Frequency Response based PID Controller Design with Set point Filter

N.Chermakani
PG Scholar
Dept. of Electronics and Instrumentation Engineering
National Engineering College, India

V.Suresh
Assistant Professor
Dept. of Electronics and Instrumentation Engineering
National Engineering College, India

A.Abudhahir
Professor
Dept. of Electronics and Instrumentation Engineering
National Engineering College, India

Prithee Madan
Assistant Professor
Dept. of Electronics and Instrumentation Engineering
National Engineering College, India

ABSTRACT
In the present paper a simple procedure to design PID controller with setpoint filter is proposed. Designing a PID controller to meet gain and phase margin specification is a well-known design technique. Several frequency response based tuning methods are available to achieve the requirement but higher value of overshoot is still a problem. Simple frequency response method (FR) is modified by considering the setpoint filter to minimize the peak overshoot. Even if the FR Method PID parameter calculation is simpler, it gives high peak overshoot. The set point filter coefficient is based on the zeroes of the controller. The performance of the closed loop system is analyzed by using the criterion IAE, ISE, peak overshoot and settling time. Bench mark system has been considered for analyzing the performance of the tuned parameter. The performance of proposed method is compared with simple frequency response method and Ziegler-Nichols method. The proposed procedure is valid for PI,PD and PID controller design. The method is applicable to any linear model structure with dead time process.

Keywords
Frequency response, PID control, Set point filter, Phase margin , Gain margin, Peak overshoot

1. INTRODUCTION
One of the most research areas in automatic control is the development of tuning methods for Proportional – Integral – Derivative (PID) control. In most industries PI controllers are commonly used, because derivative part in PID amplifies the feedback measurement noise. On the other hand, addition of the derivative mode with P/PI controller brings a stabilizing effect and improves the speed of response without excessive oscillation. In this work a filtered derivative type PID controller structure that attenuates the measurement noise while preserving the merits of derivative mode is used. Tuning of PID controller was initiated by Ziegler and Nichols in 1942 [6]. The criterion used for Ziegler-Nichols tuning rule is one quarter decay ratio only, but it gives poor robustness in many application[3]. Several tuning methods have been proposed like direct synthesis method [9] and Astrom and Hagguland method [3], Among these a simple procedure to design PID controllers in the frequency domain proposed by Roberto sanchis, uses only one tuning parameter which makes it simple. It provides excellent robustness at the cost of peak overshoot. But in many process industries peak overshoot is undesirable and to be minimized to the extent possible to ensure safety and economical norms. V.Vijayan etal. proposed a setpoint filter design with PID to minimize the peak overshoot[5]. The present work aims to achieve the robustness with minimum overshoot by fusing the setpoint filter with FR based tuning. .

The layout of the paper is as follows : first, the PI and PID design problem is stated. Then, the proposed method compared with other methods found in the literature. The conclusion section summarizes the analysis and inferences made.

2. DESIGN METHODS
The conventional PID control loop with setpoint filter is considered in this paper is shown in figure 1. Where r is the reference signal, τ_f is the filter coefficient, u is the controller output, y is the controlled output and d is the disturbance.

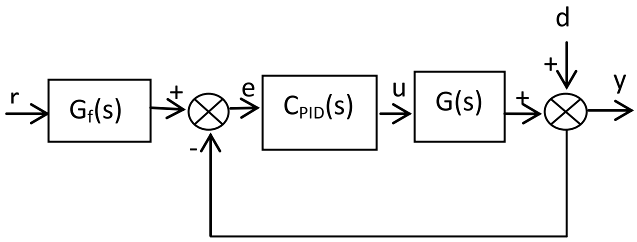

Fig 1. PID controller with setpoint filter

The setpoint filter is the first order filter , that transfer function is shown in equation (1).

$$G_f(s) = \frac{1}{\tau_f s + 1} \tag{1}$$

A tuning parameter 'a' , that is defined as the ratio of final gain cross over frequency of the process with controller to the zero of the controller is determined using (2) . For the PI and PID controller, the maximization of the controller gain is equivalent to minimization of the integral error [1].

$$a = \frac{w_{cg}}{z_c} \tag{2}$$

While sweeping the setpoint filter coefficient from ten percentage of$1/z_c$ to $1/z_c$, overshoot is reduced gradually . It is observed that ninety percentage of $1/z_c$ yields better performance

$$\tau_f = \frac{0.9}{z_c} \tag{3}$$

The PID parameters are those that maximize the controller gain k_c , subject to the following constraints;

1) The phase margin (ϕ_m) should be equal to the required (specified) phase margin(ϕ_r). 2) The gain margin (γ_m) should be larger than or equal to the required (specified) gain margin (γ_r) .

2.1 Design Method for PI control

The transfer function of the PI controller is represented in (4) [1].

$$C(s) = K_P\left(1 + \frac{1}{T_i s}\right) = K_c \frac{1 + \frac{s}{z_i}}{s} \tag{4}$$

where

$$K_P = \frac{K_c}{z_i}; T_i = \frac{1}{z_i} \tag{5}$$

The following six steps are involved to tune the controller by using single tuning parameter '*a*'.

1) Phase of the controller at gain crossover frequency of the process with controller (arg(C(jw_{cg})) is calculated using (6).

$$\arg(C(jw_{cg}) = \arctan(a) - \left(\frac{\pi}{2}\right) \tag{6}$$

2) phase of the process at gain crossover frequency of the process with controller (arg(G(jw_{cg})) is calculated using (7)

$$\arg(G(jw_{cg}) = -\pi + \phi_r - \arg(C(jw_{cg})) \tag{7}$$

3) By using the equation (7) and process transfer function the value of w_{cg} is calculated.

4) The zero of the controller $z_c = z_i$ is obtained from (2).

5) By equating the magnitude expression to unity after substituting w_{cg} , the value of k_c is calculated.

$$\lfloor C(jw_{cg})G(jw_{cg})G_f(jw_{cg} \rfloor = 1 \tag{8}$$

The resulting equation for the PI controller is

$$K_c = \frac{w_{cg}\sqrt{0.81a^2 + 1}}{\left|G(jw_{cg}\right|\sqrt{1 + a^2}} \tag{9}$$

6) The PI controller parameters K_p and T_i are calculated using from (5).

2.2. Design Method for PID control

The transfer function of the PID controller is given in (10) [1].

$$C(s) = K_P\left(1 + \frac{T_d s}{1 + \frac{T_d s}{N^1}} + \frac{1}{T_i s}\right) = K_c \frac{\left(1 + \frac{s}{z_i}\right)\left(1 + \frac{s}{z_d}\right)}{s\left(1 + \frac{s}{z_d N}\right)} \tag{10}$$

Where

$$K_P = K_c\left(\frac{z_d + z_i}{z_d z_i} - \frac{1}{z_d N}\right)$$

$$T_d = \frac{1}{z_d + z_i - \frac{z_i}{N}} - \frac{1}{z_d N}; \; T_i = \frac{z_d + z_i}{z_d z_i} - \frac{1}{z_d N};$$

$$N^1 = \frac{z_d N}{z_d + z_i - \frac{z_i}{N}} - 1 \tag{11}$$

The following six steps are involved to tune the controller by using single tuning parameter '*a*'.

1) Phase of the controller at gain crossover frequency of the process with controller (arg(C(jw_{cg})) is calculated using (12).

$$\arg(C(jw_{cg})) = 2\arctan(a) - \arctan\left(\frac{a}{N}\right) - \left(\frac{\pi}{2}\right) \tag{12}$$

2) Phase of the process at gain crossover frequency of the process with controller (arg(G(jw_{cg})) is calculated using (13).

$$\arg(G(jw_{cg}) = -\pi + \phi_r - \arg(C(jw_{cg})) \tag{13}$$

3) By using (13) and process transfer function the value of w_{cg} is calculated.

4) To simply the design method, two zeros are imposed to be equal ($z_c = z_i = z_d$). The zero of the controller is calculated using (2).

5) The value of k_c is calculated using (8). The resulting equation for the PID controller is given in (14).

$$K_c = \frac{w_{cg}\left(\sqrt{1+\frac{a^2}{N^2}}\right)\sqrt{b^2a^2+1}}{\left|G(jw_{cg})\right|\left(1+a^2\right)} \qquad (14)$$

6) The PID controller parameters K_p, T_i, and T_d are calculated using (11).

3. SIMULATION AND RESULTS

To evaluate the efficiency of the setpoint filter method, it has been applied to three benchmark transfer function.

The three benchmark transfer functions [2] are:

$$G_1(s) = \frac{1-2s}{(s+1)^3} \qquad (15)$$

$$G_2(s) = \frac{e^{-5s}}{(s+1)^3} \qquad (16)$$

$$G_3(s) = \frac{1}{(s+1)^6} \qquad (17)$$

servo response of the chosen models with proposed tuning is compared with Z-N and FR methods for both PI and PID controllers

3.1 Simulation results for PI controllers

The specification for the PI controller design is $\varphi_r = 35$. The closed loop responses of three models with PI controllers are obtained and the performances indices are given in Table 1. The lower proportional gain attained by the proposed method has minimized the overshoot and the settling time (10% mismatch) over Simple frequency response method (FR) and Ziegler – Nichols (ZN) tuning method. The proposed method also reduces the integral errors such as IAE and ISE to a reasonable extent when compared with ZN and FR .

Table 1.Performance of proposed method with existing method for PI controller

Process	Method	IAE	ISE	Over shoot %	Settling time (sec)
$G_1(s)$	FRS	5.781	3.879	5.1	14.5270
	FR	9.144	6.609	54.9	33.2088
	ZN	11.92	6.6467	0	49.7952
$G_2(s)$	FRS	24.49	14.52	17.36	102.088
	FR	46.16	25.62	64.5	213.473
	ZN	65.49	31.3	0	293.514
$G_3(s)$	FRS	6.392	3.389	7.19	27.1818
	FR	9.723	5.297	40.91	45.6985
	ZN	8.536	4.736	2.18	45.9632

The finally obtained phase margin for the process $G_1(s)$, $G_2(s)$ and $G_3(s)$ are 35.0089 , 35.0007 and 34.9873 respectively. Closed loop responses of considered model $G_1(s)$, $G_2(s)$ and $G_3(s)$ with PI controllers for a step change in setpoint are shown in figure 2 , 3 and 4 respectively .

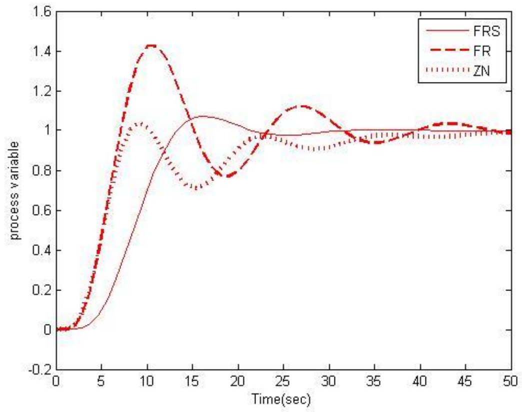

Fig 2 :Simulation results of PI controllers for G_1(S)

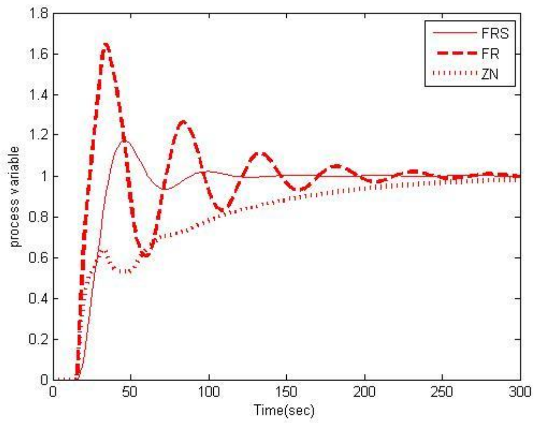

Fig 3 :Simulation results of PI controllers for G_2(s)

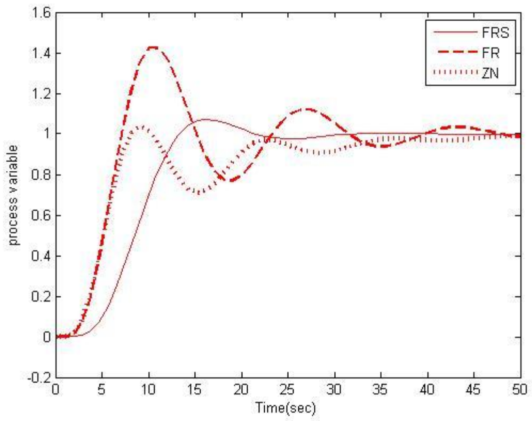

Fig 4 : Simulation results of PI controllers for G_3(s)

3.2Simulation results of PID controllers

The specification $\varphi_r = 35$ is considered for the above process .Table II shows the performance for the closed loop response of three chosen model with PID controller are obtained .

Table 2 .Performance of proposed method with existing method for PID controller

Process	Method	IAE	ISE	Over shoot %	Settling time (sec)
G_1(s)	FRS	4.424	2.806	15.37	18.7686
	FR	7.801	6.491	63.14	24.006
	ZN	5.57	4.907	0	17.216
G_2(s)	FRS	39.11	14.69	39.07	329.35
	FR	46.67	25.77	82.06	223.835
	ZN	28.47	19.49	11.87	125.22.
G_3(s)	FRS	4.424	1.91	2.12	27.75
	FR	7.841	4.207	43.48	40.6641
	ZN	5.832	3.94	22.23	24.405.

It is observed that the proposed method gives better overshoot, settling time (10% mismatches), IAE, and ISE than the Simple frequency response method. For process G_2(s), the ZN method gives better performance than the proposed method. Even though the proposed method gives poor performance, it gives better robustness by specification of phase margin than the ZN method. The final obtained phase margin for the process G_1(s),G_2(s) and G_3(s) are 35.021 , 35.0349 and 35.2446 respectively.

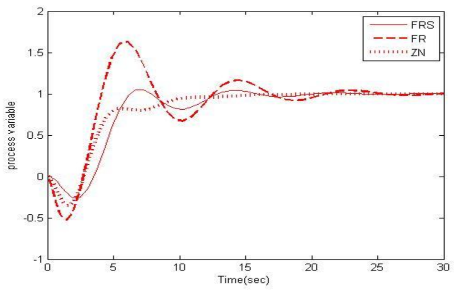

Fig 5 :Simulation results of PID controllers for G_1(s)

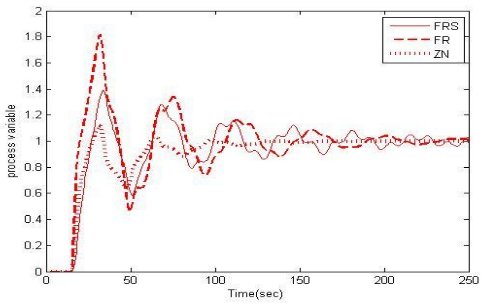

Fig 6 : Simulation results of PID controllers for G_2(s)

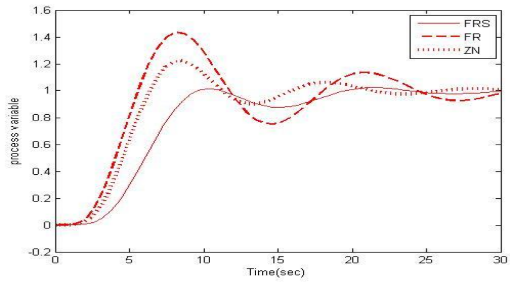

Fig 7:Simulation results of PID controllers for G_3(s)

4. CONCLUSION

In this paper, performance of the PID controller with setpoint filter for servo and regulator problem has been analyzed. The performance has been tested on a set of bench mark transfer function. The proposed method yields better result in obtaining closed loop performance IAE , ISE, overshoot and settling time for servo problem .than the existing methods namely simple frequency response method and Ziegler - Nichols method. One main drawback of the method is setpoint filter coefficient is not optimum. Optimum value of filter coefficient will produce better result than the present method. By varying the filter coefficient can help to achieve the overshoot to the desired level.

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