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A REVIEW: FRACTIONAL ORDER PID (FOPID) CONTROLLER

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ABSTRECT

A fractional order PID (FOPID) controller is the advanced version of PID controller. It has five parameters K_p (proportional gain), K_d (derivative gain), k_i (integral gain), µ (derivative order), λ (integrator order). The factorial order controller gives better response than classical PID controller. Basically it is represented by fractional order calculus (FOC). Using different tuning methods or optimizing algorithm, we can calculate the value of the parameters of FOPID controller and adjust the performance of the controller. The parameters also permit us to design the controller as proportional controller, proportional-integration controller, proportional-derivative controller and classical order PID controller. We define the stability criteria for FOPID controller by the complex plane.

KEYWORDS: Fractional Order PID Controller, Effect Of Parameters, PID Controller.

INTRODUCTION

Fractional calculus (FC) is used to calculate for classical differential calculus and derivatives and integrals of a real or complex order functions [1-3, 6, 23-24]. Recently, the FC theory is widely used in the field of science and technology for controlling of dynamic systems and also used in superior modelling [1, 3, 6, 8, 12, 23]. ASME & ISFE arranged an international workshop on fractional derivatives & its applications [2, 4]. The Fractional order controllers are represented by fractional order differential equations [2- 3, 11]. It is based on the closed-loop control system. Based on four situations i.e. IO (integer order) plant with IO controller, IO plant with FO (fractional order) controller, FO plant with IO controller and FO plant with FO controller [3, 30], PID controller has been popular controller for many applications [5-7]. PID controllers are designed based on the fractional derivatives & integrals and their applications [8-9, 13]. Fractional order PID (FOPID) controller has 5 parameters i.e. K_p (proportional gain), K_d (derivative gain), k_i (integral gain), µ (derivative order), λ (integrator order); by these we can tune and design the controllers [8, 10]. Based on these parameters we can adjust the controller like adjust the value of µ, λ the controller behave as PI controller, PD controller and PID controller also [8, 9, 14]. The derivative order parameter and integrator order parameter of FOPID controller mends the design flexibility [11].

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There are some algorithms to optimize the parameters like genetic algorithm (GA), differential evolution algorithm (DE) and particle swarm optimization (PSO), Numerical optimization, adaptive seeker optimization algorithm or some tuning methods ; otherwise it is quite difficult to optimize the parameters [2, 8, 10, 15-17, 19, 27]. The main advantage of $PI^{\lambda}D^{\mu}$ controller is to provide a very good control in dynamic system [14, 18, 21-22, 31]. The main objective of design PID controller is to get high performance with low percentage overshoot and reduce the settling time [14, 27]. By tuning method, we can optimize the parameters of FOPID controller; there are many tuning method like Ziegler-Nichols tuning method [15-16, 25, 29], the Astrom-Hagglund tuning method [7, 16], Padula & Visioli tuning method [15] and Internal Model control (IMC) rule [24]. The classical PID controllers and FOPID controllers are broadly applied in the industrial field due to easily realization and tuning [21].

LITERATURE SURVEY

The rational discrete time approximation to the continuous fractional order integrator and differentiator can be developed by the technique of Pade, Prony and Shank. From the results we can see that the least-squares based methods are adequate techniques for obtaining digital approximations of continuous fractional-order operator, for the practical realization of fractional-order controllers [1]. The parameters of fractional order PID controller (FOPID) can be optimized by some techniques; otherwise it is quite difficult to optimize the parameters of FOPID. Particle swarm optimization (PSO) is a one of the effective optimization technique. Based on this technique, FOPID cab be designed easily and it can be applied in various industrial field [2]. Fractional calculus or differentiation or integration of non-integer order is used to design the dynamic systems for better performance. The simulation by Numerical method is defined easily for fractional order systems and it can perform both analog and digital realization [3]. The performance of two different fractional order controllers can be observed in temperature profile tracking methodology. From the performance of these two, we can compare them with the traditional PI/PID controller by Ziegler-Nichols tuning method [4]. There are some techniques of tuning of the controllers. By the tuning process we can optimize the parameters of FOPID controllers. There are some rules for every tuning method; to analysis these rules we can perform the tuning methods [5]. Fractional Order calculus (FOC) is broadly used in science and engineering technologies. With the help of FOC, we can design many dynamic systems and Fractional Order controllers [6]. The parameters of FOPID controller are K_p (proportional gain), K_d (derivative gain), k_i (integral gain), μ (derivative order), λ (integrator order). By the Ziegler-Nichols tuning method, we can compute K_p and K_i parameters of FOPID controller. And the other parameter K_d, μ andλ have been computed by Astrom-Hagglund tuning method; then the FOPID controllers provide very good result and give the stability region [7]. The fractional order PID controllers can be tuned with the evolutionary algorithm for robot control. In order to compare the performance of PSO and the GA under different conditions and to test the robustness of the FOPID controller tuned with these algorithms, the parameters of the system and the given trajectory were changed and white noise was added to the system. All of the simulation results for the robot trajectory experiment show that the FOPID controller tuned by PSO has better performance than the FOPID controller tuned by the GA [8]. Now a day's many advanced techniques proposed for tuning, designing and good performance of PID based controller structure. The factional-order and event-based PID controllers are presented among the most significant developments in the industrial field [9]. Genetic Algorithm (GA) is a technique by which we can optimize the parameters of FOPID

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controllers. GA produced better result for the optimal FOPID controller parameters [10]. By the Particle Swarm Optimization (PSO) the FOPID controllers can be tuned and the parameters can be optimized [11]. PID controller is most frequently used feedback controller now days. A simulation model of bio-rector control system is formed with the help of MatLab/ Simulink module. Comparison between the performances of PID controller with the fractional order PID controller, gives the better result for the performance of FOPID controller [12]. The fractional calculus in control system is used to design and control the controllers. The FOPID controllers are used to control the speed of armature controlled DC motor [13]. FOPID controller can design by two Sysquake interactive tools. The first tool deals with the time and the frequency domain to design the FOPID controller. The second tool deals with the user to determine automatically the controller parameters by applying a loop shaping technique [14]. By Ziegler-Nichols tuning method, Padula & Visioli tuning method and tuning by minimization method, the fractional order PID (FOPID) controllers can be achieved [15]. The optimal parameters of FOPID controller is tuned by PSO algorithm which have fractional or integer order transfer function. The simulation result gives the better performance than the other methods [16]. The performance of FOPID controller is compared with the performance of traditional PID controller by PSO technique. Comparative analysis shows that the FOPID controllers based on PSO technique reduces the settling time and overshoots effectively against small step load disturbances. The simulation result shows that the Fractional controller gives the better performance than the Integer order controller [17]. FOPID controller can be designed by CSTR technique. A controller said to be best controller if the settling time and rise time is small, has no steady state error and overshoot. It is quite difficult to achieve the best controller. There is no overshoot and zero steady state error in CSTR technique. By this method FOPID controller gives better result [18]. Various Evolutionary Optimization (EO) techniques have been performed for FOPID and PID controller for controlling the speed of dc motor. FOPID controllers give better robustness in GA algorithm technique [19]. By some method, we can compare the performance between fractional order PI (FO-PI) controller and integer order PI controller (IO-PI). From the simulation result, we can observe the FO-PI controller gives better result than IO-PI controller [20]. The parameters of FOPID controller is tuned by CSO technique. The simulation result shows that the CSO technique of FOPID controller gives faster response and less overshoot [21]. Conventional PID controller and PSO based fractional order controller has been designed for a Heat Exchanger Process. It is difficult to achieve small settling time, less steady state error, less overshoot. Heat exchanger provides no or less steady state error [22]. Fractional order PID controller (FOPID) is used in many industry and robotics field [23]. There is another tuning method named Internal Model Control (IMC). FOPID controller is designed based on IMC for a first order Spherical tank [24].$PI^{\lambda}D^{\mu}$ controller can be used for both fractional-order and integer-order control. By the tuning methods and the optimization algorithms, we show that the performance of fractional-order controllers is better than integer-order controllers [25]. The FOPID controller is used to control the speed of CSTR PLANT utilizing soft computing techniques [26]. The FOPID controllers are the generalization of classical PID controller. By Pareto method for numerical optimization, the FOPID gives the better result of evaluate the parameters [27]. Current Feedback Operational Amplifier (CFOA) is a method which has been applied in FOPID controller. By this method we can observe the performance of FOPID is better than traditional PID controller [28]. The FOPID controller gives much better performance than IOPID and we can optimize the parameters by various tuning

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methods [29]. The FOPID controllers can design in frequency domain by an improved non-linear adaptive seeker optimization algorithm [30]. In present time fractional order controller has many applications. This controller broadly used in science, technology, robotics etc [31].

BASICS OF WORKING AND RELEVENT DISCUSSION

Now day's industrial plants requires wide ranges of techniques. Integer order controllers are used mostly in industrial field. To improve the performance of controllers, the fractional order controllers are used. A concept of fractional order PID controllers which involves fractional order integrator and fractional order differentiator is proposed. The form of fractional order PID (FOPID) controller is $PI^{\lambda}D^{\mu}$. FOPID controller provide extra degree of freedom for designing the controller gains (K_p, K_i, K_d) and designing the order of integral and derivatives. In figure 1 we can see how the FOPID controller behaves with the parameters. The transfer function of fractional order controller is as follow:

$G_f(s) = K_p + K_i /s^{\lambda} + K_d\, s^{\mu}$

Here,

K_p= proportional gain of the controller,

K_i= integral gain of the controller,

K_d= derivative gain of the controller,

λ= order of integration,

μ= order of derivative,

s= complex frequency.

When we choose the value of λ and μ is 1 and 1 respectively then it behave as classical PID controller; when λ=1 and μ=0 then it acts as PI controller and when λ=0 and μ=1, it acts as PD controller and when λ=0 and μ=0, it acts as classical P controller. All these classical types PID controllers are special type of $PI^{\lambda}D^{\mu}$ controller.

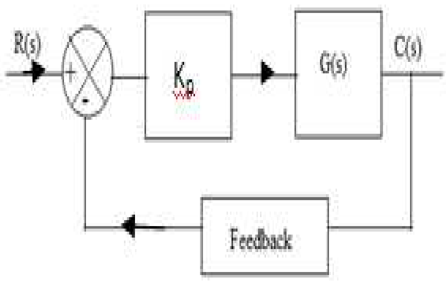

Figure 1.Classical P controller

This classical P controller is special type of $PI^{\lambda}D^{\mu}$ controller. The value of λ=0 and μ=0 for this type of controller. R(s) is the input and C(s) is the output of the system. G(s) is the gain of the system. Consider the feedback is unit negative. In figure 2, we can the bloke diagram of classical proportional controller.

So, overall transfer function of the system is,

$$\frac{C(s)}{R(s)}=\frac{g(s)}{1+g(s)}$$

Consider, $g(s) = G(s)*K_p$

This PI controller is special type of $PI^{\lambda}D^{\mu}$ controller. The value of λ=1 and μ=0 for this type of controller. R(s) is the input and C(s) is the output of the system. G(s) is the gain of the system. Consider the feedback is unit negative. In the figure 3, we can see the bloke diagram of PI controller.

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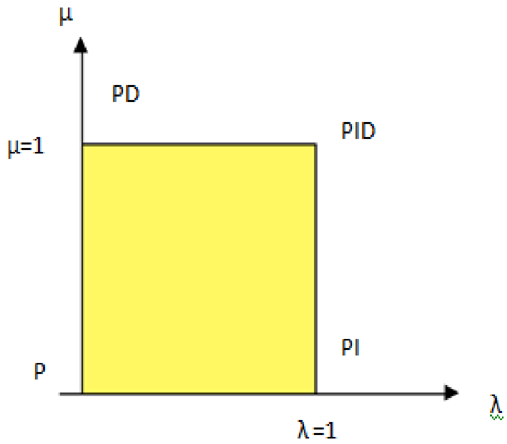

Figure 2.General form of FOPID Controller

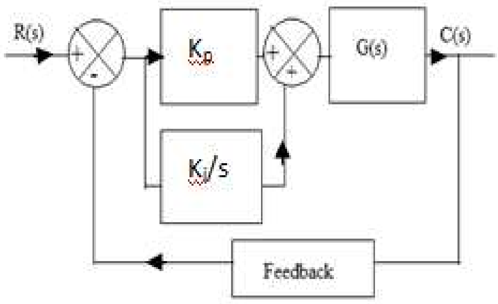

Figure 3.schematic diagram of PI controller

So, overall transfer function of the system is,

$$\frac{C(s)}{R(s)} = \frac{g1(s)}{1 + g1(s)}$$

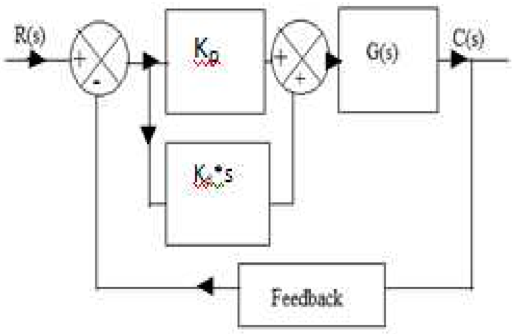

Figure 4.PD controller

Consider, $g1(s) = G(s)*(K_p+K_i/s)$

This PD controller is special type of $PI^{\lambda}D^{\mu}$ controller. The value of λ=0 and μ=1 for this type of controller. R(s) is the input and C(s) is the output of the system. G(s) is the gain of the system. Consider the feedback is unit negative. In figure 4, we can see the bloke diagram of PD controller.

So, overall transfer function of the system is,

$$\frac{C(s)}{R(s)} = \frac{g2(s)}{1 + g2(s)}$$

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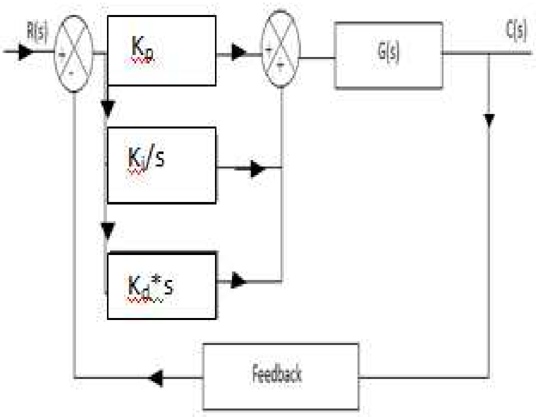

Figure 5.Schematic diagram ofPID controller

Consider, g2(s) = G(s)*(K_p+K_d*s)

This PID controller is special type of $PI^{\lambda}D^{\mu}$ controller. The value of λ=1 and μ=1 for this type of controller. R(s) is the input and C(s) is the output of the system. G(s) is the gain of the system. Consider the feedback is unit negative. In figure 5, we can see the block diagram of PID controller.

So, overall transfer function of the system is,

$$\frac{C(s)}{R(s)} = \frac{g3(s)}{1 + g3(s)}$$

Consider, g3(s) = G(s)*(K_p+(K_i/s)+(K_d*s))

Table 1.Effects of individual parameters

Para meter	Rise time	Over shoot	Settling time	Steady state error
K_p	De crease	In crease	Small change	De crease
K_i	De crease	In crease	In crease	Eli minate
K_d	Minor change	De crease	De crease	No effect

ADVANTAGES

Main advantages of fractional order controller are as follow-

- More adequate modelling of dynamic system.
- More clear-cut robust control design.

Advantages of FOPID controllers are as follow-

- Better for fractional system.
- Simplicity and compactness.
- Less overshoot and less steady state error.
- There are many tuning methods and optimization algorithm by which we can optimize the value of the parameters of FOPID controllers and it helps to reduce the value of error, overshoot etc.

DISADVANTAGES

In classical PID controller, the rise time, overshoot, settling time and steady state error is larger than FOPID controllers. In fractional order PID controller, we can tune or optimize the value of the parameters then we can control the settling time, overshoot and the steady state error. By Heat Exchanger method, the overshoot and steady state error can be reduced for FOPID controllers.

APPLICATIONS

There are many applications of FOPID controllers. Now day's the FOPID controllers are widely used in many field like science, technology, robotics etc.

This controllers also used in automatic voltage regulation industry, load frequency control DC motor, intelligent heat pacemaker industry etc. In robotics field this FOPID controller is widely used.

STABILITY CRITERIA OF FOPID CONTROLLER

We know that an integer order LTI system is stable if and only if all the roots of the polynomial are negative or have negative real part, if they are in complex conjugate system. The roots are located on the left side of the imaginary axis of the complex plane (s). Figure shows that the FOPID stability region when we treat the fractional order system the polynomial equation has various value function of 's'the domain of which is a Riemann surface. The stability region of FOPID is defined as the area bounded by a cone whose vertex is at the origin and expands to the right half of the s plane covering the angle of απ/2 as shown in figure below-

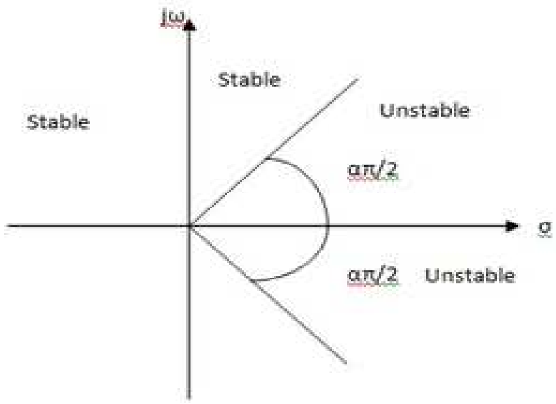

Figure 6.Stability region of factorial order PID controller system

We know that 's' represent the complex axis; It can be written as

$s = \sigma + j\omega$

Here, σ represents the real part and jω represent the imaginary part.

CURRENT RESEARCH ON FOPID CONTROLLER

Now day's fractional order PID controller is widely used in many fields. Fractional order PID controller gives much better performance than classical PID controller or integer order PID controller. By the optimization algorithms or tuning methods the parameters of FOPID controllers can be adjusted. By adjusting the parameters of FOPID controller; the overshoot, settling time, steady state error can be reduced. But in classical PID controller, we can't adjust the parameters of the controller perfectly. So, in this type of controller settling time, rise time, overshoot, steady state error is higher than FOPID controller and gives poor result compare with FOPID controller.

FUTURE SCOPE OF FOPID CONTROLLER

There are many places for working on this topic. Like-

- The real-time implementations of the controller can be made since the performance of the controller designed in off-line environment will have different performance in real-time.
- The robust performance of the FOPID controller can be verified.
- A novel approximation can be framed for the fractional calculus.

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- The performance of the fractional order controller is increased day by day. By tuning methods the flexibility of the controller is increased and gives very good performance.

CONCLUSION

In this paper, we discuss on the fractional order PID controller and its advantages, disadvantages and applications. We see that the FOPID controller gives much better performance than traditional or classical order controllers. Depending upon the value of the parameters, the FOPID controller behaves like P controller, PI controller, PD controller and the traditional PID controller. The stability of the FOPID controller can be defined in complex plane or s- plane.

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