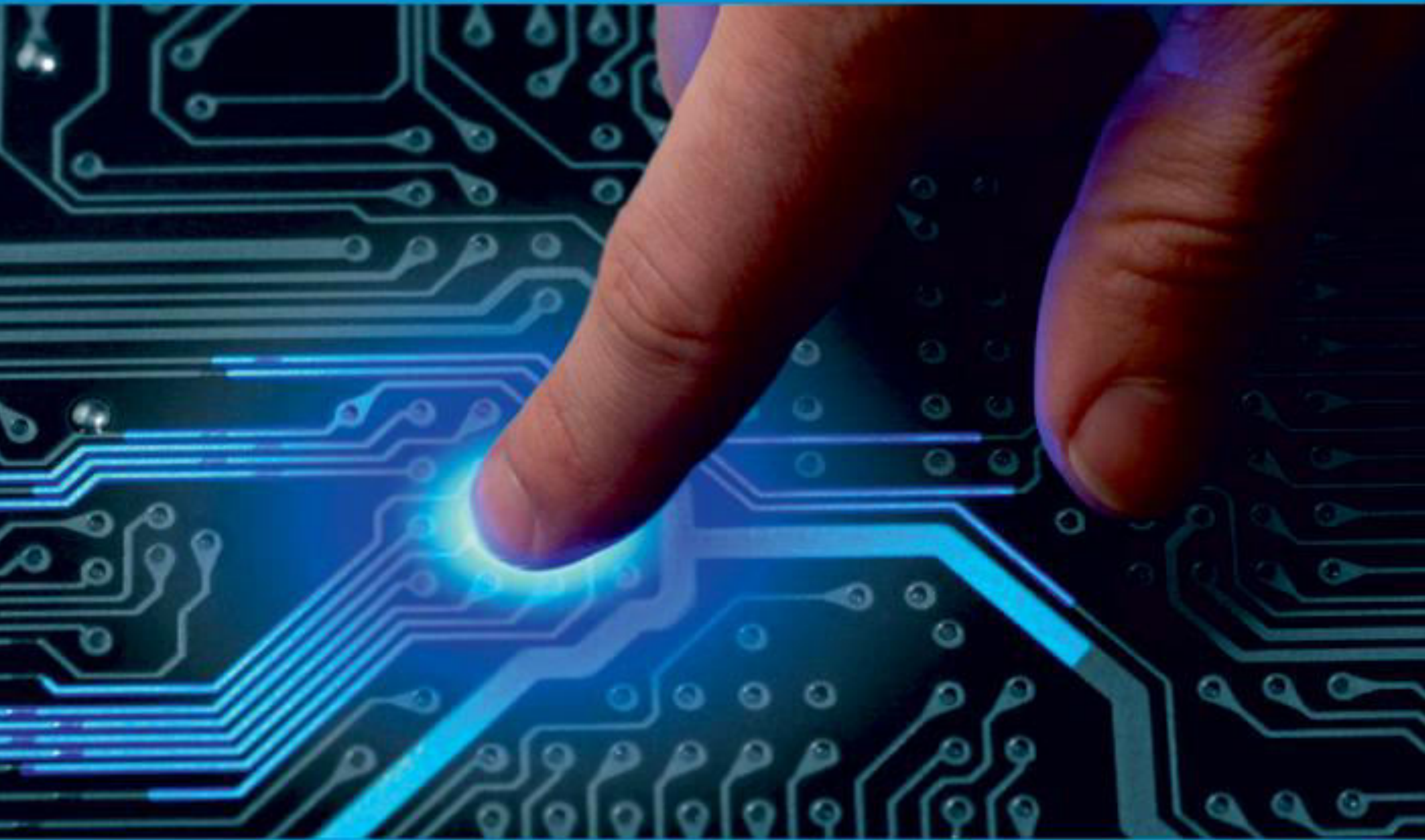
IJIRCCE

e-ISSN: 2320-9801 | p-ISSN: 2320-9798



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING

Volume 12, Issue 1, January 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.379

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 8.379 | A Monthly Peer Reviewed & Referred Journal |

|| Volume 12, Issue 1, January 2024 ||

| DOI: 10.15680/IJIRCCE.2024.1201076 |

Single Pole Placement Technique based Designing of Proportional Integral Derivative Controller for Integrating Processes

B S Patil, Dr.M.D.Uplane

Department of Instrumentation Engineering, AISSMS Polytechnic, Pune, India

Department of Instrumentation Science, Savitribai Phule University, Pune, India

ABSTRACT: In current years, Proportional-Integral-Derivative control is extensively used to adjust integrating process in industry application. In automatic control, parameter tuning of Proportional-Integral-Derivative controller for various integrating systems is a dynamic research field. Optimization method, direct synthesis, stability analysis, Internal Model Control, equating coefficient method and two degree of freedom control scheme approaches are being used to design Proportional-Integral-Derivative controller.

In this paper, pole placement method is used to study aspects of analytical designs for PID controllers. The proposed method is grounded on a low order plant model through pure integrators. The close loop transfer function which contains second order oscillator with lead-lag compensator. It is found that the zero value depend on real pole value of the closed loop transfer function. The pole has been substituted for obtaining the servo response better as much as possible. The proposed controller design technique is utilized to different transfer function models. The proposed method is compared with the presently reported approaches in terms of integral of square error and integral of absolute error. Simulated studies on first-order plus time-delay processes are carried out for demonstrating the efficiency of the controller in terms of time response specifications.

KEYWORDS: PID, Lead-Lag Compensator, Gain Coefficient, Reference Model, Levitation System.

I. INTRODUCTION

Designing of controller for integrating processes in industries is a challenging task. Complexity becomes very high when a delay time is allied within the process. Tuning and Appropriateness of proportional integral derivative (PID) controllers for integrating processes is an interesting topic. PID controller tuning is started from experimental rules given by Zeigler [1]. L. Wang and W. Cluett [2] gives explicit tuning rules of integrated plus time delay processes with gain, phase margins and allowable time delays. Sigurd Skogestant [3] has provided different analytical simple rules for tuning the PID controller which provide good closed-loop performance. M. Dela Sen [4] has studied spectrum assignment properties which are associated with output feedback pole placement based controllers. It has commensurate point delays and used for single linear time invariant systems which gives single output on single input. Qing Guo et al [5] propose two easy and modest approaches that can promise the power of the allocated two poles for PID control systems. Ahmad Ali and S. Majhi [6] have provided guidelines for choosing the gain crossover frequency and slope of Nyquist curves to govern integrating processes. They provide analytical expressions that correlate controller parameters to plant model parameters. K.G. Papadopoulos et al. [7] have proposed a symmetrical optimum criterion based control law which shows substantial enhancement when considering disturbance rejection. Alfaro V. M. and Vilanova R. [8] have proposed a robust tuning based two degree freedom proportional integral controller and evaluate close loop performance. In this method, they have used non-oscillatory and under-damped targets using optimization methods. It is also found that the target with non-oscillatory responses gives smoother output with improved servo performance. For model-free as well as time-delay systems, an analytical method is proposed by Linlin Ou et al.[9] to characterize the stabilizing PID region based on the frequency response data. Such characterization uses linear programming which is computationally efficient. Anil Ch. and Padma Sree R. [10] have direct synthesis method and time delay utilized to design a PID controller to integrate systems.

It is rely on the characteristic equation of the integrating system and PID controller and a filter with desired characteristic equation. In this desired characteristic equation, at similar desired location the multiple poles are positioned. Tuning parameters are adjusted to succeed the desired strength. For many kinds of integrating systems, tuning actions are well-defined in expressions of process parameters. This controller design technique is useful to

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| DOI: 10.15680/IJIRCCE.2024.1201076 |

numerous transfer function models and nonlinear models. Kumar D.B. and Padma Sree R. [11] have applied IMC principles to design PID controllers. In this proposal, IMC filter (Q) have used. The order of numerator is one greater than the order of the denominator of the IMC controller. IMC filter time constants are tuned which to provide a balanced robustness and performance for both regulatory and servo problems. The suggested controller is applied to many processes to prove its applicability and effectiveness. Zafer Bingul and Oguzhan Karahn [12] have used Artificial Bee Colony and Particle Swarm Optimization algorithms have used for tuning and designing proportional integral derivative. Chacon et al. [13] have suggested that classical controllers with several non-linear alterations can be measured to cope up with dissimilar control needs. He used different optimization algorithms to fix the finest controller parameters. Amirreza Tootchi et. al. [14] have developed mathematical expressions for Air Levitation system and investigated that PID controller which is the best choice for Air Levitation. Mohammed Irshad and Ahmad Ali [15] used well known integral performance approach in controller designing. In this approach, new objective function is proposed for controller design with modification of integral of squared error (ISE) criterion. Wei Zhang et.al [16] has used suggested tuning rules to design differential forward proportional integral derivative to integrate systems with direct synthesis and time delay. Many of these methods are somewhat complicated in the design process.

The purpose of this research work is to design PID controller using simplified analytical expressions. With application of a pole placement technique, controller parameters become dependent on the plant parameters and closed-loop transfer functions. PID variables are dependent on single pole placement techniques. An ordinary closed-loop method can be approximated by a second order reference model. If the plant has a clean integrator and a PID controller, then a closed loop transfer function (CLTF) must comprise an additional lead-lag compensator. The ideal model has four parameters; two are from the second order and two from the compensator.

The test part of paper is organized as below. Section 2 delivers mathematical models of PID controller. Section 3 contains time response and performance. Section 4 presents results of simulation on different processes. Section 5 précises the conclusions of the projected work.

Bharat Kumar Shamrao Patil et.al [17] Higher solicitation not withstanding defer time (HOPDT) frames are suggested to use a discrete time sliding mode controller (DSMC). A sliding mode surface is chosen, and the dominating post-circumstance technique is used to resolve the tuning parameters of the sliding mode controller as part of the structural states and botch. The "ball in a barrel" control object regulates the speed of a fan that forces air into a chamber in order to maintain a ball hanging in the barrel at a certain, predetermined location.

Bharat S. Patil et.al [18] PID controllers are commonly utilized in industrial control systems because of their straightforward operating principles. PID controllers are used in daily life by numerous control and instrument engineers and operators. Numerous changes are possible with PID controllers, enabling them to handle a broad range of systems and circumstances. The PID controller's settings must be fine-tuned in order to improve performance. Numerous authors have adjusted PID controller settings using various optimization strategies. The performance of these optimization strategies is lower. This study proposes a refined PID controller for the air levitation system.

II. MATERIAL AND METHODS OF PROPOSED METHOD FOR PID CONTROLLER

In this segment, mathematical models for process simulations, PID controllers, and ideal closed loop systems are discussed. Grounded on the pole placement technique, the classical factored forms of transfer functions are measured to express poles and zeros. The paper studies a low-order plant model with a pure integrator. PID controller is used according to performance requirements of a closed loop system. Figure1 depicts the classical structure of the control loop.

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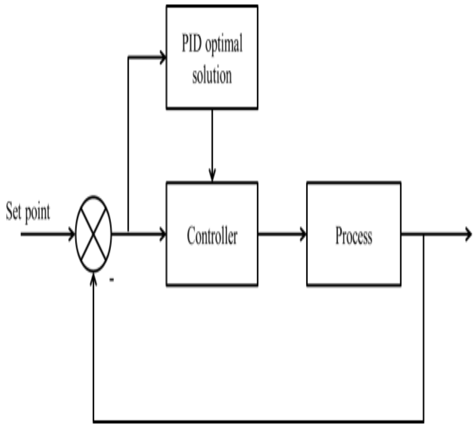

Figure 1: Structure of the closed loop control.

The plant consists of a low-order model and a pure integrator which is described by a dominant time constant (T_1) and gain coefficient (K). Analytical expressions for plant models and PID controllers rely on the process type..

In this research, the classical factored forms of transfer functions are deliberated to express poles and zeros. Mathematical models for process, PID controller, and reference closed loop system used in simulations are discussed as below.

Consider the following integrating system

$$P_{(s)} = \frac{K}{s(sT_1+1)(sT_2+1)} \qquad (1)$$

The PID controller in this situation is of the following form:

$$H_c(s) = \frac{Kc}{sT_i}(sT_iT_1 + 1)(sT_d^{\blacksquare} + 1) \qquad (2)$$

From equation(1) and equation(2), open loop transfer function become

$$H_{(s)} = [\frac{K}{s(sT_1+1)(sT_2+1)}][\frac{Kc}{sT_i}(sT_iT_1 + 1)(sT_d^{\blacksquare} + 1)] \qquad (3)$$

The general performance of a closed-loop system is defined by a second order reference model.

$$H_o(s) = \frac{\omega_0^2}{s^2+2s\xi\omega_0+\omega_0^2} \qquad (4)$$

Where, $\omega_0 > 0$ indicate natural frequency and $\xi > 0$ represent the damping coefficient. The performance depends on the natural frequency and damping coefficient.for obtaining expression of OLTF, using the plant model with the pure integrator,poles and zeros must be added to the reference model with a pole-zero pair with real and negative values

$$H_o(s) = \frac{k_0 \cdot (s+z)}{(s^2+2s\xi\omega_0+\omega_0^2)(s+p)} \qquad (5)$$

Where, z>0, p>0 and $k_0 = \frac{\omega_0^2 \cdot p}{z}$

Values for the pole-zero pair of the compensator shorten the mathematical expressions for the controller parameters. The PID controller parameters are .

$$K_p = \frac{\omega_0}{k_{\blacksquare}} \cdot \frac{2\xi p+\omega_0}{2\xi\omega_0+p} \qquad (6)$$

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$$T_i = \frac{2\xi p+\omega_0}{\omega_0 p} = \frac{1}{\omega_z} \quad (7)$$

$$T_d = T_1 \quad (8)$$

The proposed work aims to achieve the desired results by using a phase lead filter as follows:

i) The zero of the controller is kept close to the imaginary axis, as compared with the pole of the controller.
ii)The pole of the controller is kept far from the zero of the controller and the imaginary axis.
iii)The distance between the pole of the controller and the zero should be large.
iv)The added pole has a larger negative value than the added zero because zero is close to the origin.

The equation of PID filter is given by equation 9.

$$f= (\alpha s + 1)/ (\beta s + 1) \quad (9)$$

Where, $\alpha >> \beta$
filter is connected in series with PID controller

III. THEORY AND PERFORMANCE AND TIME RESPONSE SPECIFICATIONS

The PID controller is intended to balance the system in terms of performance and speed. The performance of the system is evaluated using performance indices and time response specifications.

3.1 Performance Index

For comparing the performance of proposed controllers with recent controllers, different performance indices are used. Large errors are penalized by the integral of square errors (ISE). Integral of absolute error (IAE) considers all errors equally. Integral of Square Errors is given by equation (10).

$$ISE=\int_0^{\infty} e^2 dt \quad (10)$$

And Integral of absolute error is calculated by using equation 11.

$$IAE=\int_0^{\infty} |e| dt \quad (11)$$

Error is denoted by the letter e, the variance among the set point value and the process parameter value. Smaller values of ISE and IAE indicate that the proposed method is enhanced than previous methods.

3.2 Time Response Specifications

Control systems are designed to meet time response specifications. These specifications play a dynamic role in the compression and investigation of systems. The rise, delay, peak, and settling times are influenced by the system's speed. Peak overshoots are associated with the tolerance method for a particular system. Using the specifications as a transpose process of analysis, damping factor and natural frequency can be designated through these specifications. Rise time specifications are calculated using equation 12.

$$t_r = \frac{\pi-\Theta}{\omega_n\sqrt{(1-\xi^2)}} \text{ Sec} \quad (12)$$

And Peak time and Peak overshoot are calculated using equation 13 and 14 respectively.

$$T_p= \frac{\pi}{\omega_n\sqrt{(1-\xi^2)}} \text{ Sec} \quad (13)$$

$$M_p = e^{-\xi\pi/\sqrt{(1-\xi^2)}}, \quad (14)$$

Settling time calculated using equation 15.

$$T_s=4/\xi\omega_n \text{ Sec} \quad (15)$$

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The above time response specifications are related to location of poles.

IV. SIMULATION STUDIES RESULTS AND DISCUSSIONS

For demonstration the usefulness of the suggested method, a few case studies were examined. Performance of the proposed technique was associated with recent methods stated in the literature. The performance results of case studies proposed by Zafer Bingul and Oguzhan Karahn [12], Mohammad Irshad and Ahmad Ali [15] and Kumar DBS and Padma Sree R. [11] have compared with proposed method of designing controller. The proposed controller designing also have compared with methods suggested by Anil Ch. and Padma Sree R [10], Amirreza Tootchi et al. [14] and J. Chacon et al. [13]. The performances of proposed methods for PID controller designing and existing some methods have given in Table 1, 2 and 3. Different case studies have discussed in details as below.

4.1 Case Study 1.

According to Zafer Bingul and Oguzhan Karahn [12] and optimization algorithms designed by Zafer have used to determine the optimal PID for FOPDT, given by equation 16.

$$P(s) = \frac{0.5}{s(s+1)} e^{-15s} \qquad (16)$$

In this research study, the equation(16) have rearranged and shown in equation(17).

$$P(s) = \frac{0.033}{s(s+1)(0.067s+1)} \qquad (17)$$

When we compare equation (17) with equation (1), we get

$K=0.0333$, $T_1=1$

The terms p, ξ and ω_0, come from the performance conditions, where
$p=1.5, \xi = 0.5$ and $\omega_0 = 0.1$

As a result of equations (6) to (8), we get Kp=3.03, $T_i=10.6666$, $T_d = T_1=1$, The PID parameters calculated by Bingul by PSO optimization are $K_p = 0.095, K_i = 0.000001, K_d = 0.0795$, and PID parameters calculated by Bingul using ABC optimization are $K_p = 0.1098$, $K_i = 0.000001, K_d = 0.0709$. Proposed method provides values for PID parameters such as $K_p = 0.284$, $K_i = 0.284, K_d = 3.03$ with filter parameters $\alpha = 900, \beta = 0.001$. The step response for the process is shown in Figure 2.

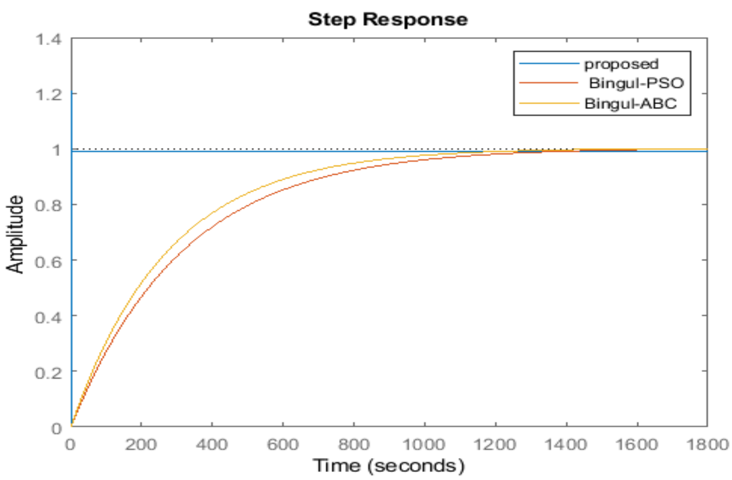

Figure 2: Step response for example 1.

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Performance indices such ISE, IAE and time response specifications (rise time, settling time, and peak time) are revealed in Table 1. This indicates the proposed method has excellent performance.

Table1. Time response specifications and performance indices for example-1.

Parameters of PID and Filter / Performance Measures	Proposed Method for PID controller	Bingul (PSO) Ref.[12]	Bingul (ABC) Ref.[12]
Kp	3.03	0.095	0.1098
Ki	0.284	0.000001	0.000001
Kd	3.03	0.0795	0.709
α	900	Not Available	Not Available
β	0.001	Not Available	Not Available
Rise time	0.0013	686.459	595
Settling time	0.0075	1.1974e+03	1.0401e+03
Peak time	0.0003	2.1724e+03	1.8785e+03
ISE	0.0863	8.76	8.734
ISA	0.6352	8.879	8.866

4.2 Case Study 2.
Take a look at a plant.
$P_{(s)} = \frac{0.2e^{-s}}{s(4s+1)}$,

As a result of rearrangement of above equation, it becomes as equation 18,

$$P_{(s)} = \frac{0.2}{s(4s+1)(s+1)} \qquad (18)$$

Where K=0.2,$T_1 = 4$. the terms p,ξ and ω_0 are chosen from performance conditions, where, p=1.5,$\xi = 0.9$ and $\omega_0 = 0.5$, from equation (6) to (8), we get

K=3.33, T_i=4.266, T_d =4,$K_i = 0.781$,$K_d = 13.32$, T=0.4166, ω_z=0.23, ω_p=2.4.

The PID's parameters calculated by Mohammad Irshad [15], for this process are Kp=1.491, $K_i = 0.419$. As per strategies reported in kumar and Sree[11] values of parameters of PID becomes Kp=7.415, $K_i = 0.951$,$K_d = 14.4496$, Tuning parameters from Ch.Anil et al.[10] are Kp=5.7422, $K_i = 0.9725$,$K_d = 11.21$ a closed loop response is shown in Figure 3, indicating that the suggested method gives a faster response than existing methods.

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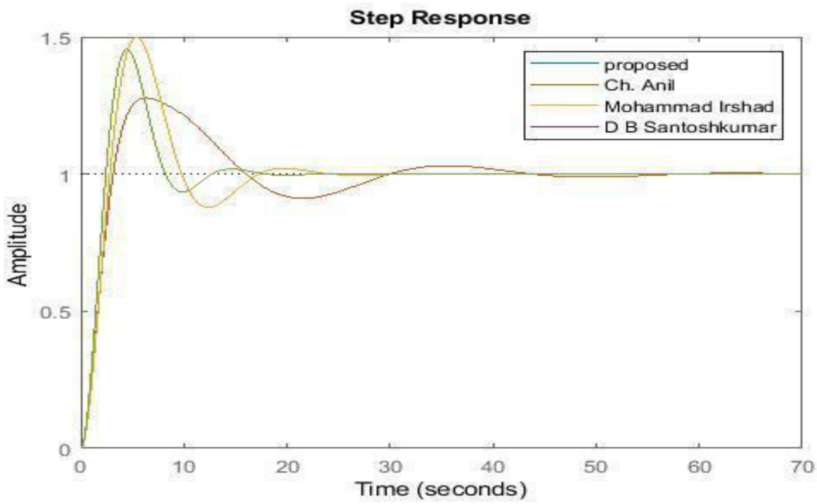

Figure 3: Step response for example 2

Table 2 shows performance indices and time response specifications, demonstrating how well the proposed method performs.

Table.2. Time response specifications and performance indices for Example-2.

Parameters of PID and Filter / Performance Measures	Proposed Method for PID controller	Ch.Anil Ref.[10]	Mohammad Irshad Ref.[15]	D.B.Santoshkumar Ref.[11]
Kp	3.33	5.7422	1.491	7.415
Ki	0.781	0.9725	0.419	0.951
Kd	13.32	11.21	0	14.4496
Settling time in Second	10.72	20.2203	11.9496	11.9618
Overshoot	27.7228	49.9659	45.4983	45.4983
Peak time in Second	1.2772	1.4997	1.4550	1.4561
Rise time in Second	1.6132	1.9229	1.6526	1.7354
IAE	3.024	3.707	8.27	3.31
ISE	1.558	2.05	4.57	8.667

4.3 Case study 3.
Mathematical equation of air levitation system is,

$$H_p(s) = \frac{0.88}{s(3.023s+1)(s+1)} \quad (19)$$

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Compare equation (19) with equation (1), we get

$$k_{\blacksquare} = 8.88, T_1 = 3.023$$

From equation (6) to (8), we get $\omega_0 = 0.5, \xi = 0.9$ and $p = 1.5$

$$k_p = 0.0751, T_i = 4.267, T_d^{\blacksquare} = 3.023$$

whereas other methods by J Chacon et al. [13] and Sigurd [3] are presented in Table 3. A closed loop response is shown in Figure 4, indicating that the suggested method gives a faster response than existing methods. Table 3 shows performance indices and time response specifications, demonstrating how well the suggested method performs.

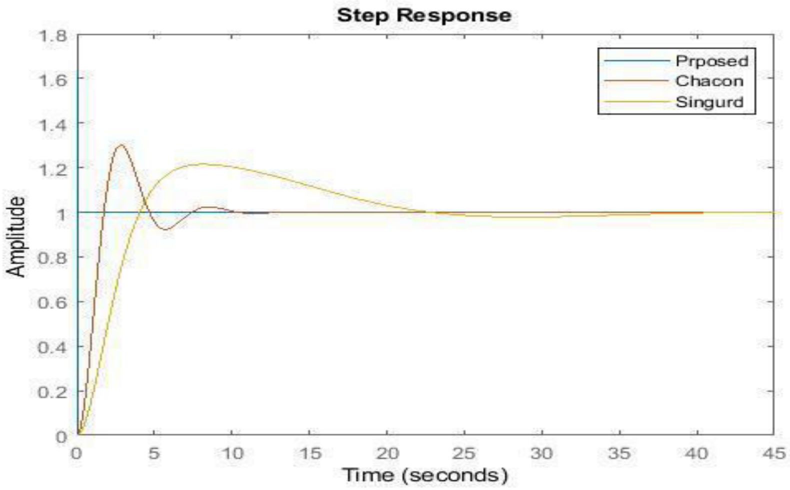

Figure 4. Step response for example 3.

Table.3. Time response specifications and performance indices for Example-3.

Parameters of PID and Filter / Performance Measures	Proposed Method for PID controller	Chacon Ref.[13]	Sigurd Ref.[3]
Kp	1.3333	0.005	0.05624
Ki	0.3125	0.002	0.007
Kd	4.03	0	0.17
α	100	100	100
β	0.01	0.01	0.01
Rise time in Second	0.0034	1.1625	0.0312
Settling time in Second	0.0757	9.4264	0.1480
Peak time in Second	0.0091	2.7882	0.0620
ISE	0.6171	5.328	1.503

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V. CONCLUSION AND FUTURE SCOPE

In this paper, designing of PID controller using a pole placement method for integrating first order plus time delay processes have presented. The parameters of controller are grounded on the parameters of the plant and closed loop transfer functions. Analytical formulas are given to calculate the PID parameters. Simple tuning rules are proposed to achieve the excellent performance. This proposed method have compared with recently presented methods for integrating first order with time delays. In this research, the single pole is used which have offered better servo response than those of previous existing methods. Experimental results and case based Simulation results show that the proposed method provides better performance in terms of ISE, IAE, settling time, rise time, peak time than existing developed methods. In the future, multiple dominant pole placement technique can be used to obtain improved the performance and robustness of PID controller.

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