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Design of PID Controller with Compensator using Direct Synthesis Method for Unstable System

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ABSTRACT

In industrial processes, unstable system produces undesirable peak overshoot. So, PID controller with compensator and set point filter is designed using direct synthesis method. The set point filter reduces the peak overshoot. PID controller with compensator improves the overall response of the system. In this method, the characteristics equation of the system with PID controller and a compensator is compared with a desired characteristics equation. A single tuning parameter is used to find controller parameters, compensator and set point filter.

Key words: PID controller, Synthesis method, Tuning, Compensator

1. INTRODUCTION

A new method for tuning of PID Controllers is needed by the process industries to improve the process quality and to achieve desired performance. Many more new methods for tuning of PID also reported in the literature. Lee et al. [1] considered two loop controller and set point weight s to reduce peak overshoot. Shamsuzzoha & Lee [2] and Vijayan & Panda [3-4] designed set point filters to improve the loop performance and to decrease peak overshoot. Zhang [5] reported a simple set point filter to reduce the peak overshoot. Recently, Nie et al [6] implemented compensator based on gain and phase margin specifications to reduce the peak overshoot. Nusret Tan et al [7] designed a method to calculate all stabilizing PI controllers. Anwar and Somnath [8] designed a tuning method based on Frequency response of the system. Jeng et al [9] designed PID controller based on plant step response data. Hamamci and Tan [10] proposed a tuning method based frequency domain specifications. Panda [11] proposed analytical method of PID tuning for various processes. Panda [12] designed PID controller for integrating process by synthesis method. Many tuning formulas describing the three controller parameters of PID are found in literature (Dwyer [13]). Vijayan et al [14] discussed about stability analysis of PID controller. IMC type PID controllers are designed by many researchers (Rivera et al. [15], Chien and Fruehauf [16], Chen and Seborg [17], Skogestad [18]). These equivalent PID controllers are robust in nature and even they are being used for higher order systems. Sarayana [19], Ramadevi [20] and Devikumari [21] designed PID controller for multivariable system. Rajinikanth [22] proposed a tuning algorithm based on Bacterial foraging optimization method. Dey et al [23] and Ajmeri [24] designed PID controller for integrating process. Hu et al. [25] derived an analytical method for PID controller tuning with specified gain and phase margin. Anil & Padma Sree [26] and Jung et al [27] explained about tuning of PID controller using direct synthesis method. Nivetha et.al [28] discussed about tunable method of PID controller for integrating processes. Recently, Suresh Manic et al [29] designed centralized PI controller for interacting conical tank system. Dinesh kumar et al [30] designed a gain scheduled PI controller for nonlinear system. Mikhalevich et al [31] proposed new method tuning PID controller based on phase margin specifications. Anusha Rani et al [32] designed sliding mode controller for chemical process. In this paper tuning of PID controller in double feedback loop with compensator and set point filter is proposed. This improves the robustness of the system. The PID controller with compensator is designed using synthesis method.

2. CONTROLLER DESIGN USING DIRECT SYNTHESIS METHOD

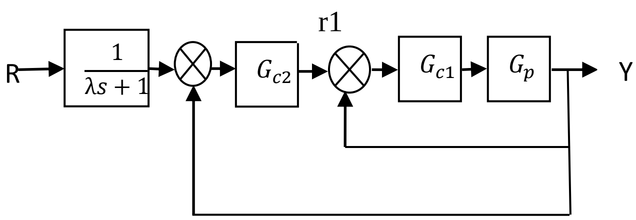

Figure 1 Basic Structure of Proposed Closed Loop System

The general transfer function is:

$$G_p = \frac{k(fs+g)e^{-ds}}{as^2+bs+c} \quad (1)$$

Proportional controller ($G_{c1}=K_{c1}$) is used in the inner loop. The inner loop is tuned by Ziegler-Nichols [33] Method. The closed loop transfer function of inner loop is given by

$$G_{p1} = \frac{y}{r_1} = \frac{k_{c1}k(fs+g)(1-0.5ds)}{k_{c1}k(fs+g)(1-0.5ds)+(as^2+bs+c)(1+0.5ds)} \quad (2)$$

The dead time is approximated using Pade approximation. In the outer loop, PID controller with compensator is used which is given by

$$G_{c2} = K_{c2}\left(1+\frac{1}{\tau_I s}+\tau_D s\right)\frac{(\alpha s+1)}{(\beta s+1)} \quad (3)$$

The characteristics equation of outer loop is given as

$$1+G_{p1}G_{c2}=0 \quad (4)$$

By substituting equation (2) and (3) in equation (4), we get (5)

$$1+\left(\frac{k_{c1}k(fs+g)(1-0.5ds)}{k_{c1}k(fs+g)(1-0.5ds)+(as^2+bs+c)(1+0.5ds)}\right)*$$
$$\left[K_{c2}\left(1+\frac{1}{\tau_I s}+\tau_D s\right)\frac{(\alpha s+1)}{(\beta s+1)}\right]=0 \quad (5)$$

The desired characteristics equation [26] is given as

$$(\lambda s+1)^5=0 \quad (6)$$

After expanding equation (5) and (6), the coefficients are equated. Once the coefficients are equated, ***fsolve*** in **MATLAB** is used to obtain the known values of Kc2, τ_I, τ_D, 'α' and 'β'. The 'λ' is used as tuning parameter. The same 'λ' is used as time constant of set point filter.

3. SIMULATION RESULT

3.1. Example 1

An example for Unstable First order plus time delay Process [27] is given by

$$Gp=\frac{e^{-0.5s}}{(s-1)} \quad (7)$$

For the λ=1.07, the proposed method gives better result. The PID tuning parameters of proposed method are kc1=1.268, kc2=0.4976, τ_I=5.6321, τ_D =0.0674, α=0.759 and β=4.7812. The tuning parameter of IMC-PID with filter method is given by kc=1.274, τ_I=12.69, λ=2.7. The servo response this system is shown in Figure 2. The performance index Integral Time weighted Absolute Error (ITAE), Integral Absolute Error (IAE), Integral Square (ISE) and Percentage of Peak Overshoot (PV) are calculated from servo response.

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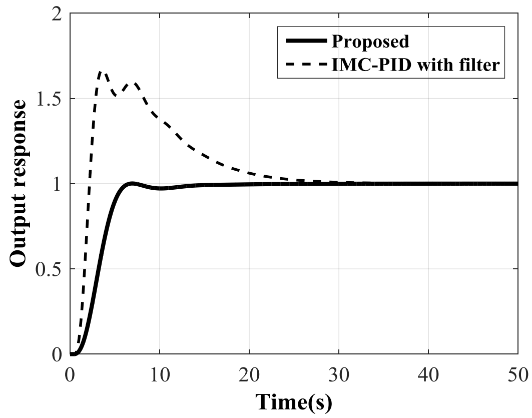

Figure 2 Servo Response of the Example 1

Table 1 Performance Index of Example 1

Method	ITAE	IAE	ISE	PV (%)
Proposed method	**8.844**	**3.468**	**2.556**	**0.1226**
IMC-PID with filter	57.91	7.759	3.983	66.86

The Figure 2 and Table 1 shows that the proposed method produces better result compared with IMC-PID with filter method in terms of less ITAE, IAE, ISE and Peak Overshoot.

3.2 Example 2

A unstable second order plus delay time system [6] is given by

$$Gp = \frac{e^{-0.5s}}{(0.5s+1)(2s-1)} \quad (8)$$

For the λ=0.8, the proposed method gives better result. The PID tuning parameters of proposed method are kc1=1.3977, kc2=0.7636, τ_I=2.5368, τ_D =1.1125, α=0.5158 and β=0.5167. The tuning parameter of Zhuo-Yun Nie method is given by kc=0.155, τ_I=0.314 . The servo response this system is shown in Figure 3. The performance indexes are given in Table 2 which shows that the proposed method is better than Zhuo-Yun Nie method.

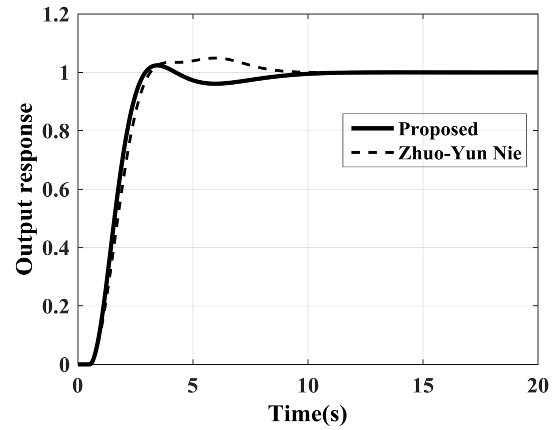

Figure 3 Servo Response of the Example 2

Table 2 Performance Index of Example 2

Method	ITAE	IAE	ISE	PV (%)
Proposed method	**2.482**	**1.793**	**1.324**	**2.427**
Zhuo-Yun Nie	2.874	1.958	1.424	4.9287

4. CONCLUSION

Double feedback controller structure is used for the closed loop system. In the inner loop proportional controller is used. It stabilizes the system. The outer loop contains PID controller with compensator which improves the overall response of the system. The set point filter reduced the peak over shoot of the system. A direct synthesis method is proposed to design the PID controller with compensator and set point filter. A single tuning parameter is used to find the system PID parameter, compensator and time constant of set point filter. Two examples are chosen and simulated using the proposed method. The simulated responses are compared with existing method to prove the efficacy of the proposed method. The proposed method produced better result compared with the existing method.

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