Arg[G(j\omega_{cp})] = Arg[C(j\omega_{cp})P(j\omega_{cp})] = -\pi + \phi_{pm} \tag{8}$$

Where, $C(j\omega_{cp})$ is the PID Controller in frequency domain with crossover frequency and $P(j\omega_{cp})$ is the IR plant (FOPID) in frequency domain with crossover frequency.

ii. Robustness to gain variation in the plant gain

The phase bode plot is flat at a certain gain crossover frequency when the gain variation of the plant shows that the phase directives with respect to the frequency is zero i.e

$$\left(\frac{d\left(Arg(G(j\omega))\right)}{d\omega}\right)_{\omega=\omega_c} = 0 \tag{9}$$

According to the mathematical description of the IR heater, a transfer function $G_{IR}(s)$ represents FOPTD as:

$$G_{IR}(s) = \frac{K}{sT+1}e^{-Ls}$$

According to the IOPID Controller transfer function when λ=1, μ=1, the frequency response representation for IOPID as:

$$C(j\omega) = K_p + \frac{K_i}{j\omega} + j\omega K_d$$

The gain and phase of $C(j\omega)$ are as follow:

$$|C(j\omega)| = \sqrt{K_p^2 + \left(K_d\omega - \left(\frac{K_i}{\omega}\right)\right)^2}$$

$$Arg[C(j\omega)] = \tan^{-1}\left(\frac{(K_d\omega^2 - K_i)}{\omega K_p}\right)$$

According to design specification (1) the magnitude and is given as:

$$|G(jw)| = \frac{K\sqrt{K_p^2 + \left(K_d\,\omega - \frac{K_i}{\omega}\right)^2}}{\sqrt{1+\omega^2T^2}}$$

and

$$Arg\left[G(j\omega_{cp})\right] = \tan^{-1}\left(\frac{K_d\omega_{cp}^2 - K_i}{\omega_{cp}K_p}\right) - \tan^{-1}(\omega_{cp}T) - L\omega_{cp} = -\pi + \phi_{pm}$$

According to design specification given by equation (2), value of K_p, K_i, and K_d derive as:

$$K_p = \frac{1}{K}\sqrt{\frac{B_1}{1+A_1^2}} \tag{10}$$

Where, $B_1 = 1 + \omega_{cp}^2T^2$ and $\frac{K_d\omega_{cp}^2 - K_i}{K_p\omega_{cp}} = A_1$, and

$$K_i = \frac{1}{2K}\sqrt{\frac{1+A_1^2}{B_1}}\left(T\omega_{cp}^2 + LB_1\omega_{cp}^2\right) - A_1\omega_{cp}\sqrt{\frac{B_1}{1+A_1^2}} \tag{11}$$

$$K_d = \frac{1}{2K}\left[\sqrt{\frac{1+A_1^2}{B_1}}\left(T + LB_1\right) + A_1\omega_{cp}^{-1}\sqrt{\frac{B_1}{1+A_1^2}}\right] \tag{12}$$

The phase margin and gain margin of the process plant as per Bode and Nyquist plot are shown in Fig.3(a,b). From Fig. 3(a,b), we found the value of ω_{cg} and ϕ_m as 0.008 rad/sec and 80^o respectively. By putting up the value of the transfer function of ceramic IR heater having K=2.6770, L=46 and T= 262 in equation (10), (11) and (12) and we calculate the K_p, K_i and K_d as 0.9768, 0.0063, 25.6246.

So the value of controller as:

$$C(s) = 0.9768 + \frac{0.0063}{s} + 25.6246s \tag{13}$$

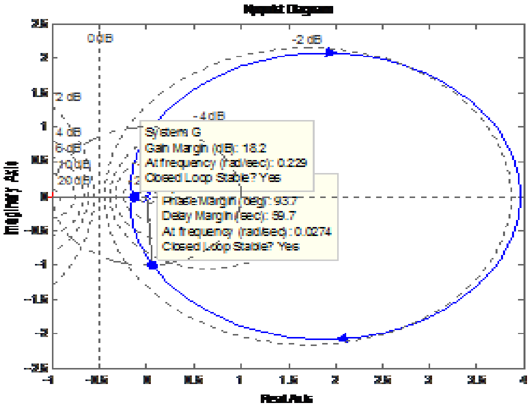


Figure. 3(a) Nyquist plot of IOPID Controller for Specification

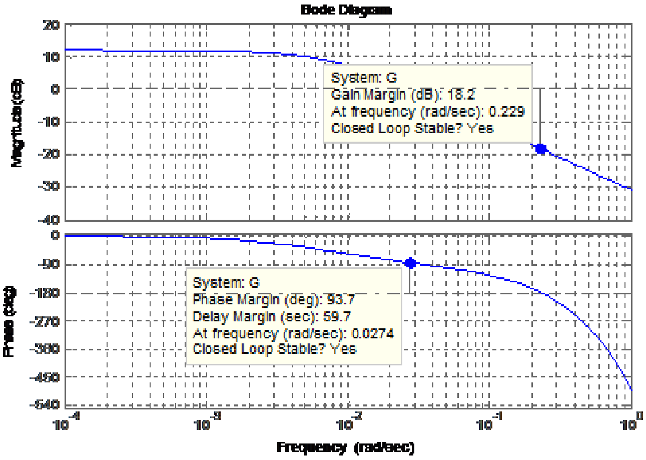


Figure. 3(b) Bode Plot of IOPID Controller for Specification

By using MATLAB simulation of ZN closed loop and IOPID designed controller the output as shown in Figure. 4(a) and 4(b)

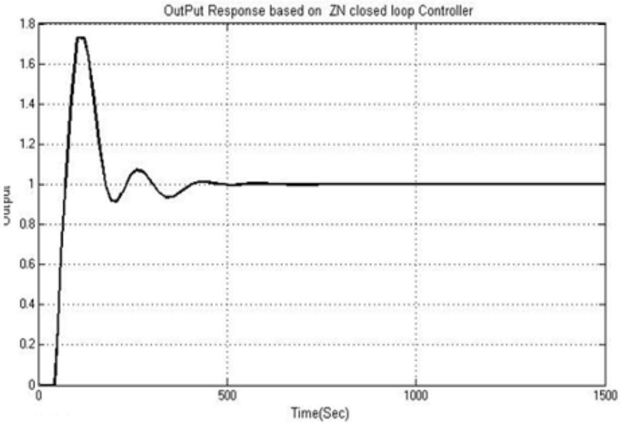


Figure.4(a). Simulation Output response of ZN-Closed Loop Controller

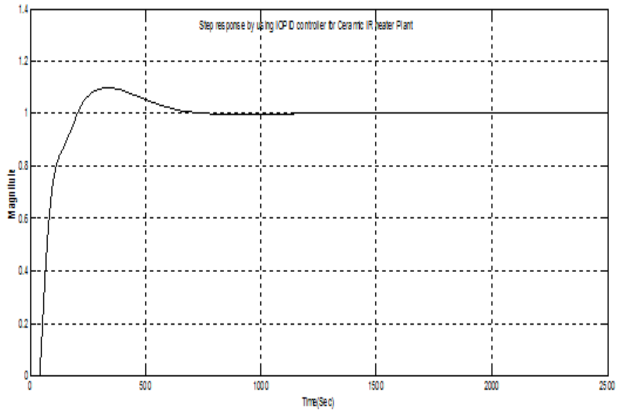


Figure.4(b). Simulation Output response of IOPID Controller

Table 2. Performance Table of ZN Closed loop and IOPID Controller.

Performance	Rise Time (*Tr*)	Peak Overshoot(*Mp*)	Peak Time (*Tp*)	Settling Time (*Ts*)	ISE	IAE
ZNC-PID	25.39	74.70	116.93	389.36	80.55	116.4
IOPID	112.41	9.8	341.91	613.86	66.92	114.8

VII. PROCESS MODELING

PID controller does well for the system having set parameters. If there is presence of parameter disturbance or major variation, the PID controllers took action to perform fast response with considerable overshoot or smooth but it show slow response output.

Closed loop temperature control is considered one of the most difficult design problems due to major variation or disturbance in the control engineering. Temperature control arises in many engineering fields.

Fig. 5shows the block diagram of the open loop response test. The hardware component for the experiment consist of the computer, a power module controller, to modify the power input to the ceramic IR heater (oven) and a temperature sensor (temperature transducer) to measure the output temperature of IR heater.

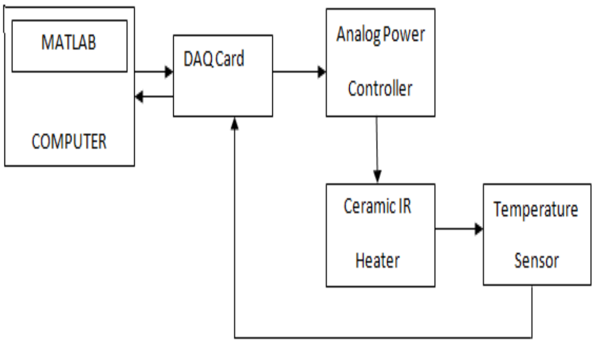


Figure.5. Block diagram of the open loop response test.

The purpose of data acquisition is to measure an electrical or physical phenomenon. Data acquisition systems integrate with input/output signals, actuators, sensors, signal conditioning circuit, data acquisition interfacing devices, and application software. The data acquisition for the temperature measurement instituted in this experimental work is accomplished in two ways. In the first instance it is needed to complete the experiment in which the transfer function of a ceramic IR heater is found, because the software used to complete the experiment was MATLAB, a compatible hardware and software was chosen to facilitate the measurement procedure. In the development of the controller however the software used was MATLAB SIMULINK. Both these methods when implemented proved very successful. Zeltom(Hi-Link Card) hardware is a low cost high performance DAQ unit that communicates with the computer and compatibles. The HILINK DAQ card platform offers interface between experimental hardware plants and MATLAB/Simulink for real time implementation of hardware-in-the-loop.

6.1 Analog Power Controller:

Power control method has been investigated for this paper, with the aim being to find the most appropriate type of control for the type of load required. The power controller needs to be able to control and switch large loads, typically currents of up to 10 A and load rated for 400W.

Single phase power regulator is used for heating control of inductive or resistive loads made by Libratherm LTC-16 as shown in Figure. 6. This regulator took input by the user having variable control signal range of 0-5V, 0-10V and 4-20mA or 10K potentiometer. The output voltage can be varying proportionally to the input signal. The back to back connected SCR can control the load of 10A (2kW), 20A (4kW) and 40A 8lkW) at 230VAC which is build in it. The phase angle firing control technique ensures steady and smooth voltage control across the load.

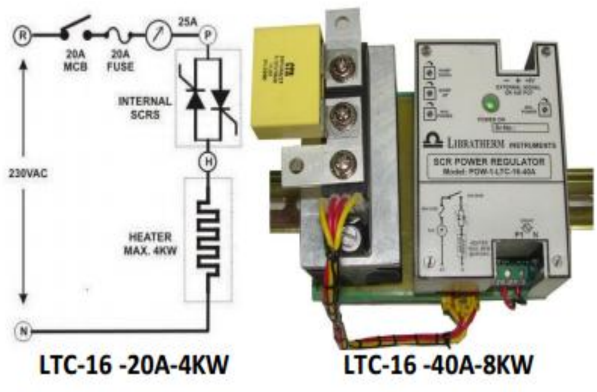


Figure.6. Circuit diagram of Analog Power Controller (Libratherm, LTC-16)

The laboratory setup and wiring diagram as shown in Fig. 7 (a) consists of Ceramic IR heater, DAQ card, Analog power controller and temperature sensor (K-type thermocouple). The power delivered to the IR heater is controlled using an analog signal using analog power controller. DAQ card is used for the analog signal generation, where output is 0-5 V DC and it provides to analog power controller which get in firm of fixing angle to back to back SCR of analog power controller to maintain the desired analog power or voltage to IR Heater. The actual laboratory photograph of the experimental set-up is shown in Fig. 7(b).

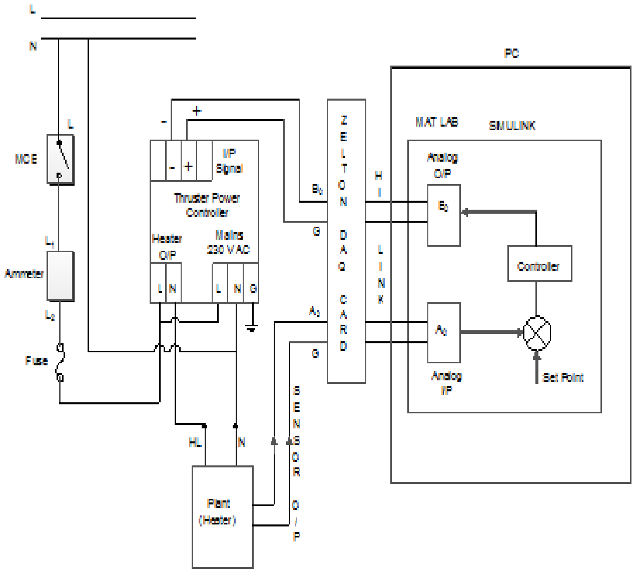


Figure.7(a). Wiring diagram of HIL Hardware system.

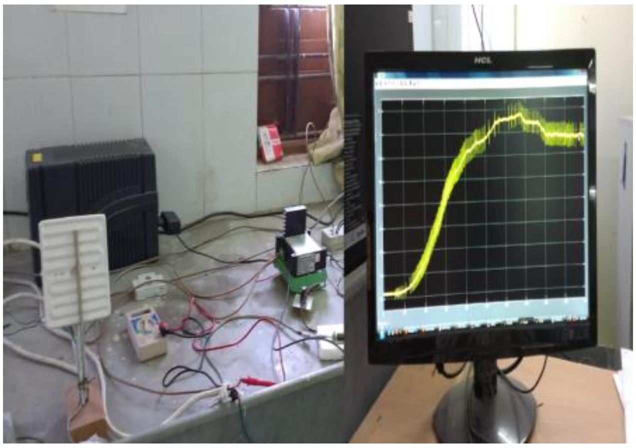


Figure.7(b).Laboratory photograph of the experimental setup.

Real time performance regarding Zeigler Nichols closed loop method and Controller output as shown in Fig. 8.

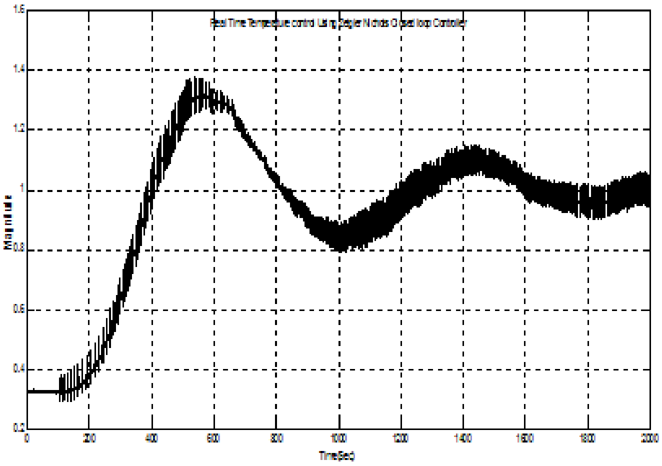


Figure.8(a). Real Time Temperature Control Using Zeigler Nichols Closed Loop Controller

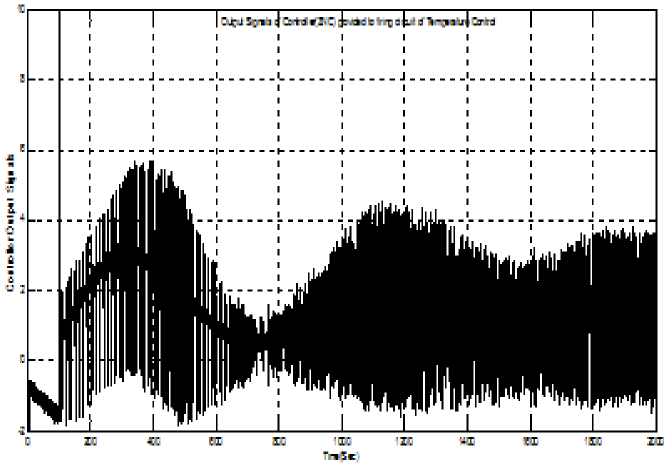
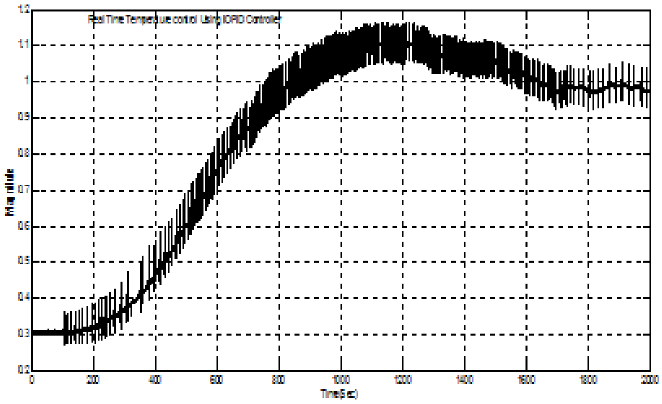


Figure.8(b). Real Time Temperature Controller Output Signal.

Real time performance regarding Integer Order PID method and Controller output as shown in Fig. 9.



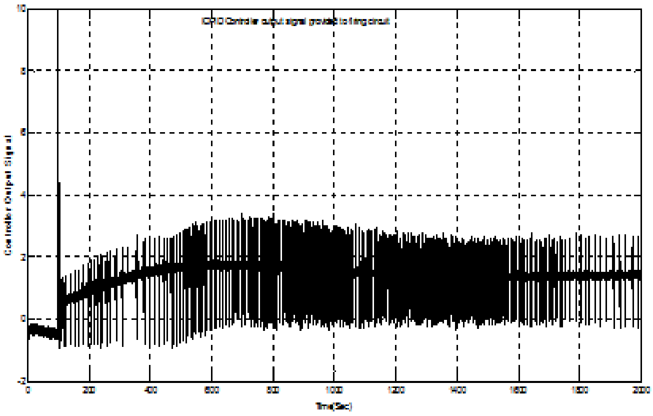


Figure.9. Real Time Temperature Control Using IOPID Controller and Controller Output Signals.

Table 3. Performance table of Experimental Setup of temperature System

Performance Parameter	Rise Time (Sec)	Settling Time (Sec)	Peak Time (Sec)	Peak Overshoot (%)
ZNC-PID	226.16	1999	536.3	38.15
IOPID	484.47	1989	1129	20.07

VIII. CONCLUSION

The work has been undertaken with a vision to analyze an impact of fractional calculus in the development of classical control theory through challenging infrared heating control problem. The performance and robustness characteristics of IOPID controller was analyzed by conducting simulation and experimental studies of HIL System. The experimental as well as simulation results proved that the IOPID controllers took corrective action even in the presence of nonlinearity and enhanced the performance in all aspects when compared to existing classical controllers. Finally, it is concluded that the Integer Order Controller furnishes a flexible design and convenient under the following conditions are satisfied like stability and robustness, which provides enhanced performance in terms of the set point tracking and disturbance rejection capabilities.

REFERENCES

1. Oldham,K.B., Spanier, J.: The Fractional Cal. Academic Press. New York. London. (1974).
2. Axtell, M. Bise, M.E.: Fractional calculus applications in control systems. Nat. Aero. and Electro. Conf. Newyork. USA. (1990) 563-566.
3. Engheta, N.: On fractional calculus and fractional multipoles in electromagnetism. IEEE Trans. Antenn. Propag. 44 (1996) 554-566.
4. Unser.M., Blu,T.: Wavelet theory demystified. IEEE Trans. Sig.Proce. 51 (2003) 470-483.
5. Podlubny, I.: Fractional-order systems and PID controllers. IEEE Trans. Auto. Cont. 44 (1999) 208-214.
6. Oustaloup, A., Sabatier, J., Moreau,X.: From fractal robustness to the CRONE approach. ESAIM. 5 (1998) 177-192.
7. Xue, D.Y., Chen, Y.Q.: Advanced Mathematic Problem Solution Using. MATLAB. Beijing. Tsinghua University Press.(2004).
8. Lv,Z.F.: Time-domain simulation and design of SISO feedback control systems. Doctoral Dissertation. National Cheng Kung University. (2004).
9. Zhao, C.N.,Xue, D.Y., Chen,Y.Q.: A fractional order PID tuning algorithm for a class of fractional order plants. Proc. of the IEEE International Conference on Mechatronics and Automation. Niagara Falls.Canada. (2005) 216-221
10. Monje,C.A., et al.: Proposals for fractional PID tuning. The First IFAC Symposium on Fractional Differentiation and its Applications. Bordeaux. France. (2004).