Performance Analysis of Conventional Controller for Infrared Heater

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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 simulink model of control system can be designed more straight forwardly with specification based on frequency response which can be change continuously.

Keywords: Integer order controller, Hardware in Loop, First Order Plus Time delay.

I INTRODUCTION

The PID controllers are the most commonly used controller in industrial application in industry. Now a day, various methods for tuning PID controllers, the Ziegler-Nichols (Z-N) tuning method is the most popular and is extensively used for the determination of the PID parameters. It is well known that the compensated systems with controllers tuned by Zeigler-Nichols method shows high percent overshoot with step input.

The enhancing of classical integer order calculus to non-integer order cases is new by means of new 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 shows the attention of researchers in applied sciences as well as \44in engineering and examples may be found in [3] and [4]. Some applications such as automatic control arc 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].

II 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

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

And Laplace transform of equation (1) is given as

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

Where, $K_i = \frac{K_p}{T_i}$ and $K_d = K_p T_d$ (3)

(a) IOPID Controller

The most common 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.

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

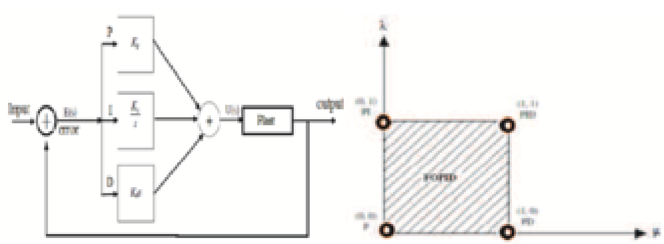

Fig.1(a). Block diagram of IO-PID Controller.
Fig.1(b). X-Y representation of FOPID parameters variation.

Fig. (1) is a block diagram configuration 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.

III PROCESS MODELING

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 obtained process reaction curve, the First Order (FO) model parameters are process gain K, process time constant T of the Ceramic IR heater temperature system are determined.

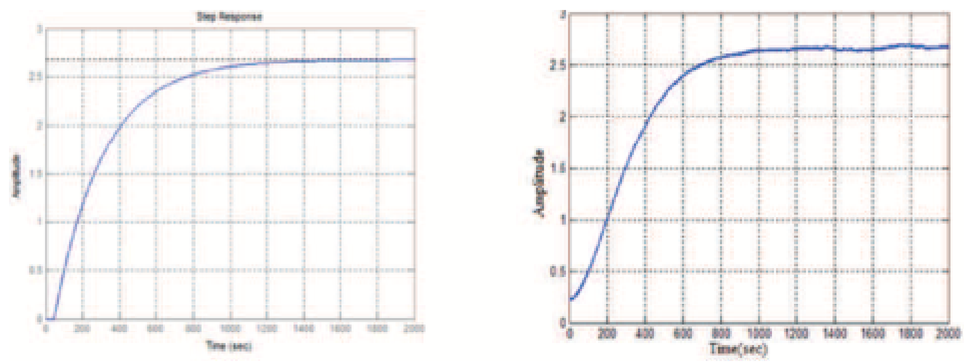

Fig. 2 Transfer function approximation using reaction curve method.

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

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

IV DESIGN OF PID CONTROLLER

ZN-PID tuning rules is the classical "closed loop" tuning rule which is normally considered as the coventional tuning rule. Ziegler and Nichols recommended the following ZN-PID tunings formulae are:

Table 1
Tuning rule for ZN-PID Controller

Controller	Gain (K_p)	Integral Gain(K_i)	Derivative Gain(K_d)
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 K_p, $K_i$and $K_d$as 2.15, 0.027389 and 42.193, so the value of controller as:

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

V INTEGER ORDER BASED PID CONTROLLER

(a) 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:

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

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

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

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

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 PID Controller transfer function, the frequency response 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:

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

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

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

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

and

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

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, $B_1 = 1+\omega_{cp}^{\;2}T^2$ 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. 5. From Fig. 6, we found the value of ω_{cg} and ϕ_m as 0.008 rad/sec and 80° 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:

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

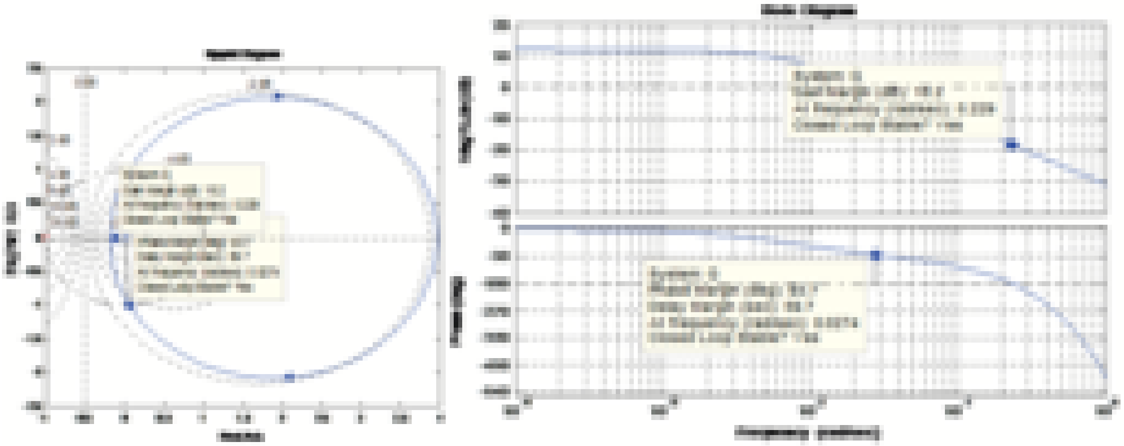

Fig. 1Nyquist plot and Bode Plot of IOPID Controller for Specification

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

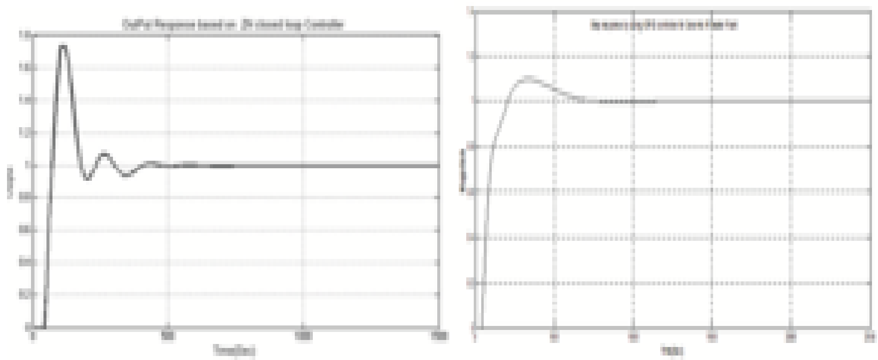

Fig.4(a). Simulation Output response of ZN-Closed Loop Controller.
Fig.4(b).Simulation Output response of IOPID Controller.

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

VI EXPERIMENTAL STUDIES

PID controller works well for the system having fixed parameters. If there is presence of large parameter variations or major external disturbances, the PID controllers shows fast response with significant overshoot or Smooth but slow response.

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.

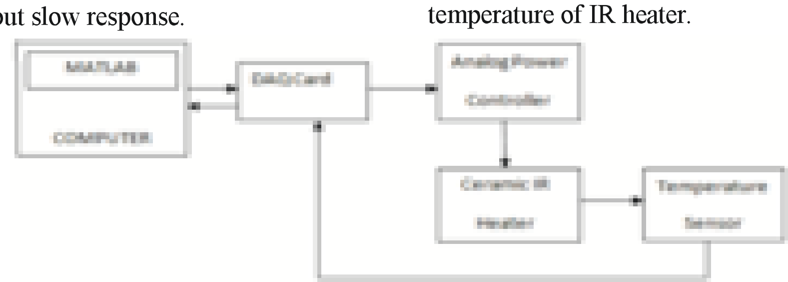

Fig.5. Block diagram of the open loop response test.

Data acquisition systems incorporate input/output signals, sensors, actuators, signal conditioning circuit, data acquisition interfacing devices, and application software

(a) Analog Power Controller:
The power controller needs to be able to control and switch large loads, typically currents of up to 10 Ampere 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. The output voltage can be varied 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 gradual and smooth voltage control across the load.

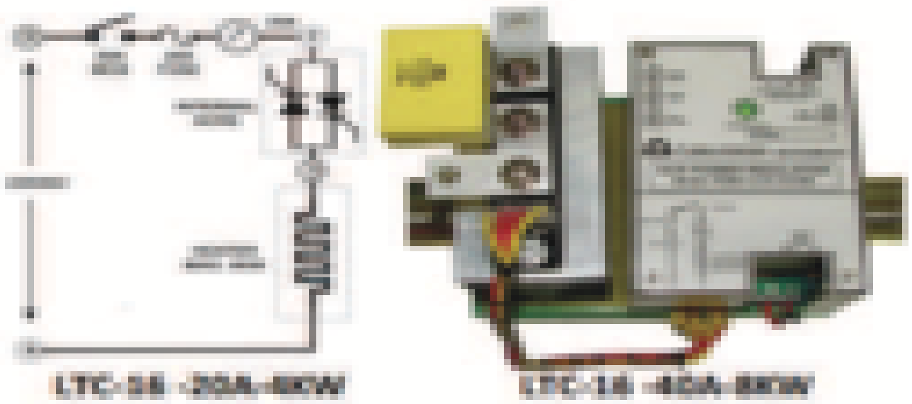

Fig.6. Circuit diagram of Analog Power Controller (Libratherm,LTC-16)

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).

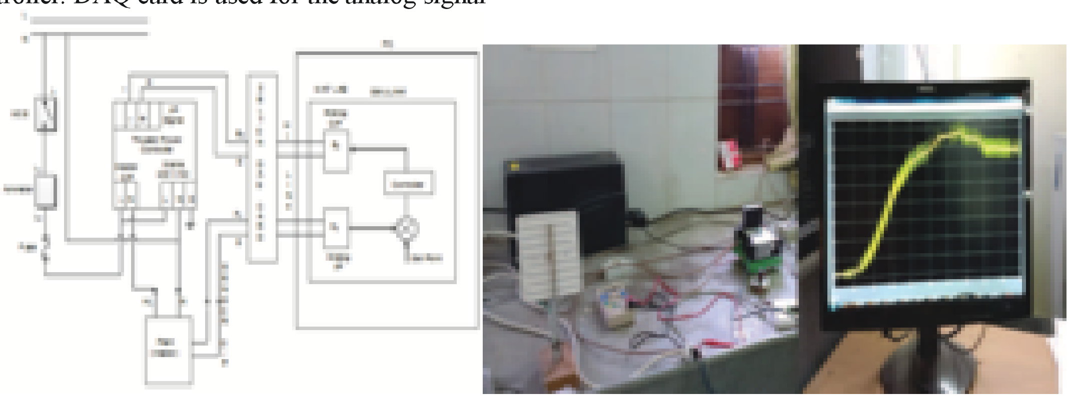

Fig.7(a). Wiring diagram of HIL Hardware system.
Fig.7(b).Laboratory photograph of the experimental setup.

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

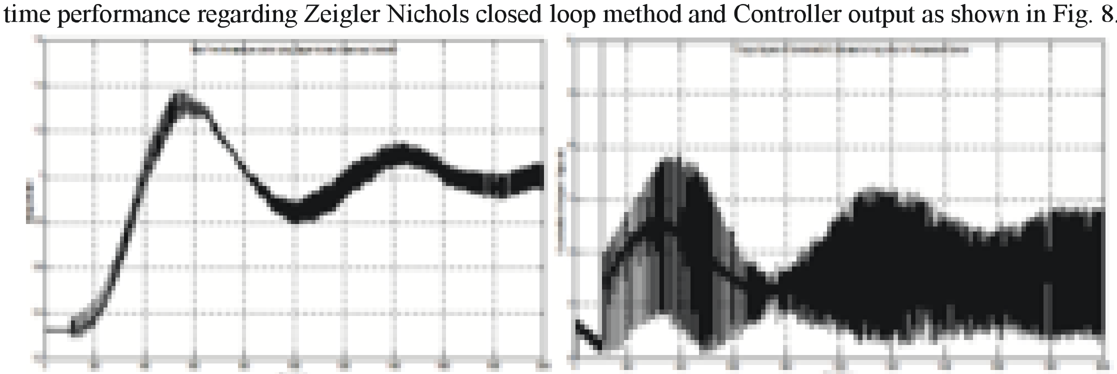

Fig.8.Real Time Temperature Control Using Zeigler Nichols Closed Loop Controller and Controller Output Signal.

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

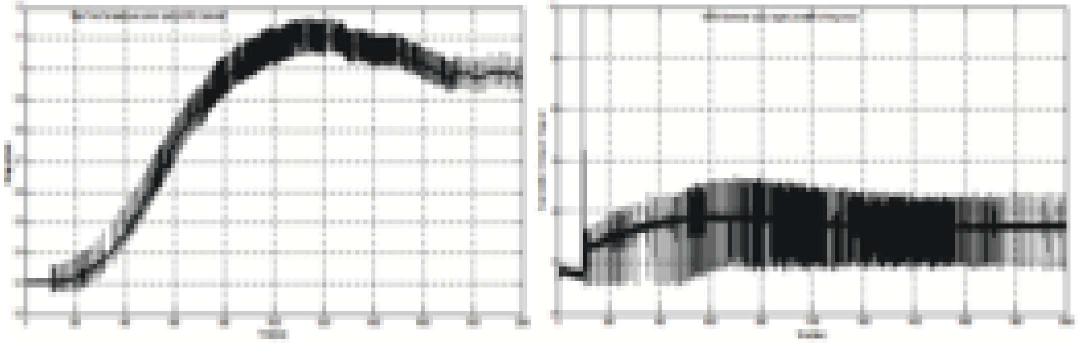

Fig.9. Real Time Temperature Control Using IOPID Controller and Controller Output Signals.

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

VII 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 shows 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.

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