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TUNING OF AN I-PD CONTROLLER FOR USE WITH A THIRD-ORDER OSCILLATING PROCESS

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Abstract:

This paper presents a technique for tuning an I-PD controller for use with a third order process having about 57 % maximum percentage overshoot and 77 s settling time. The controller parameters have to be adjusted to provide an optimal performance forth closed-loop control system, using the MATLAB's optimization toolbox through minimizing an objective performance criterion. Five objective functions (ITAE- ISE- IAE-ITSE- ISTSE) were investigated to assess the closed loop control system performance. The performance of the control system using the tuned I-PD controller with this technique is compared with that using the minimum ITAE standard form tuning technique,when using a PID controller and PI-PD Controller.

Keywords —**I-PD controller tuning, PID controller tuning, Third order process, MATLAB Optimization, Control system performance.**

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I. INTRODUCTION

It was not until 1922 that classical PID controllers were first developed using a theoretical analysis, by Russian American engineer Nicolas Minorsky for automatic ship steering [1]. The PID controllers were firstly applied for industrial applications in 1939 [2]. However, the major drawbacks of the basic parallel PID controllers are the effects of proportional and derivative kick. In order to overcome these effects, modified forms of parallel controller structures such as I-PD were purposed [3]. The application of the I-PD controller is expected to improve the performance of the control system compared with the classical PID one.

The advantage of I-PD control over PID control is that I-PD control can realize milder response to set-point changes than PID control, while both control algorithms achieve the same performance against disturbances [4].Prasad, Varghese and Balakrishnan (2012) designed and tuned an I-PD controller for a first order lag plus time delayed process. They used particle swarm optimization to tune the controller and compared with other tuning methods [5].Rajinikanth and Latha proposed an I-PD tuning technique for a class of unstable process model using Bacterial Foraging Optimization (BFO) algorithm [6].

Shiota and Ohmori(2013) proposed an adaptive IPD control scheme with variable reference model as one of the control schemes to overcome model uncertainty, theyshowed the validity of their scheme through numerical simulation [7].

Hassaan (2014) investigated using an I-PD controller to generate an improved performance to set-point tracking when controlling a second order process having 85.4 % maximum overshoot. He tuned the controller using MATLAB optimization toolbox and an ISE objective function. He compared his results with ITAE standard forms tuning technique. He used five objective functions to tune the controller for time delay up to 5 s and compared his results with those obtained using PD-PI and PIDF controllers for the same process [8].

I-PD controllers differ from the basic type PID controllers that in the I-PD the error signal only takes integral action, the output signal only takes proportional and derivative action, so sudden changes in the set-point variable cannot produce Proportional Kick and Derivative Kick [9].

Puangdownreong,Nawikavatanandhammarata (2016)designed optimal I-PD controller for DC motor speed control system using the cuckoo search method [10]. Aishwarya,Agalya,Nivetha and Ramya(2016) studied the I-PD design for electro mechanical system using particle swarm optimization (PSO), bacterial foraging optimization (BFO) and Firefly Algorithm (FA), the study confirmed that FA offers faster convergence compared with the PSO and BFO algorithms [11].

Kurnianto,Sanjaya andTurner (2017) used the I-PD controller to control the three-phase voltage in a microgrid, the system showed a very good reference tracking capability during set point and load change and the coupling effect due to active and reactive power was reduced [12]. Erkan, Yalçın and Garip (2017) designed an I-PD controller based on coefficient diagram method (CDM) to overcome instability issue of a 4-pole hybrid electromagnetic \systems which have a potential usage in many industrial area, the proposed controller offered a good equilibium in terms of simplicity, stability, minimum overshoot and robustness, which are crucial specifications for maglev applications [13].

Aridome, Nakamoto, Wakitani and Yamamoto (2018) designed I-PD Control system with low-pass filter using the pole placement method, the proposed system shows a goodresult in DC motor speed control implementation [14].Vilanova, Arrieta, Gonzalez and Garridoand (2018) proposed theI-PDcontroller structural solution to the trade-off tuning if the controller tuning is addressed for the servo mode with I-PD Controller structure [15]. Meena andChitra (2018) they compared between PID and I-PD tuning with SISO system using to algorithm firefly and hybrid firefly with particle swarm, the objective functions considered were Peak Overshoot (PO) and ITAE, All the processes with the proposed equation the performance index, ITAE, is less independent of the structure [16].Sain, Swain, and Mishra (2018), The IPD Controller tuned using the Jaya algorithm outperforms1-DOF and 2 DOF Integer Order (IO) and fractional Order (FO) PID Controllers [17]. Kaya (2018)Designed an optimal I-PD controller for integrating time delay process using an analytical formulabased on IST^2E criterion, he compared the performance of tuned I-PDand PID [18].

Hassaan (2019) tuned an I-PD Controller for a highly oscillating second order process using MATLAB optimization toolbox. The effectiveness of used technique is investigated by comparison with ITAE standard technique and conventional PID controller [19].

II. PROCESS

The process is a third order one which can be constructed for purpose of simulation as an integrator connected in series with two successive first order process as shown in Fig.1

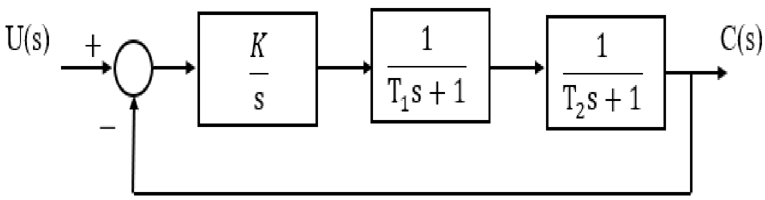

Fig. 1 Third Order Process

The process has the transfer function, $G_p(s)$ given by:

$G_P(s) = b/(a_1 s^3+a_2 s^2+a_3s+a_4)$ (1)

Where:

$b = K/(T_1T_2)$

K is an integral gain

$a_1=1$,

$a_2= T_1+T_2/T_1T_2$,

$a_3= 1/T_1T_2$

$a_4 = K/(T_1T_2)$

The following set of process parameters are selected:

$K=0.5$, $T_1=1s$, $T_2= 5$ s

The time response of the process to a unit step input is shown, in Fig.2 using the 'step' command ofMATLAB [20].

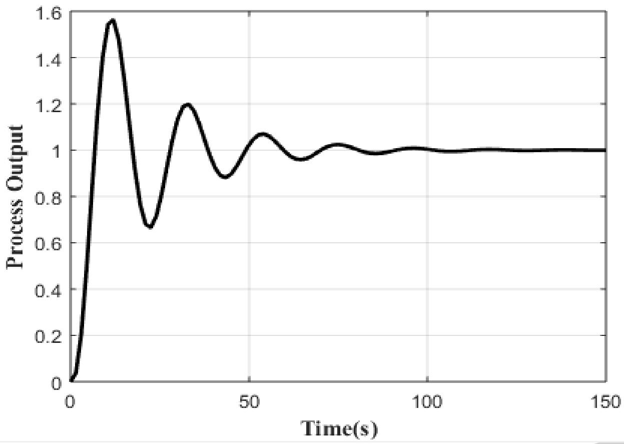

Fig. 2 Unit Step timeresponse of the process

Theprocess has the time-based characteristics:

- Maximum percentage overshoot: 57%
- Settling time: 77 s

III. CONTROLLER

The proposed I-PD Controller structure is shown in Fig.3, the integral part acts only on the error signal E(s). The proportional and derivative parts act on the process output C(s). By this it is possible to get rid of the kick following a reference input change(set-point kick) as quoted by Prasad, Varghese and Balakrishnan [5]. The block diagram of theclosed-loop control system incorporating the I-PD controller is shown in Fig.3 [5].

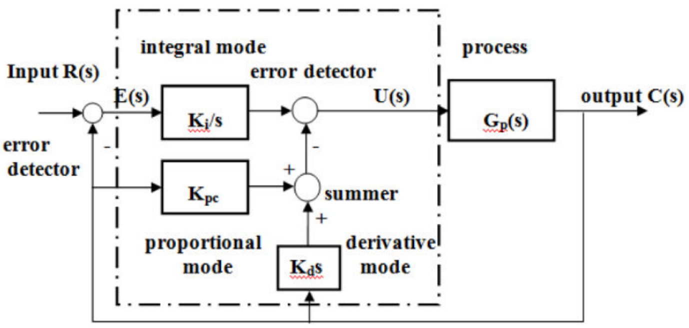

Fig. 3 Control system with I-PD controller [5].

The output signal from the I-PD controller, u(t) is:

$$u(t) = K_i \int_0^T e(t)dt - [K_p c(t) + K_d \frac{dc(t)}{dt}] \quad (2)$$

Using the block diagram of Fig.3, the control system transfer function, M(s) = C(s)/R(s) is given by:

$$M(s) = b_0 / \{a_1 s^4 + a_2 s^3 + a_3 s^2 + a_4 s + a_5\} \quad (3)$$

Where:

$b_0 = (KK_{pc})/(T_1T_2)$

$a_1 = 1$,

$a_2 = (T_1+T_2)/(T_1T_2)$,

$a_3 = (1+KK_d)/(T_1T_2)$,

$a_4 = [K(1+K_p)]/(T_1T_2)$

$a_5 = (KK_{pc})/(T_1T_2)$

IV. CONTROLLER TUNING

The I-PD Controller is tuned based on five objective functions: ISE, IAE, ITAE, ITSE and ISTSE.The objective functions dependon the error between the step time response of the control system and its steady state response. AMATLAB code based on theoptimization toolboxof MATLAB is used to tune the controller through minimizing the objective function subjected to a number of functional constraints using the command '*fmincon*' [21]. The objective functions used are [21]:

$$\text{IAE} = \int_0^T |e(t)|dt = \int_0^T |r(t) - y(t)|dt,$$

$$\text{ISE} = \int_0^T e^2(t)dt = \int_0^T [r(t) - y(t)]^2 dt, \quad (4)$$

$$\text{ITAE} = \int_0^T t|e(t)|dt = \int_0^T t|r(t) - y(t)|dt,$$

$$\text{ITSE} = \int_0^T te^2(t)dt = \int_0^T t[r(t) - y(t)]^2 dt,$$

The unit step response is of the control system had is plotted using the '*step*' command of MATLAB [20].The control system time-based specifications are extracted via using the MATLAB command '*stepinfo*' [20].

The tuning results is shown in Table 1.

TABLE 1 I-PD Controller tuning results

	ITSE	ITAE	ISE	IAE	ISTSE
Settling Time (s)	4.4265	8.8932	5.4293	10.2881	7.1663
Maximum Overshoot (%)	4.8283	4.7753	4.7764	4.7748	4.7746
Kp	23.5506	275.0617	79.8058	100.1560	102.2848
Ki	0.3960	0.2329	0.3740	0.2018	0.2875
Kd	1.4178	2.2288	1.4071	2.5946	1.8205

The unit step response of the control system is shown in Fig.4the five objective functions of Eq.4.

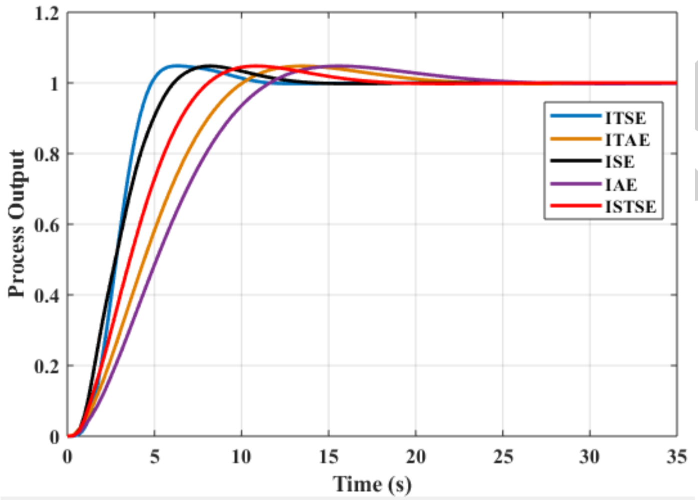

Fig. 4 step time response of the control system

The variation of the objective function type has a significant effect on the control system time response. Therefore, one of these objective functions provides the best tuning of the I-PD controller parameter which is the ISE one.

V. COMPARISON WITH STANDARD FORM TUNING

The control system in terms of its transfer function is a fourth order one. The optimal characteristic equation of such a system with a constant numerator is given using a minimum ITAE standard form given as [22]:

$$s^4 + 2.1\omega_o s^3 + 3.4{\omega_o}^2 s^2 + 2.7{\omega_o}^3 s + {\omega_o}^4 \quad (5)$$

Comparing the characteristic equation of Eq.5 with the corresponding one in Eq.3 we get, the controller parameters with the following values:

K_p=4.037901, K_i =0.05857051, K_d=2.254151

Fig.5 shows time response of the tuned proposed control system and the one tuned using the minimum ITAE Standard form.

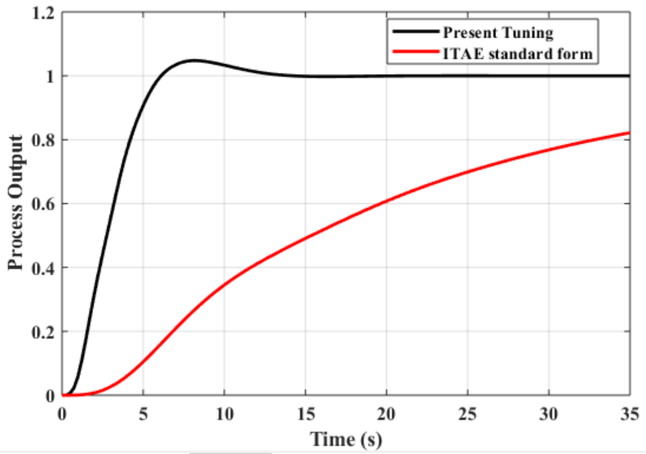

Fig. 5 Time step response comparison.

The proposed tuned control system time response is also compared with a tuned PID controller when used to control the same process through using the same technique. The time step response of the control system using an I-PD and conventional PID controller is shown in Fig.6.

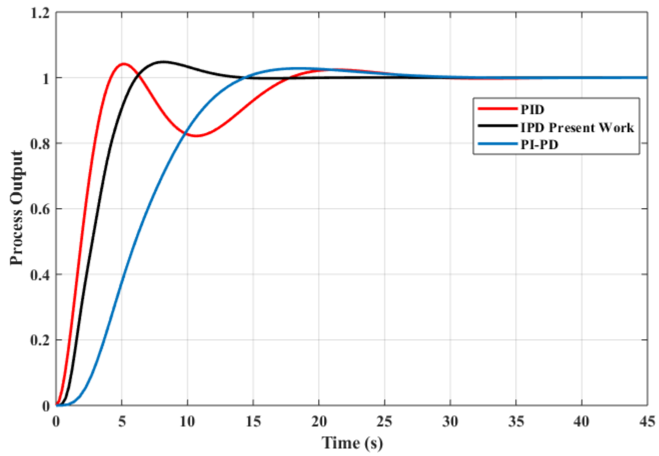

Fig. 6 step time response of the control systems.

Table2 showsa comparison between the time-based specifications of the closed loop control system using Tuned I-PD controller, PID controller and PI-PD controller [22]to control the same third order process.

TABLE2 Controlsystemtime-based specifications

	I-PD	PID	PI-PD
Settling Time (s)	5.4293	15.6506	36.1414
Maximum Overshoot (%)	4.7764	4.1428	2.8812
Gain margin (dB)	20	inf	16.75
Phase margin (degree)	63.8	52.2	65.6
K_p	79.8058	1.1035	
K_i	0.3740	0.3399	
K_d	1.4071	5.3148	

CONCLUSIONS

The I-PD Controller is tuned using the MATLAB toolbox when used with a third order process having 57 % overshoot, the tuned controller improved the system time response characteristics using the ISE as an objective function.The control system overshoot was reduced to 4.78 % and the setting time reduced from 77 s to about 5.4 s.

The I-PD controller had a significant effect on the control system step time response.

The tuned I-PD controllerusing the present tuning technique was compared with the tuning approach using the minimum ITAE standard form, The ITAE standard form method improved the system overshoot to become 0 % however the settling time increased to 59.25 s

The proposed tuned I-PD was compared with a tuned PID and PI-PD controllersusing the same tuning technique used in the present work. The I-PD controller has decreased the maximum percentage overshoot and smoothed down the kick associated with using the PID controller.

The tuned PI-PD controller decreased the overshoot to 2.88 % however the settling time decreased to 36.14 s

The I-PD has the best time-based characteristics compared with both PID and PI-PD in control such a third order process.

The performance of the I-PD controlled process is accepted as the parameters are with in the range assigned by Ogata, Lei and Man (30<Pm<60 degree),(30<Pm<90degree)[22][23].

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