Fractional Order PID Controller for Speed Control of DC Motor using Genetic Algorithm

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Abstract---In this paper we proposed an advance technique for control of DC motor speed by using fractional order proportional-integral-derivative (FOPID) controller. DC motor is used in almost every field of control so it's speed control is very important. FOPID controller parameters are composed of the proportionality constant, integral constant, derivative constant, derivative order and integral order, and its design is more complex than that of traditional integer-order proportional-integral-derivative (PID) controllers. Here the controller synthesis is formulated as a single objective optimization problem and based on Integral Time Weighted Absolute Error (ITAE) criterion. Genetic algorithm is been used to tune the FOPID controller parameter.

Keywords: genetic algorithm; fractional order PID controller; DC motor speed control.

I. INTRODUCTION

Among all motors available dc motor is best suited for industrial application. it is used as a power actuator , which converts DC electrical energy in to rotational mechanical energy . It is widely used in industry and commercial application, hair driers, disk drives, electric traction and in various other control application as well. Therefore its control is the major issue, for traditional controllers such as PI and PID have been widely used .

Here we are using nontraditional control technique which is known as fractional order control. Fractional calculus was developed 300 years ago, but came to practice in control application 1999[3],and in recent years[10] it became very popular.

Proportional –integral (PID) because simplicity of design and nice performance including low percentage overshoot and settling time for process control[11] application is very popular have been used for several decades in industry.

In FOPID integrator and differentiator are of fraction order therefore beside of having three parameter in PID Kp,Ki,Kd we have two more parameter μ and λ.

To meet the user specification for a given process plant optimization in five dimensional nonlinear search space should be done to get optimum values for K_p, K_i, K_d, μ and λ. For solving above optimization we have used genetic algorithm [7].

This paper is organized as follows: in section II we present mathematical modeling of DC motor. Section –III explains briefly about fractional order PID controller. In Section -IV problem is formulated, Section-V discusses the optimization technique Genetic Algorithm and Section VI-presents the simulation results and section VII conclude the paper.

II. MODELING OF DC MOTOR

In this approach we had considered the general modal of DC motor which is shown in fig 1. The applied voltage V_a controls the angular velocity $\omega(t)$. Transfer function of motor represented by

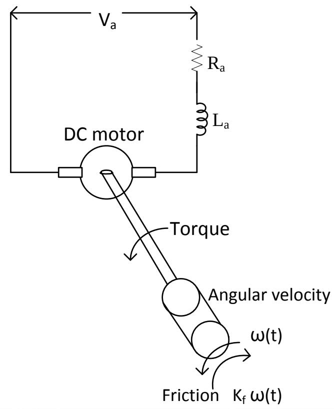

Fig. 1: General model of DC motor

In above DC motor the armature time constant is negligible and therefore a simplified model is being established and the continuous mathematical model has the following form

$$\frac{\omega(s)}{Va(s)} = \frac{(Kma/La\ J)}{(s+Ra/La)(s+c/J)+(Kb\ Kma/La\ J)} \quad (1)$$

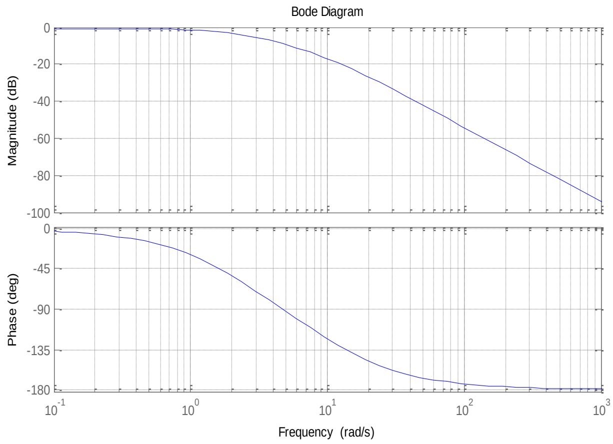

Fig. 2: Bode plot of motor mode

The physical motor constants given in table-I are taken in to consideration;

R_a	1 Ω
K_m	0.1N-m/Amp
K_f	0.1 N-ms
J	0.01 Kg-m^2
L_a	0.5 H

Table. 1: motor parameters

By making use of above motor constants the transfer function has the form

$$G(s) = \frac{0.1}{0.005s^2+0.06s+0.11} \quad (2)$$

In fig. 2 we depicted the bode diagram of DC motor(1) and we can observe that for given physical constant motor had good gain margin and phase margin as well.

III. FRACTIONAL ORDER PID CONTROLLER

Fractional-order control system is described by fractional-order differential equations. The FOPID controller is the expansion of the conventional PID controller based on fractional calculus FOPID has five parameters which are responsible for adding more flexibility and robustness to the system.

A. Fractional calculus and fractional order controller

Fractional calculus is a generalization of integration and differentiation to non-integer (fractional) order fundamental operator aD_t^r, where a and t are the limits and (r ε R) is the order of the operation. The two definitions used for the fractional differ integral aD_t^r, are the Grünwald-Letnikov (GL) definition and the Riemann-Liouville (RL) definition. Further, it has been mentioned in literature that for a wide class of functions, these two definitions are equivalent.

GL definition:

$$aD_t^r(t) = \lim_{h\to 0} h^{-r} \sum_{j=0}^{\left[\frac{t-a}{h}\right]} (-1)^j \binom{r}{j} f(t-jh) = \lim_{h\to 0}(h)^{-r}\Delta_h^r f(t) \quad (3)$$

Where, $\Delta_h^r f(t)$ is the generalized finite difference of order r with step 'h' .

RL definition:

$$aD_t^r(t) = \frac{1}{\Gamma(n-a)} \frac{d^n}{dt^n} \int_a^t \frac{f(\tau)}{(t-\tau)^{r-n+1}} \quad (4)$$

For ((n-1)<r<n) and Γ(.) is the Euler's gamma function.

The Laplace transforms of the GL and RL fractional derivative/integral, of signal f(t) at t=0 for order r is given by

$$L[aD_t^r f(t)] = s^r L[f(t)] = s^r F(s) \quad (5)$$

Using Laplace transformation

$$s^{-\lambda}F(s) = I^{\alpha} f(t), \lambda = \alpha \text{ and } s^{\delta}F(s) = \frac{d^{\delta}}{dt^{\delta}} f(t) \quad (6)$$

Then, the fractional PID controller is written as:

$$C(s) = K_P + K_i s^{-\lambda} + K_D s^{\mu}, (\lambda, \mu > 0) \quad (7)$$

Selection of λ and μ gives the classical controllers viz. PD controller (λ =0), PI controller (μ =0) and PID controller (λ, μ=1)

All the above mentioned controllers are special case of FOPID controller

B. Approximation of fractional Differentiator/integrator

Oustaloup approximation method and the algorithm is used for simulation. This method is based on the approximation of a function

$$H(s) = s^{\alpha}, (\alpha \in R) \quad (8)$$

For the frequency range (ω_L, ω_H), where ω_L *and* ω_H are the high and low translational frequencies and equation (23) are can be modified as

$$H(s) = K \prod_{k=-N}^{N} \frac{s+\omega_k^z}{s+\omega_k^p} \quad (9)$$

Using the following set of synthesis formulae, the approximation for poles, zeros and are obtained as follows:

$$\omega_k^z = \omega_L(\omega_L/\omega_H)^{(k+N+0.5+0.5\alpha)/(2N+1)}$$

$$\omega_k^p = \omega_L(\omega_L/\omega_H)^{(k+N+0.5-0.5\alpha)/(2N+1)}$$

$$K = \left(\omega_L/\omega_H\right)^{\frac{-\alpha}{2}} \prod_{k=-N}^{N} \left(\omega_k^z/\omega_k^p\right)$$

In above equation α is the order of differ-integration,*(2N+1)* is the order of filter. In current study 5 order approximation is taken in frequency band of the constant phase elements as ω is $\{10^{-2},10^{2}\}$ rad/sec.

IV. PROBLEM FORMULATION

We made use of integral time weighted absolute error *(ITAE)*

as our fitness function ,which has an advantage of providing lesser overshoot along with the less settling time, which is mathematically defined as :

$$ITAE = \int_0^t t(|e(t)|) \quad (10)$$

V. GENETIC ALGORITHM

Genetic algorithm is a robust optimization technique based on natural selection and evolution process.

Initiates without knowledge of the correct solution and depends entirely on responses from its environment and evolution operators to arrive at the best solution.by starting at several independent points and searching in parallel, the algorithm avoids local minima and converges to sub optimal solutions.in this way, GA has been shown to be capable of locating high performance areas in complex domains without experiencing the difficulties associated with high dimensionality.

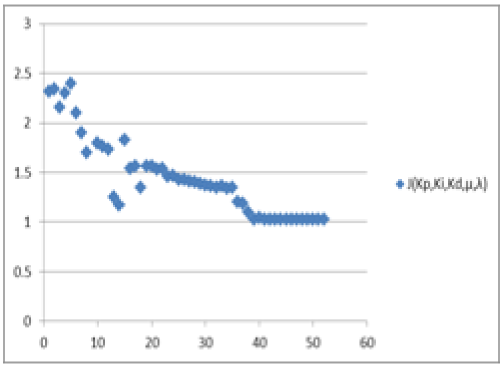

Fig. 3: Fitness value Vs generations for FOPIOD tuning

GA consists of three fundamental operations: reproduction, crossover, mutation. these operator work with a number of artificial creatures called a generation.by exchanging information from each individual in a population ,GA preserves better individual and yields higher fitness function evolution .it performs the basic task of copying stings, exchanging portions of string and changing some bits of string. finally, it finds and decodes the solution to the problem from the last pool of mature strings.

Following GA parameters are taken for tuning purpose

Population size = 100
Crossover probability = 0.65
Crossover function= Arithmetic crossover
Selection function =stochastic uniform
Generation number=50

By running GA with above parameters we obtained best value for ITAE=1.125

VI. SIMULATION RESULTS

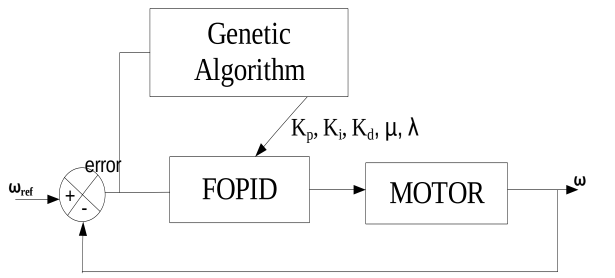

Fig. 4: SIMULINK model feedback control of DC motor

Fig 4. Shows the closed loop response of DC motor for the step input with FOPID controller the simulation results obtained from fig 6 are tabulated in table -3

parameter	GA-PID	GA-FOPID
Kp	10.808	136.611
Ki	19.927	198.739
Kd	1.271	151.152
μ	-	0.519
λ	-	0.892

Table. 2: PID and FOPID parameters obtained using genetic algorithm

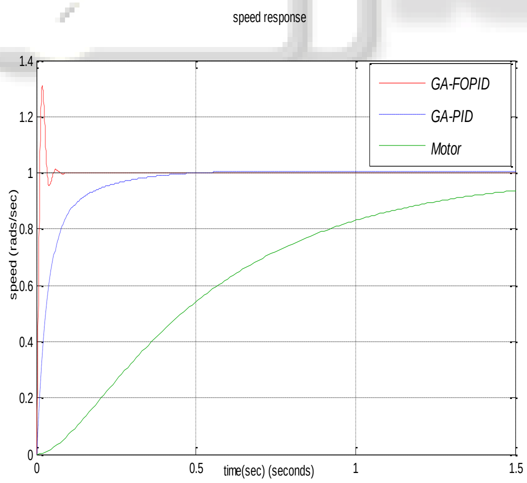

Fig. 5: comparision of step responses of PID and fopid controllers

PARAMETER	GA-PID	GA-FOPID
Rise time(sec)	0.1275	0.0074
Peak Overshoot	0.52	31.105
Settling time	0.3217	0.0486
Steady State error	0.001	0.0003

Table. 3: summary of close loop response of DC motor

VII. CONCLUSION

In this paper, scheme for feedback speed control of DC motor using a fractional –order PID controller using GA is presented. The parameter of PID and FOPID are optimally searched by genetic algorithm. The results of both controllers are compared.it is observed that the FOPID controller reduces rise time, settling time and steady state error as compared to traditional PID controller and provides more robustness in parameter variation than integer order PID due to two extra degree of freedom.

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