Tuning of PID and Fuzzy Logic Controlled Plants Without Ultimate Frequency

[1]K.V.V.S.Chowdary, [2]U.V.Ratna Kumari
UNIVERSITY COLLEGE OF ENGINEERING, KAKINADA
[1]M.Tech Student, [2]Associate Professor
Email Id: [1]chowdarykalthuri@gmail.com,[2]vinayratna74@gmail.com

Abstract

In this paper describes the relay feedback method for tuning of Proportional Integral Derivative (P-I-D) controllers can't be connected to plants whose Nyquist diagram does not crosses the -180 degree axis; so tuning depends on the responses. In this Ziegler -Nichols tuning approach is depends on a modified relay feedback analyze **.** In this analysis a transfer function of high range of frequencies is embedded into loop. The Ziegler-Nichols like tuning techniques by allows the PID tuning depends on relay method for a classes of plants without ultimate frequency. In this by using Fuzzy logic to improve the step response performances. Hence compare the performance of PID controller with the fuzzy logic controller.

keywords : Fractional-order systems, PID auto tuning, Ziegler-Nichols (ZN) Methods, Fuzzy logic controller, Ultimate frequency**.**

I. INTRODUCTION

PID controllers are used in many industrial applications. They are simple and exhibit robustness over large range of operating conditions. The PID controller tuning methods based on the open loop and closed loop step responses. they are two groups, in the first group the plants with finite extreme frequency otherwise states whose nyquist plot does not crosses the -180 degree axis. In the group the plants does not have extreme frequency they must be tuned by Ziegler-Nichols method .By using Ziegler-Nichols method large range frequencies of plants can be applied. The PID controller is designed and tuned by using Z-N method and the responses are observed. Then the same transfer function of the fuzzy logic with defuzzification method. Compare the performance of the system response parameters that is settling time and maximum overshoot. In section II discussed the basics standards of the plants and the controllers. In section III discussed priori knowledge of the plants frequency responses i.e, extreme frequency and the extreme gain. In section IV discussed the modified relay feedback analysis allows the fractional order systems is embedded into the loop. In section V discussed the fuzzy logic controller and fuzzy inference system steps. In section VI discussed the applications of real time issues not applicable in the Z-N method. In section VII different class of plants are discussed.

II. Closed loop Control System

The block diagram of a general closed loop control system is shown in below figure 1.

A. Plant:

Let us assume causal LTI plant, is given as

$$O(s) = G(s)U(s) \qquad (1)$$

Here G(s) is transfer function of plant, U(s) and O(s) are Laplace changes of control input and output of the plant (the controlled variable), individually. Causal LTI controller is used to control the plant G(s) is shown in figure 1.

$$E(s) = I(s) - O(s) \qquad (2)$$

$$U(s) = F(s)E(s) \qquad (3)$$

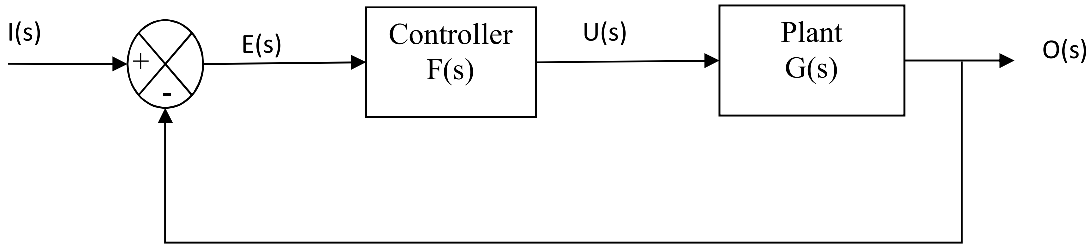


Fig.1 Block diagram of a closed loop Control system

where I(s) : set value of input,
E(s) : error and
F(s) : Controller's transfer function.

B. Controller:

The Controller may be PI or PID type.

(1) PI controller transfer function is written as:

$$F_{PI}(s) = K_P\left(1 + \frac{1}{T_i s}\right) \quad (4)$$

Where T_i : Integral time constant;
k_p: Propotional gain .

T_i and K_p are tuned, to design the PI controller. For the design of PID controller, the ideal derivative action included with PI.

(2) PID controller transfer function is written as:

$$F_{PID}(s) = K_P\left(1 + \frac{1}{T_i s}\right)(1 + T_d s) \quad (5)$$

Derivatives cannot be exactly implemented, so the PID controller transfer function is represented as:

$$F_{PID}(s) = K_P\left(1 + \frac{1}{T_i s}\right)\left(1 + T_d \frac{s}{Ls + 1}\right) \quad (6)$$

Here L is a constant parameter and T_d is the derivative time constant. The equation(5) is used for design purpose here. For the simulation experiments, real transfer function (6) is used . The specification L must be small enough so that the controller transfer function in equation(5) is approximately equal to real transfer function (6) in the interested frequency range. The lesser estimation of L may be the better guess. In simulation experiments, the value of L is assumed to be $10^{-3}/\omega_{120}$. About the ω_{120} is discussed in Section III-B.

III. Different Oscillation methods

A. Classical Forced Oscillation Method:

There are plenty of different tuning methods are available for PID controller [2]. The extension to these methods presented in multivariable plants [4] and event based controllers [3] etc. These techniques and expansions comprise in difference of approach's proposed in this work [3]. A tuning technique proposed in [3] that consists, causing oscillation in closed loop, and the oscillation frequency and its amplitude are estimated by applying simple formulas.

In [1], the approach is to be better and revived by analyze and the unequivocal assumptions of gain and phase margin. In this concise, consider this approach as classical forced oscillation (CFO) approach. CFO approach is exclusively depends on the extreme point location in the plant's frequency reaction curve. The extreme point of a given plant's transfer function is the point where the Nyquist diagram crosses the -180 degree axis. The characteristics of extreme point are K_u and ω_u, these parameters are derived from the following equations :

$$\omega_u = \min_{\omega \geq 0} \omega : \angle G(J\omega) = -\pi \qquad (7)$$

$$k_u = \frac{1}{|G(J\omega_u)|}$$

where K_u : Gain corresponding to the Extreme point and
ω_u: Frequency corresponding to the Extreme point.

From these standards, CFO approach can be follows as : 1) Identify an extreme point on the frequency response of the plant, that decide ω_u and K_u. 2) select the specifications of controller, such that

$$F(J\omega_u) = -k_u s \qquad (8)$$

Here s is predefined area in the S-plane. From starting stage of strategy is basically achieved by a relay feedback analysis , which comprises in closed loop with the accomplishing of non-linear control activity:

$$u(t) = d \text{ sign}(e(t)) + b \qquad (9)$$

where sign(•) is the sign function.[sign(x) = 1 for x>0 and sign(x) = −1 for x<0], d is the specification as been picked, and b is a bias. The bias specifications b is balanced, with the target as oscillation is symmetric. Once a symmetric oscillation is acquired, amplitudes A_u, Time period T_u are estimated and extreme values given by :

$$k_u = \frac{4d}{\pi A_u} \qquad \omega_u = \frac{2\pi}{T_u} \qquad (10)$$

From second stage of technique is expert by explaining (8) for controllers additions K_p, T_i and T_d with the selected area of s. Below the sensible suspicion, the plant's frequency response is a smooth curve, moving the extreme point far from the location s =−1+j0 in the complex plane moving the entire frequency reaction far away it, accordingly prompting great stability margin. Distinctive area p has been proposed throughout while ago, every one giving diverse transient execution and stability margin. From initial ZN tuning equations in [3] relate to s = −0.4 + j0.08 is PI controllers and s = −0.6 − j0.28 is PID controllers. Plants that don't have an extreme point are don't applicable for the utilization of this approach.

From these situations, the phase stability of the second order class of plants smaller than that of three. For example. A strategy depends on transfer input for larger classes of plants to be proposed in [6], where in excess of single test is taken, and at every trial, a creator must intervene to modify the specifications of following examination. Other comparable strategies have likewise been proposed, with similar ideals (starting relevant to higher classes of plants) and impediments.

Our technique, is to displayed straightaway, is depends on an indistinguishable hypothetical support from the CFO appreach: putting one especially important point of loop frequency reaction at a predefined area in complex S-plane, that ensures the corresponding stability margin gave the system frequency reaction is adequately flat. It is connected to every plants with relative degree > 1, hence starting appropriate, substantially more extensive for various plant's compare to CFO method. Also, not at all like [6] and other comparable arrangements, it doesn't require additional examinations and additionally intervention of design. It requires a better technique than CFO for further enhancing the plants response. The EFO (extended forced oscillation) technique is introduced here.

B. EXTENDED FORCED OSCILLATION METHOD:

The CFO approach objective is suitable to get the desired stability margin (i.e. Gain margin / phase margin(PM)). In this event that the plant's reaction curve does not cross the -180 degree axis, at that point gain margin to be limitless, and the plant's controller cannot present too large phase delay. So, here, the Phase Margin is the control objective .

The Controller designed based on the desired point on frequency response obtained by using theoretical CFO approach. The Controller designed with the goals: i) Controller's role corresponding to this frequency point is very minute. ii) Magnitude of loop transfer function to this 1. Give M_φ a chance to the required phase margin and $\theta = M_\varphi - 180°$.Distinguish the frequency ω_θ characterized as $G(J\omega_\theta) = \theta$, and the magnitude of system response: $M_\theta = |G(J\omega_\theta)|$. That is shown in Section IV relay feedback analysis introduced this data; that is, ω_θ and M_θ has known. with the goal that the point of corresponding PM is precisely as desired, gave the M_θ diminishes for frequencies above ω_θ .

$$F(J\omega_\theta)G(J\omega_\theta) = 1\angle\theta \tag{11}$$

Thus, the controller needed to fulfill (11) or, equally

$$F(J\omega_\theta) = \frac{1}{M_\theta}\angle 0^0 \tag{12}$$

It is to indicate what might be a desired PM to select. Various books propose it to be around 45° to give suitable robustness and dynamic execution of useful circumstances [4]. With the knowledge of one particular point of frequency, the controller designed, without a plant model. understanding the frequency response at a particular point, parameters for PM to all frequencies Planned (that the large range of plants), PI or PID controllers with the knowledge of various details of PM and assessed the subsequent execution based on response of the closed loop system for a given step input. With these, decision $M\varphi = 60°$ (comparing for $\theta = -120°$) rise for the required values is proposed, Briefly said that, the utilization of (12) to acquire tuning of PI or PID controllers.

1. Proportional Integral (PI)

In order to obtain equation (4), $F_{PI}(J\omega) < 0\ \forall\omega$, in this manner it isn't conceivable to fulfil (12) precisely with PI controller. For this situation, the controller to be extent that

$$F(J\omega_\theta) = \frac{1}{M_\theta}\angle -\beta \tag{13}$$

Here $\beta > 0$. The equations of Classical Forced Oscillation approach with Proportional Integral controller corresponding to −10° commitment the controller at extreme frequency, hence receive a comparable standard, picked $\beta = 10°$. From these decision transfer function of controller equation (4), (13) exactly to

$$F(J\omega_{120}) = K_P - J\frac{K_P}{\omega_{120}T_i} = \frac{1}{M_{120}}\angle -10^0$$

Equating real and imaginary parts from this equations of tuning recipes for PI controller is detailed

$$k_p = \frac{\cos(10^0)}{M_{120}} \quad T_i = \frac{1}{\omega_{120}\tan(10^0)} = \frac{T_{120}}{2\pi\tan(10^0)} \tag{14}$$

2. PID (Proportional Integral Derivative)

The assumption of a corresponding subsidiary (PD) block in (5), allows to accomplish the goal of zero phase lag by controller at distinguished frequency, is required to fulfil (12) precisely. For sure, that PD block $1 + sT_d$ gives us phase lead to make the phase embedded by PI block $1 + 1/sT_i$. Give us a chance to begin the PI controller tuned by recipes of (14); at that point the PI block embeds a phase delay of 10° at distinguished frequency of ω_{120}.

Table 1

Controller	K_p	T_i	T_d
PI	$\frac{0.98}{M_{120}}$	$0.90T_{120}$	
PID	$\frac{0.97}{M_{120}}$	$0.90T_{120}$	$0.028T_{120}$

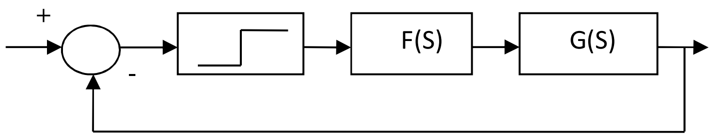


Fig. 2. Relay feedback analysis for the identification of extreme point of F(s)G(s).

To make up this lag, along these lines acquiring a controller that embeds no postponement of loop for the frequency ω_{120}, is

$$\angle 1 + J\omega_{120}T_d = \arctan(\omega_{120}T_d) = 10^0$$

That is

$$T_d = \frac{\tan 10^0}{\omega_{120}} = \frac{\tan 10^0}{2\pi}T_{120}$$

Then again, the Proportional Derivative block builds a multiplied block by factor

$$\sqrt{1 + (T_d\omega_{120})^2} = \sqrt{1 + \tan^2 10^0} = \frac{1}{\cos 10^0} \qquad (15)$$

So as to take controller's magnitude at set value is unchanged, fulfilling (11), the controller's gains k_p mostly less than the equal factor. These prompts the other tuning of relative proportional gain $k_p = \frac{\cos^2(10^0)}{M_{120}}$ shown in (13) partitioned by (15) for tuning of PI/PID controllers are appeared as Table I, here the trigonometric functions are gathered together two huge numerical.

IV. DETERMING OF ω_{120}-POINT

The relay feedback analysis in Section III-A is a traditional instrument to tentatively decide a extreme point of a plant [2]. A characteristic augmentation of relay analysis to allows the various locations on the frequency response of the system. Let a known transfer function F(s) is embedded in the loop with relay feedback, in Fig. 1, at that location of the oscillation will develop oscillations with extreme frequency for the given system F(s)G(s), at ω_1 i.e.:, At $\angle F(J\omega_1)G(J\omega_1) = -180^0$ this point, the frequency reaction curve of the plant can be given by :

$$|G(J\omega_1)| = \frac{\pi A}{4d|F(J\omega_1)|} \angle G(J\omega_1) = -180^0 - \angle F(J\omega_1) \quad (16)$$

The known $F(J\omega_1)$ is to execute controller tuning methodology depicted in Section III-B, It require to recognize that the location of the frequency response of phase goes to a predefined point of frequency, to be particularly, $M\varphi - 180°$. For that, required to put a system F(s) whose response $-M\varphi$ at particular frequency, still this frequency isn't recognized early—in reality, it is one of two quantities that the examination goes for perceiving it, better F(s) is found and faltering comes to the needed frequency. Systems for this purpose, the resources of CFO methodology—it is basically ease and speedily impaired. The system function F(s) response is equal at any frequency i.e., $F(J\omega) = -M\varphi\ \forall\ \omega$, at that point just a single investigation would be fundamental, by kept same working highlights of CFO technique. The transfer function of phase frequency reaction of an FOI which can be effortlessly observed as :

$$F(s) = \frac{1}{s^m} \qquad (17)$$

$$\angle F(J\omega) = -\angle (J\omega)^m = -\angle e^{\frac{j\pi}{2m}} = -\frac{\pi}{2} m \qquad (18)$$

By taking m = $M_\varphi/90°$ equation (18) introduce that the $\angle F(J\omega) = -M_\varphi\ \forall\omega$, as needed. For $M_\varphi = 60°$, m is equal to 2/3.

A. Fractional-Order Integrator:

The implementation of these controllers are not as ease of Integral systems in practical point of view. Mostly, partial request systems are actualized by the general systems with integral order. From execution is portrayed in Section VI, Here MATLAB Tool, FOMCON [8], is used to get a system function, and also the magnitude and phase attributes of the required FOI. The assumed transfer function with-13.34dB/decade magnitude and a phase estimation equal to −60° for the range of frequencies from 10^{-3} to 10^{3} rad/s, is portrayed by equation (18) from these values are appeared in Table II.

$$F(s) = \frac{\sum_{K=0}^{11} b_k s^k}{\sum_{n=0}^{11} a_n s^n} \qquad (19)$$

Various alternatives of fractional order integral systems to be employed the different PM details, select suitable m and getting a finite order of the fractional order integrals correspondingly.Fig.3 demonstrates the magnitude and three phase responses of Fractional Order Integral, with −13.34 dB/decade for −60°, −10.01 dB/decade for −45°, and −6.67 dB/decade for −30°.

TABLE I
Coefficients Of F(s)

I	a_i	b_i
0	0	0.07152
1	11.13	1.445×10^3
2	1.098×10^4	4.387×10^5
3	1.920×10^6	2.678×10^7
4	6.970×10^7	3.473×10^8
5	5.407×10^8	9.671×10^8
6	9.021×10^8	5.798×10^8
7	3.241×10^8	7.486×10^7
8	2.507×10^7	2.080×10^6
9	4.164×10^5	1.238×10^4
10	1.466	15.447
11	1	0.0036

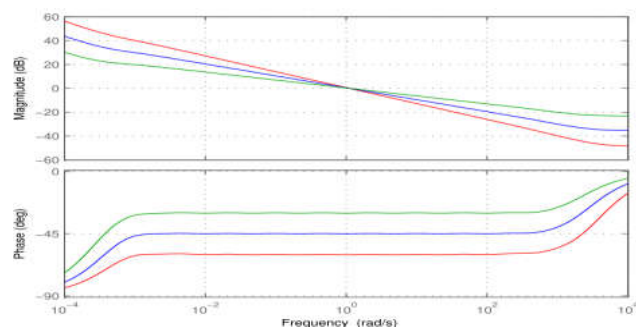


Fig. 3. Frequency response of fractional order integral systems with -60^0 in red lines,-45^0 in blue lines and -30^0 green lines

V. FUZZY LOGIC CONTROLLER

The FLC (Fuzzy Logic Controller) consists of fuzzification, fuzzy inference engine and defuzzification is shown in below fig.4.

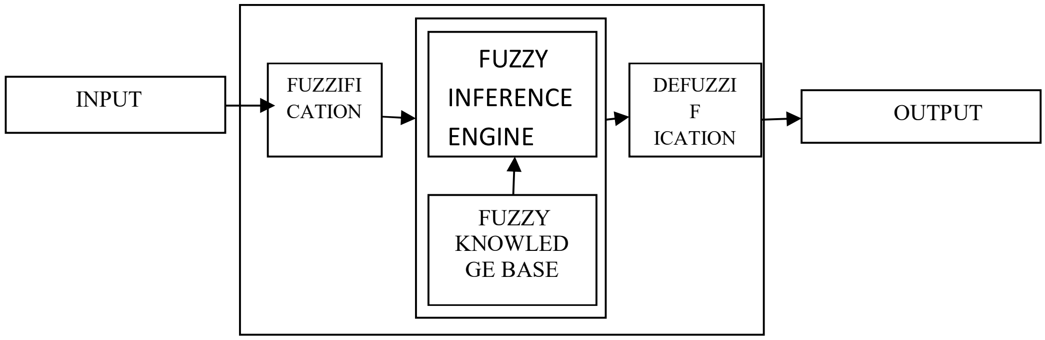


Fig.4 Fuzzy logic controller

Fuzzification: It is the process of converting the crisp values input of a controller to fuzzy domain.

Fuzzy Knowledge Base: It is divided into rule base and data base.
The rule base contains number of IF-THEN FUZZY rules. The data base defining the membership functions in the fuzzy sets used in fuzzy rules.

Fuzzy Inference Engine/System(FIS) : It is the process of converting the fuzzy input into fuzzy output with the help of fuzzy logic. Table 3 indicates rules of fuzzy inference system. Meaning of the linguistic variables in FIS : Negative Medium(NM), Negative High(NH), Negative Low(NL), Positive Low(PL), Positive High(PH), Positive Medium(PM), Zero(Z).

TABLE - III
Basic rules for Fuzzy Inference system

Change in error	ERROR						
	NH	NM	NL	Z	PL	PM	PH
NH	PH	PH	PH	PM	PM	PL	Z
NM	PH	PH	PM	PM	PL	Z	Z
NL	PH	PM	PL	PL	Z	NM	NH
Z	PH	PM	PL	Z	NL	NM	NH
PL	PM	PL	Z	NL	NM	PH	NH
PM	PS	Z	NL	NM	NM	PH	NH
PH	Z	NL	NM	NM	NH	PH	NH

The FIS has the four steps:

i. Apply fuzzy rules for input.

ii. Apply input as triangular membership function for simplicity.

iii. Implication method using Mamdani's operator.

iv. Defuzzification using weighted average method.

Defuzzification: It is the process of converting an aggregate output of one crisp value of each output variable. The defuzzification as the following methods. They are: Centroid , bisector method , mean of maximum, largest of maximum, smallest of maximum, weighted average.

VI. CASE STUDIES

With a specific end goal to approve the proposed PI/PID tuning technique, two various plants to be assumed. In this two plants, a point by point investigation to be obtain, depicting every step is outline. The initial plant to a linearized model of aircraft pitch angle dynamics is described, a non auto regulated system with transfer function :

$$G(s) = \frac{2.23s + 0.20}{s^3 + 0.78s^2 + 0.97s} \quad (20)$$

The frequency response of plant described by (20) is appeared in Fig.5. With a specific end goal for the tuning of PI/PID controller's gains follows through Ziegler-Nichols like techniques, in initial place the open-loop step response methodology is acquired, results are shown in Fig.6(a). Obviously, it is a non auto regulated plant, tuning depends on open loop response can't be connected. At that point, a closed loop relay feedback analysis is performed, going for utilization of CFO approach. The consequence of this analysis is shown in Fig.6(b), observed that CFO approach does not applied, due to self oscillation condition does not obey.

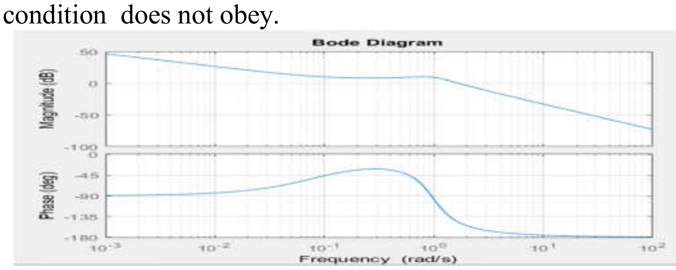
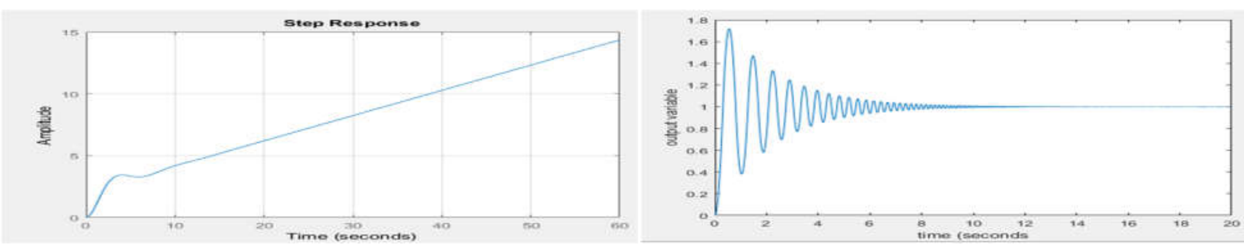


Fig.5 Frequency response of aircraft pitch model.



(a) (b)

Fig. 6. (a) Open loop response—unitary step. (b) Relay feedback analysis-d = 10 and b = 0.

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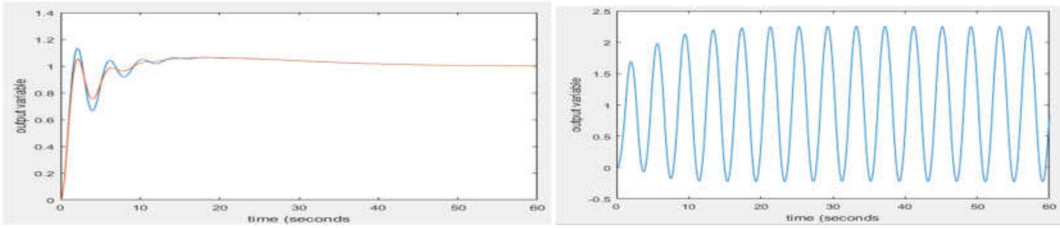
It isn't conceivable to decide the PI/PID controller increases from conventional Ziegler-Nichols tuning approach, EFO approach to be induced. Fig. 7(a) demonstrates that self-oscillatory system running for closed loop with a relay and a fractional order integral, in Fig. 1. From these analysis, conceivable to decide that amplitude A = 0.82 and time period T_{120} = 5.61sec for resulting signal, and furthermore magnitude of FOI at the frequency of ω_{120}: $|F(j\omega_{120})| = 0.99$, finishing the arrangement of information for defining of PI/PID controller gains. The specifications for PI and PID controllers are $K_p = 0.76$, $T_i = 5.03$, and $T_d = 0.17$. The closed loop resulting of aircraft pitch angle of two controllers are appeared as Fig.7(b). Two specifications are equal for two controllers that is settling time (t_s)= 17sec and maximum overshoot (Mo) = 11% with small oscillations of PID controller to that of higher phase margin.



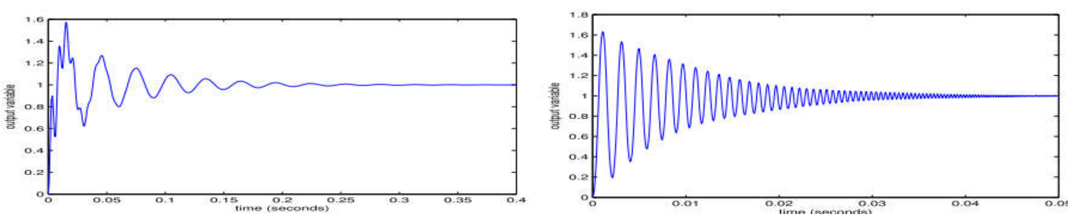
(a) (b)

Fig. 7.(a) Relay feedback analysis with FOI-d =30and b = 0
Fig 7.(b) Closed-loop step response with PID (blue line) and PI (red line) .

The other plant is assumed for utilization of proposed PI/PID tuning technique for read/compose head situating system, described in [5], depicted by transfer function :

$$G(s) = \frac{5.00 \times 10^{5} s^{2} + 1.40 \times 10^{7} s + 4.67 \times 10^{10}}{s^{4} + 178 s^{3} + 1.09 \times 10^{6} s^{2} + 4.21 \times 10^{7} s + 4.67 \times 10^{10}} \quad (21)$$

It is a self-managed plant with zero frequency increase equivalent to one, the open loop step response shown in Fig. 8(a), isn't an all around characterized S-curve, excludes the utilization of open loop step response. The Nyquist diagram of G(s)/2 are shown in Fig. 9, in green lines. Observe that Nyquist diagram does not cross -180 degree axis, along these lines excludes the use of CFO approach the blue line shows that the Nyquist plot crosses the −120° line, and the intersection compares to the oscillations that is seen in relay feedback analysis various locations regarding the fractional order systems. For , the relay feedback analysis for FOI on the up and up the observations in resulting signal are shown in Fig. 10(a), a long these the time period T = 0.027seconds and amplitude A=2.54; with magnitude of fractional order integral to these frequency at ω_{120} is | $F(j\omega_{120})$ | = 0.0282. Tuning observations for PI/PID controllers are K_p= 0.41, T_i = 0.024 and T_d = 7.6×10−4, Nyquist diagram of loop of the system C(s)G(s) for PID controller is appeared in Fig. 9 (red line). The closed loop response of both controllers is shown in Fig. 10(b).



(a) (b)

Fig. 8. Open-loop and Closed-loop response of ZN technique.
(a) Open loop response—unitary step. (b) Relay feedback analysis d=10 and b=0 .

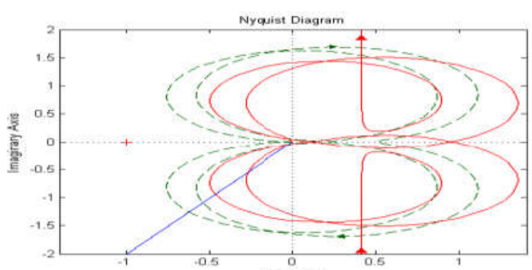
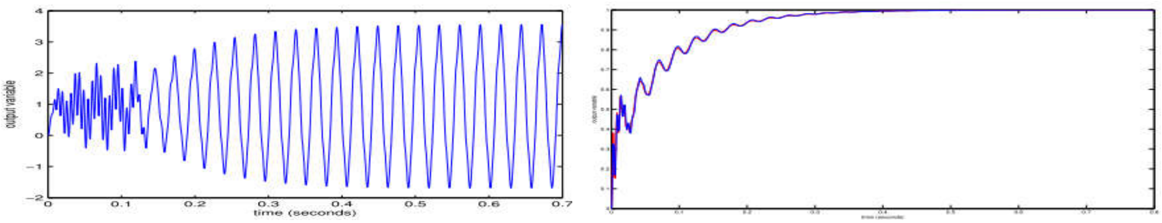


Fig. 9. Nyquist plot (green line: module separated by two to fit the scale) and red line indicates plant with PID controller. Blue line is at −120°.

The two specifications are equal for two controllers— settling time(t_S)= 0.4sec and the maximum overshoot(M_O)= 0. The multiple cases are discussed in this section have extremely various dynamic performance is slow, compare to the aircraft pitch angle read/compose head situating system. That equal FOI, similar values is appeared in Table II, is completely for two plants.



(a) (b)

Fig. 10. (a) Relay feedback analysis with FOI—d = 30 and b = 0.
(b) Closed-loop response with PI (Red line) and PID (Blue line).

VII . Examples

The Ziegler-Nichols approach is connected tuning of PI/PID controllers for four various types of plants, the tuning of controller, is shown in Table I. In Section VII-i– VII-iii point of interest for the application to one of these classes of plants. The performance is evaluated for every situation the two specifications that is settling time (t_s) and maximum overshoot (Mo) in the closed loop step response. The tuning approach is detailed for these class of plants whose Nyquist diagram doesn't cross -180 degree axis, and three various class of plants to be assumed .

i. Second-order plant with real poles

Let us assume second order plant transfer function:

$$G(s) = \frac{\alpha}{(s+3)(s+\alpha)} \qquad (22)$$

In this method by applying α = 0.01 with the controller parameters K_p= 66.9, T_i = 9.85 and T_d = 0.306. The settling time (t_s)=40sec and the maximum over shoot (M_O)=18% is shown in below figure. The open and closed loop responses of PI controller is appeared in figure(11).

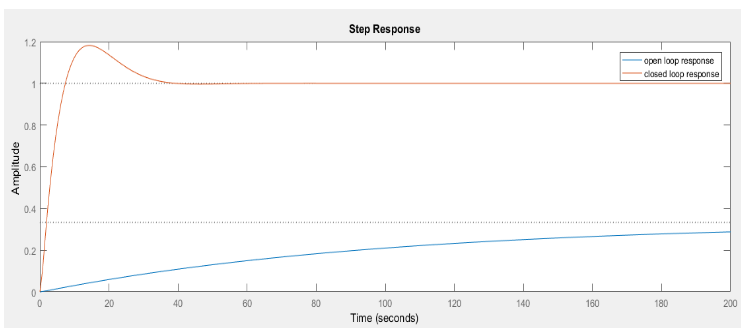


Fig11. Shows Open Loop response and Closed- loop response for PI Controller

ii. Second order plant with Complex poles

Let us assume second order plant transfer function:

$$G(s) = \frac{1}{s^2 + 3\alpha s + 2} \qquad (23)$$

In this method by applying α =0.5 with the controller parameters K_p = 1.50 and T_i= 4.31. The settling time (t_s) = 27sec and the maximum over shoot (M_O) = 19% is shown in below figure. The results is shown in figure 12.

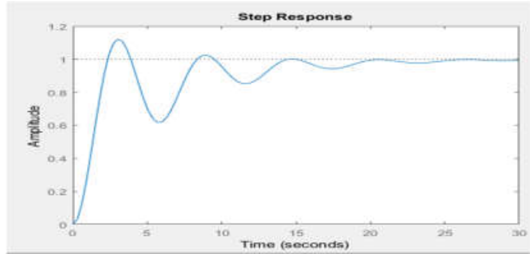


Fig.12 Shows that Closed- loop step response of plant for PI Controller.

iii. Third-order plant with real poles

a) **Lead Block:** Let us assume third order plant transfer function:

$$G(S) = \frac{\alpha\left(\frac{3S}{\sqrt{\alpha}} + 1\right)}{(S+1)(S+\alpha)\left(\frac{S}{3\sqrt{\alpha}} + 1\right)} \qquad (23)$$

which comprises of second-order transfer function (21) is added with lead block. These block the transfer function (23) comprises of pole zero arrange into middle of pole at −1 and −α, and that α as multiplication of its individualities. In this method by applying α =0.5 with the controller parameters K_p =3.17 and T_i=1.30.The settling time (t_s) = 5.1sec and maximum over shoot (M_O) = 24% is shown in below figure. The closed loop step response, incorporating the gains of PI controller is tuned by using Z-N method, shown in Fig.13.

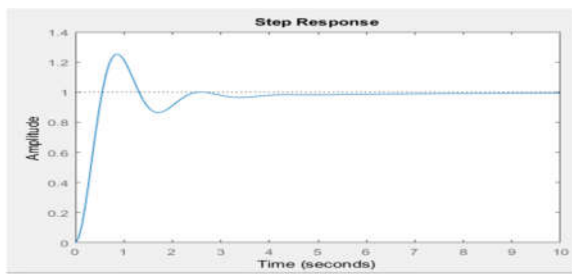


Fig.13 Shows that Closed- loop step response of plant for PI Controller.

b) **Lag Block:** Assuming plant transfer function:

$$G(s) = \frac{\alpha\left(\frac{s}{3\sqrt{\alpha}} + 1\right)}{(s+1)(s+\alpha)\left(\frac{3s}{\sqrt{\alpha}} + 1\right)} \qquad (24)$$

which comprises of second order plant transfer function (21) is added with lag block. In this method α =2 with the controller parameters K_p=3.17 and T_i=1.30. The settling time (t_s) =5.9sec and the maximum over shoot (M_O) = 19% is shown in below figure .The closed loop step reaction, incorporating gains of PI controllers is tuned by using Z-N technique, appeared in Fig.13.

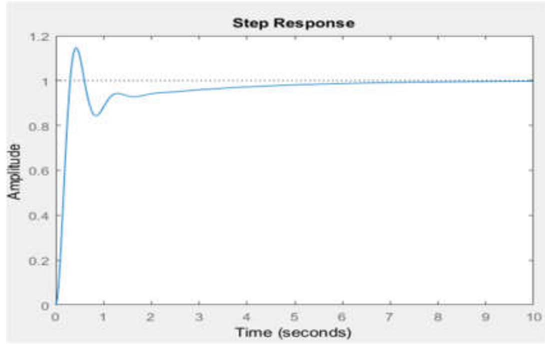


Fig. 13.Shows that Closed Loop step response of plant for PI Controller.

VII. COMPARISON OF RESULTS

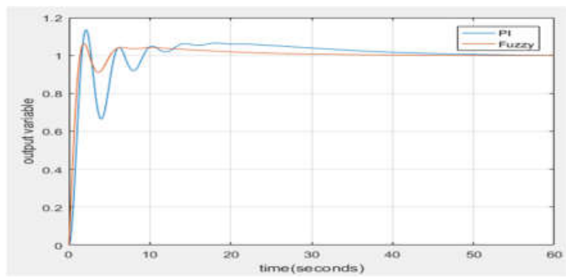


Fig. 14. Equation (20) Shows comparison of results for Closed loop step response with PI and Fuzzy Logic Controller

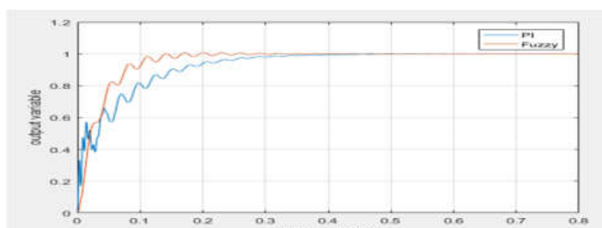


Fig. 15. Equation (21) Shows comparison of results for Closed loop step response with PI and Fuzzy Logic Controller

VIII. CONCLUSION

The tuning of PID controllers for different class of plants not applicable to relay method of Zeigler-Nichols technique as CFO. The EFO approach extends to the CFO approach that possess open loop response to this class of plants for large range of frequencies is embedded into the loop for FOI. By using Fuzzy logic controller the parameters that is settling time and maximum overshoot is less when compared to the PI and PID controllers. Further such that the various controllers may be a good research work in this field.

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