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COMPARISON OF PID TUNING METHODS FOR FIRST ORDER PLUS TIME-DELAY SYSTEM

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ABSTRACT

Controlling the process is the main issue that rises in the process industry. It is very important to keep the process working probably and safely in the industry, for environmental issues and for the quality of the product being processed. PID control is a control strategy that has been successfully used over many years. Simplicity, robustness, a wide range of applicability and near-optimal performance are some of the reasons that have made PID control so popular in the academic and industry sectors. Recently, it has been noticed that PID controllers are often poorly tuned and some efforts have been made to systematically resolve this matter. This paper demonstrates an efficient method of tuning the PID controller parameters using various tuning techniques. It involves calculating the gain of the controller (K_p), integral time (T_i) and the derivative time (T_d) for PID controlled system whose process is modeled in First order plus time-delay (FOPTD) form. In this paper the performance of PID tuning techniques is analyzed and compared based on time response specifications.

***Keywords**:Comparison, MATLAB, Performance Specifications, PID Controller, Tuning rules.*

I. INTRODUCTION

The Proportional- Integral- Derivative (PID) controller is widely used in the process industries. The main reason is their simple structure, which can be easily understood and implemented in practice.

A PID controller produces an output signal consisting of three terms – one proportional to error signal, another one proportional to integral of error signal and third one proportional to derivative of error signal. The combination of proportional control action, integral control action and derivative control action is called PID control action. The combined action has the advantage of each of the three individual control actions. The proportional controller stabilizes the gain but produces a steady-state error. The integral controller reduces or eliminates the steady-state error. The derivative controller reduces the rate of change of error. The main advantages of PID controllers are higher off stability, no offset and reduced overshoot. According to the survey more than 90% of the control loops were of the PID type.

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II. THE PID STABILIZATION PROBLEM

Consider the feedback control system shown in fig.1 where 'r' is the reference input, 'e' is the error signal, 'u' is the control signal and 'y' is the output signal. The plant $G_p(s)$ is a first-order system with a transport lag as follows;

$$G_p(s) = \frac{K\,e^{-Ls}}{Ts+1} \quad (1)$$

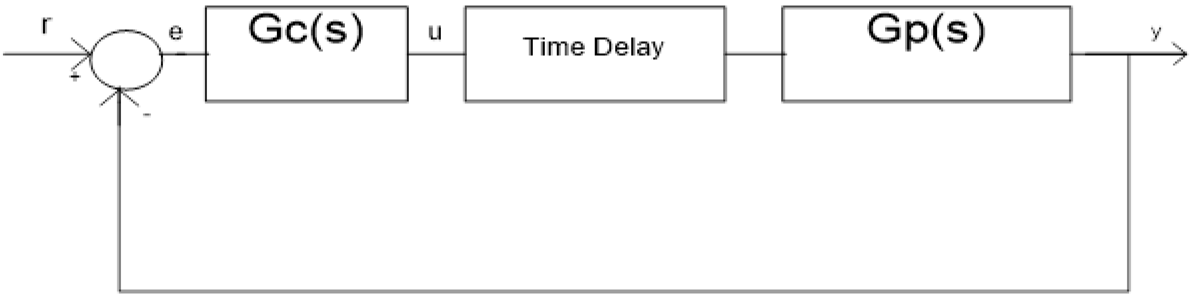

Fig.1Feedback control system

where 'K' represents the steady-state gain of the plant, 'L' represents delay time and 'T' represents time constant.

The controller $G_c(s)$ is of the PID type having the combination of proportional control action, integral control action and derivative control action;

$$G_c(s) = K_p\left(1 + \frac{1}{T_i\,s} + T_d\,s\right) \quad (2)$$

Where K_p is the proportional gain,

$K_i = \frac{K_p}{T_i}$;

$K_d = K_p * T_d$

T_i is the integral time constant,

$T_d$is the derivative time constant.

Different tuning methods have been therefore proposed in the literature to estimate the three parameters by performing a simple experiment on an open-loop step response or on a closed-loop feedback system.

III. CONVENTIONAL PID TUNING TECHNIQUES

3.1. Ziegler-Nichols step response method

The Ziegler-Nichols step response method is an experimental tuning method for determining values of the proportional gain K_P, integral time T_i and derivative time T_d based on the transient response characteristics of a

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given plants [1]. The first step in this method is to calculate two parameters T (time constant) and L (delay time) that characterize the plant. These two parameters (T, L) can be determined graphically from a measurement of the step response of the plant as illustrated in fig 2. First, the point on the step response curve with the maximum slope is determined and the tangent is drawn with the time axis. Once T and L are determined, the PID controller parameters are then given in terms of T and L TABLE 1.

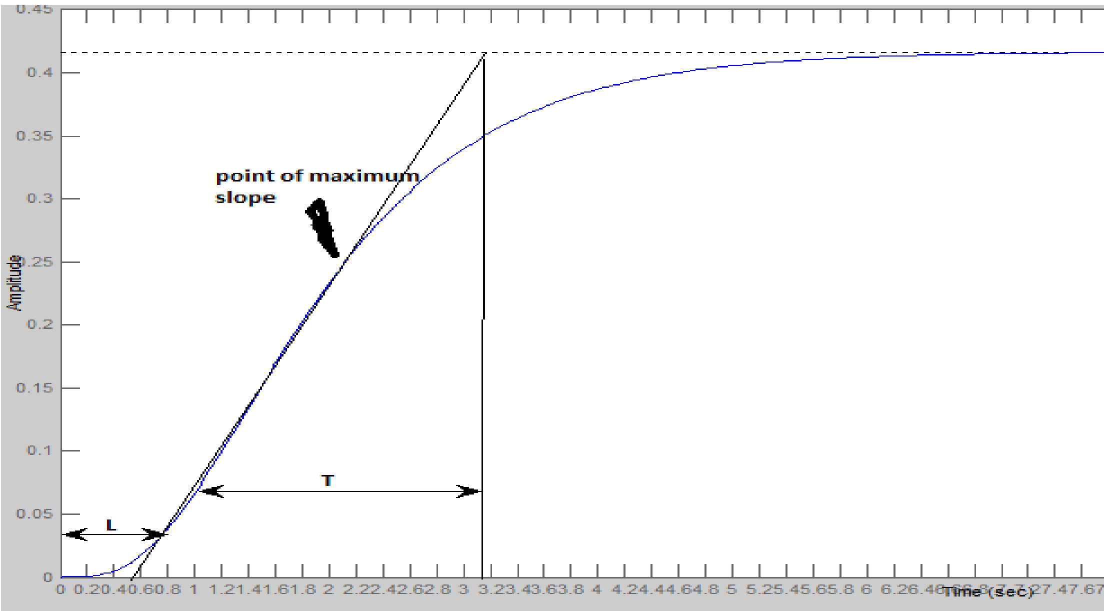

Fig.2 Graphical determination of parameters T and L.

The PID controller tuned by this method gives;

$$G_c(s) = \left(K_p + \frac{K_i}{s} + K_d\, s\right)$$

$$= 1.2\frac{T}{L}\left(1 + \frac{1}{2Ls} + 0.5Ls\right)$$

$$= 0.6T\,\frac{\left(s+\frac{1}{L}\right)^2}{s} \qquad (3)$$

Table.1. PID controller parameters

Type of controller	K_p	T_i	T_d
PID	$1.2\frac{T}{L}$	2L	0.5L

The PID controller has a pole at the origin and double zeros at s = -1/L.

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3.1.1 Simulation Result:

Using this technique on the experimental plant, the PID controller parameters are obtained as mentioned inTABLE 2.

Table.2. PID controller parameters

K_p	T_i	T_d
3.36	2	0.5

The step response and performance specifications obtained are accordingly shown in fig.3 and TABLE 4.

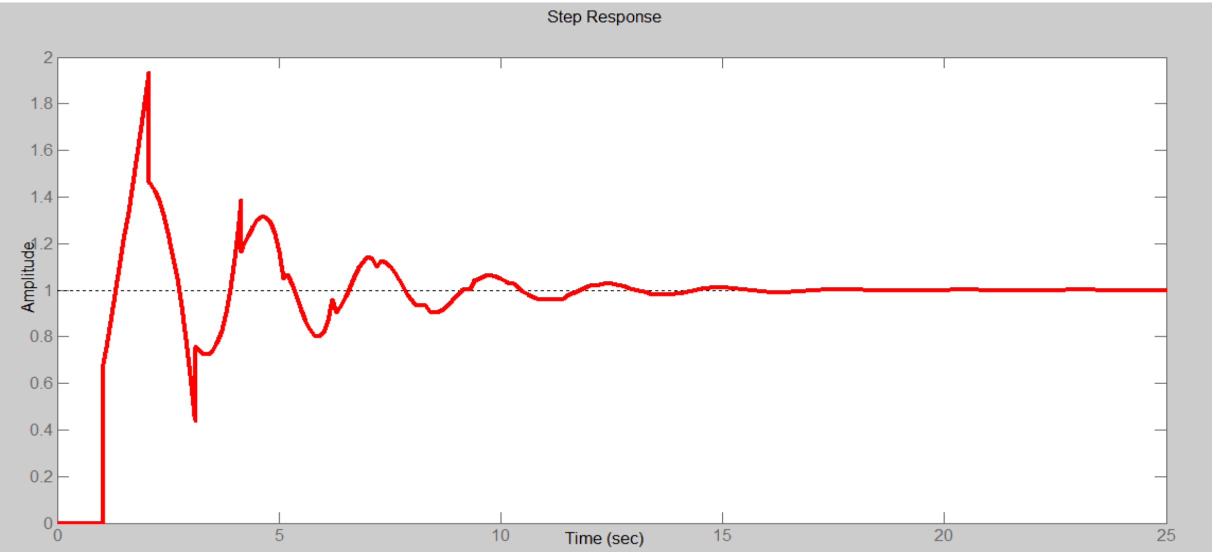

Fig.3. Step response of the experimental plant

Table.4. Performance specifications

Rise time	Peak Amplitude	Overshoot (%)	Time at which Overshootoccurs	Settling time	Steady state
0.192	1.93	93.4	2.08	13.8	1

3.2. The Ziegler-Nichols Frequency-Response Method

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The Ziegler-Nichols frequency-response method is a closed-loop tuning method [1]. In this method, the two parameters to be calculated are the critical gain $\mathbf{K_{cr}}$and the corresponding period $\mathbf{P_{cr}}$which can be calculated experimentally in the following way:

Set the $\mathbf{T_i = \infty}$and $\mathbf{T_d}$ **= zero** and hence the controller become in the proportional mode only. The proportional gain $K_p$is then increased slowly until a periodic oscillation in the output is observed. This critical value of $\mathbf{K_p}$is called the critical gain $\mathbf{K_{cr}}$. The resulting period of oscillation is referred to as the ultimate period $\mathbf{P_{cr}}$.

Based on $\mathbf{K_{cr}}$and $\mathbf{P_{cr}}$**,** the Ziegler-Nichols frequency response method gives the following simple formulas for setting PID controller parameters as mentioned in TABLE 5

Table.5. PID controller parameters

Type of controller	$\mathbf{K_p}$	$\mathbf{T_i}$	$\mathbf{T_d}$
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

The PID controller tuned by this method gives;

$$G_c(s) = K_p\left(1 + \frac{1}{T_i\, s} + T_d\, s\right)$$

$$= 0.1K_{cr}\left(1 + \frac{1}{0.5P_{cr}\, s} + 0.125P_{cr}\, s\right)$$

$$= 0.075K_{cr}P_{cr}\frac{\left(s + \frac{4}{P_{cr}}\right)^2}{s} \qquad (4)$$

The PID controller has a pole at the origin and double zeros at $s = -4/P_{cr}$.

3.2.1 Simulation Result:

Using this technique on the experimental plant, the PID controller parameters are obtained as mentioned inTABLE 6 .

Table.6. PID controller parameters

$\mathbf{K_p}$	$\mathbf{T_i}$	$\mathbf{T_d}$
3.4273	1.3675	0.3419

The performance specifications and step responseobtained are accordinglymentionedin TABLE 7 and in fig.4.

Table.7.Performance specifications

Rising time	**Peak**	**Overshoot**	**Time at which Overshoot**	**Settling time**	**Steady**

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	Amplitude	(%)	occurs		state
0.327	1.98	98	2.08	10	1

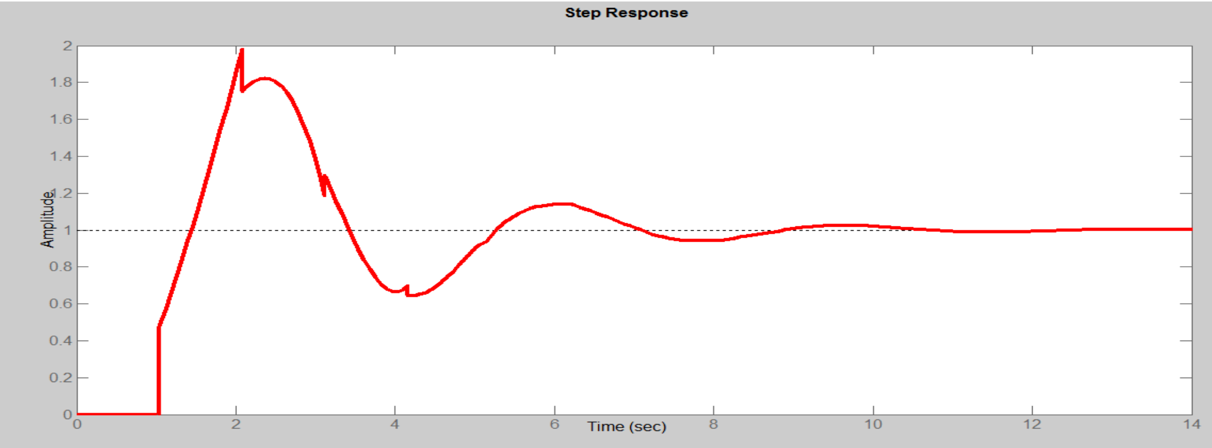

Fig.4. Step response of the experimental plant

IV. IMC PID TUNING METHOD

While IMC controller implementations are becoming more popular, the standard industrial controllers remain the PID controllers [2]. Based on Rivera *et al.* [1986], the goal of control system design is to achieve a fast and accurate set-point tracking;

$y \cong y_s \quad \forall t, \ \forall d$ (5)

This implies that the effect of external disturbances should be corrected as efficiently as possible and also being assured of insensitivity to modeling error;

$y' \cong y_s - d \ \forall t, \ \forall d$ (6)

The PID tuning law based on the relationship of the IMC and the PID controller has been proposed by Rivera *et al*. [1986]. PID control structure is shown in fig 5.1, where $\mathbf{g_c}$ and $\mathbf{g}$ are the PID controller and the controlled process, respectively. They are given by;

$$g_c = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (7)$$

$$g = \frac{K e^{-Ls}}{Ts+1}$$

where K_p, T_i, T_d are the proportional gain, the reset time and the derivative time, respectively. Meanwhile, the structures of the IMC is shown in fig 5.2, where g_c^* and $g^\vee$ are the IMC controller and the internal model respectively. The IMC controller is given by

$$g_c^* = \frac{1+Ts}{K} \text{ x } \frac{1}{1+\lambda s} \qquad (8)$$

where $\lambda$is the filter constant and its value recommended by Rivera *et al.*[1986] should be greater than 0.8L because of the model uncertainty due to Pade approximation.

By comparing fig 5a with fig 5b, the following relation is given

$$g_c = \frac{g_c^*}{1-g^\vee g_c^*} \qquad (9)$$

The IMC-PID setting for FOPTD process is given TABLE 8. [2]

Table.8. PID controller parameters for IMC-PID

Type of controller	K_p	T_i	T_d
PID	$\frac{T+0.5L}{K(\lambda+0.5L)}$	**T + 0.5 L**	$\frac{TL}{2T+L}$

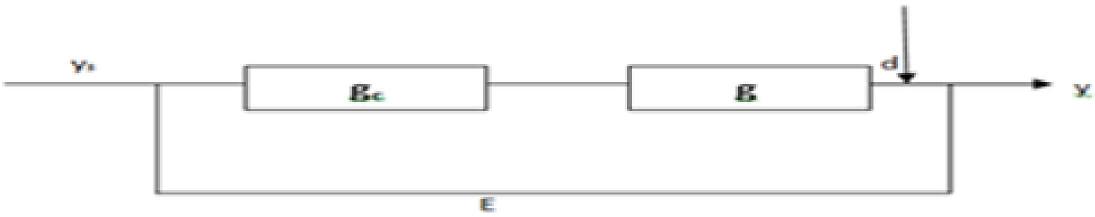

Fig 5.1 Conventional Configuration

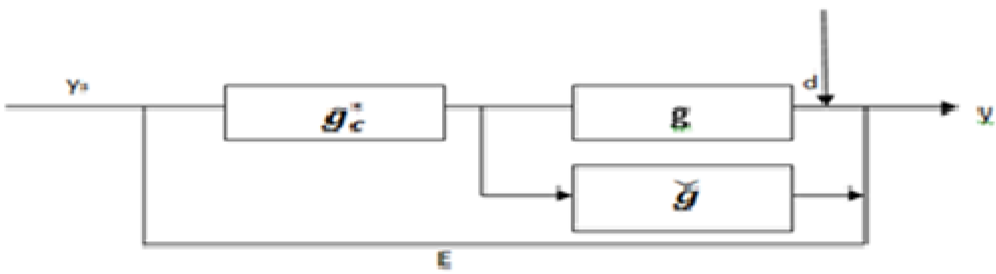

Fig 5.2 Internal model control configuration

4.1 Simulation Result

Using this technique on the experimental plant, the PID controller parameters are obtained as mentioned in TABLE 9 .

The step response and performance specifications obtained are accordingly shown in fig.6and TABLE 10.

Here λ is taken 0.9 which is greater than 0.8312.

Table.9. PID controller parameters

K_p	T_i	T_d
2.091	2.9675	0.4286

Table.10.Performance specifications

Rise time	Peak Amplitude	Overshoot (%)	Time at which Overshoot occurs	Settling time	Steady state
4.26e-005	1.15	70.1	2.08	11.2	0.676

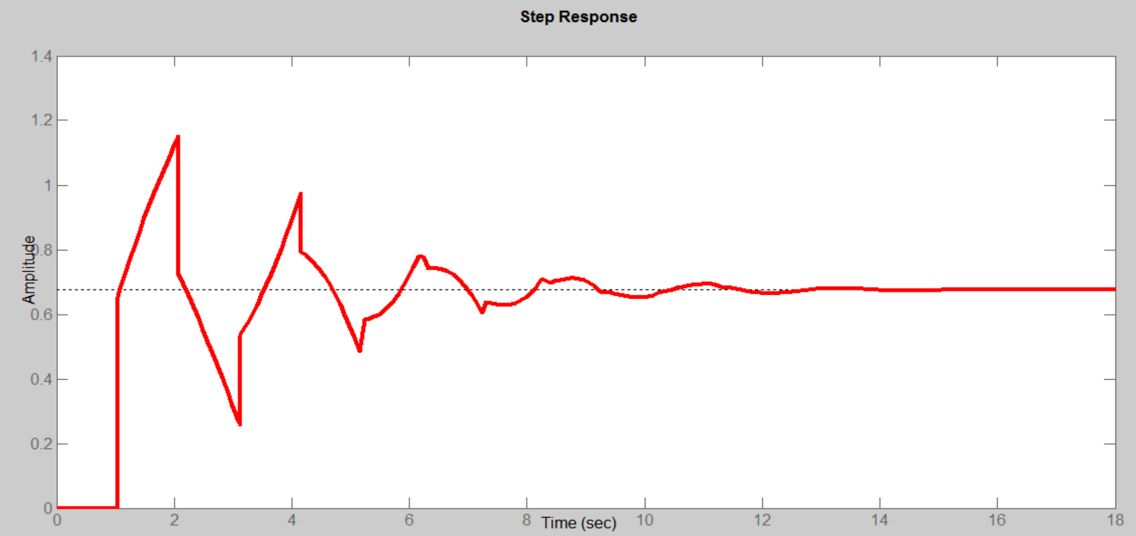

Fig.6. Step response of the experimental plant

V . CHIEN, HORNES AND RESWICK METHOD

CHR is believed to provide a better way to select a compensator for process control applications [3]. CHR was developed from the Ziegler-Nichols's method for implementation of certain quality requirements of open

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systems. Using a periodic step response as in fig.7, the conditional parameters of the process will be determined as mentioned in TABLE11.

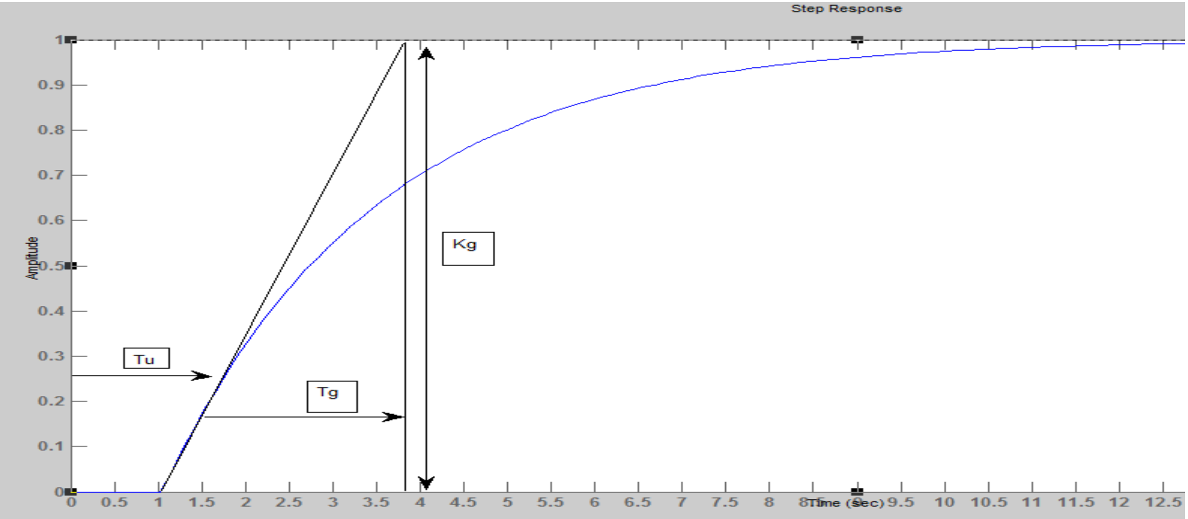

Fig.7. Open loop response of CHR method

Table.11. CHR Compensator

Type of controller	K_p	T_i	T_d
PID	$0.6T_g/T_uKg$	T_g	$0.5T_u$

5.1 Simulation Result

Using this technique, the PID controller parameters and Performance specifications are obtained as mentioned in TABLE 12 and TABLE13.

Table.12. PID controller parameters

K_p	T_i	T_d
1.68	2.8	0.5

Table.13.Performance specifications

Rising time	Peak Amplitude	Overshoot (%)	Time at which Overshoot	Settling time	Steady state

			occurs		
3.48e-005	0.966	54.1	2.08	8.27	0.627

The step response obtained is shown in fig.8

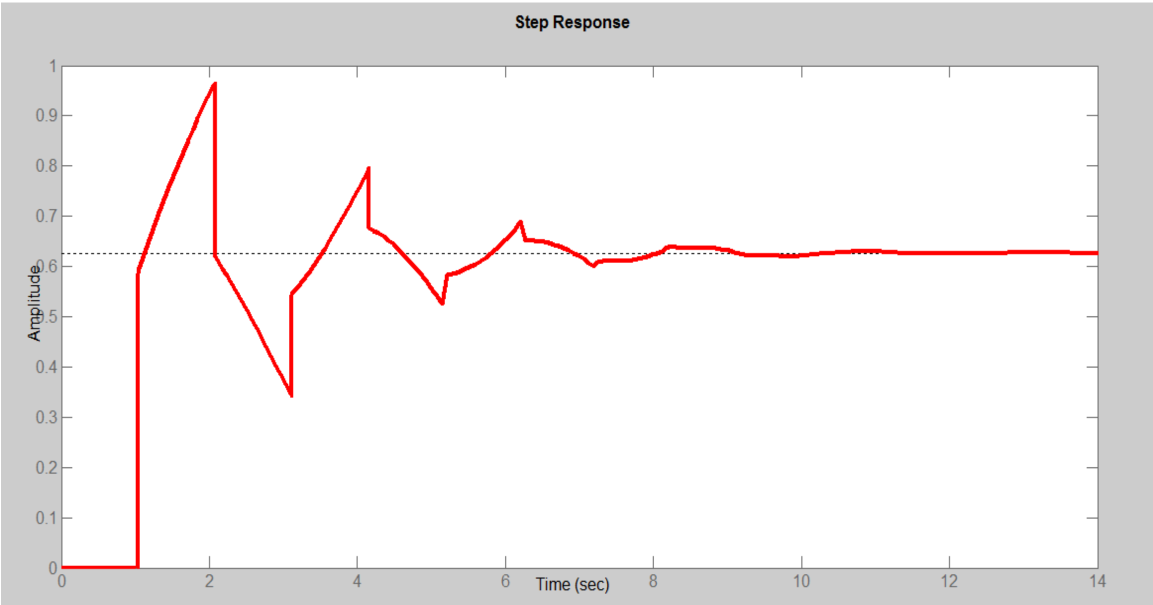

Fig.8. Step response of the experimental plant

VI. LAMBDA TUNING METHOD TECHNIQUE

Lambda tuning method is principally a pole placement method. The process model is assumed to be the first order transfer function [4].

The closed-loop transfer function of the process is desired to be of first order;

$$G_p(s) = \frac{K\,e^{-Ls}}{Ts+1} \qquad (10)$$

where λ=0.35*L is a tuning parameter that determines the pole location. The parameters of the process will be determined as in TABLE13.

Table.13 Lambda Tuning PID controller parameters.

Type of controller	K_p	T_i	T_d
PID	$\frac{T + \frac{1}{2}L}{K\,(\lambda + L)}$	$T + \frac{L}{2}$	$\frac{TL}{2T + L}$

6.1 Simulation Result

Using this technique, the PID controller parameters are obtained as given in TABLE14.

The Performancespecifications and step response obtained from above parameters are given in TABLE15 and fig.9

Here λ=0.35*L=0.3637.

Table.14. PID controller parameters

K_p	T_i	T_d
2.1156	2.9675	0.4286

Table.15.Performance specifications

Rising time	Peak Amplitude	Overshoot (%)	Time at which Overshoot occurs	Settling time	Steady state
4.17e-005	1.16	71.5	2.08	12.2	0.679

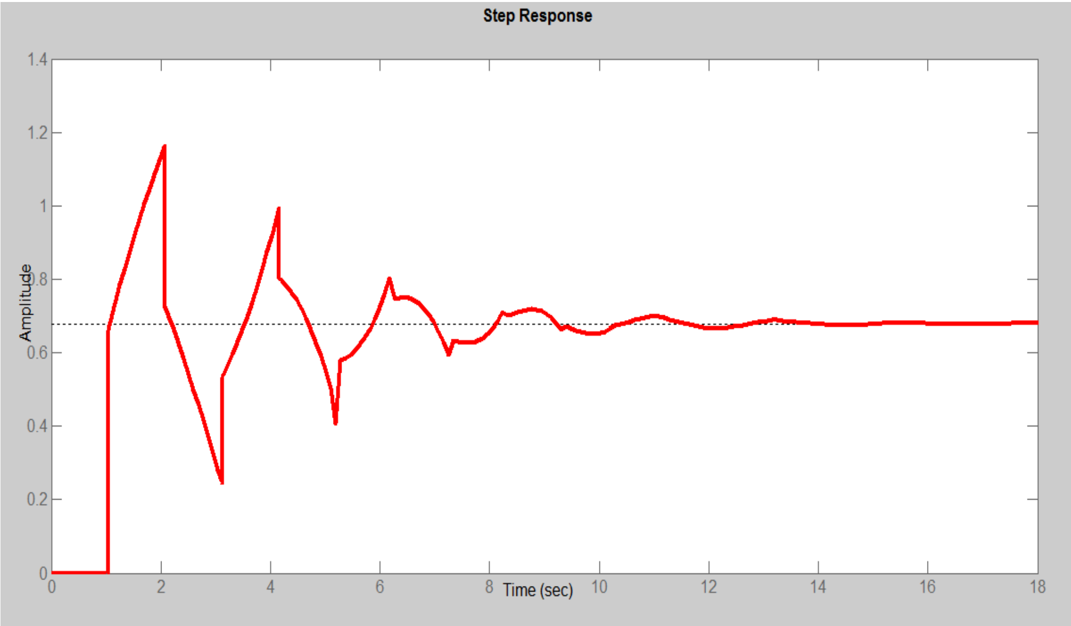

Fig.9. Step response of the experimental plant

VII .PERFORMANCE ANALYSIS

Consider the following stable proces

$$G_p(s) = \frac{K\,e^{-Ls}}{Ts+1} \quad (10)$$

where K=1, T= 2.448, L= 1.039

The MATLAB results for different PID tuning techniques are summarized in TABLE16.

Table.16. Time response Parameters

Tuning Method	Rise time	Peak amplitude	Peak overshoot	Settling time	Steady state
Z-N method	0.192	1.93	93.4	13.8	1
Z-N Frequency response method	0.327	1.98	98	10	1
IMC method	4.26e-005	1.15	70.1	11.2	0.676
CHN method	3.48e-005	0.966	**54.1**	**8.27**	0.627
Lambda method	4.17e-005	1.16	71.5	12.2	0.679

VIII.CONCLUSION

The paper describes design of PID controller for a First-order system with time-delay. Total five PID tuning techniques were implemented and their performances analyzed. Among them, Ziegler Nichols tuning technique exhibit largest settling time and maximum overshoot and Chien, Hrones and Reswick Method gives smallest overshoot and settling time. Among the five PID tuning techniques, the CHR method tuned PID Controller gives the best results for a First-order time-delay system.

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