Intelligent Controller Design for PM DC Motor Position Control Using Evolutionary Programming

Guang-hui Chang , Yan-fei Li , Quan Gang
College of Naval Architecture and Power
Naval University of Engineering
Wuhan, China
e-mail: cgh_navy@163.com

Abstract—**This paper is concerned with the optimum proportional-integral-derivative (PID) controller design for a PM dc motor position control. Since the evolutionary programming (EP) algorithm has been considered as a useful technique for finding global optimization solutions for certain complicated functions in recent years. In this paper, we attempt to combine the EP algorithm with the PID control design to solve the positioning control problem of a PM dc motor, such that a performance index of integrated-absolute error (IAE) is minimized. Last, a SYL-5 PM dc motor position control system is used to verify the superiority of the proposed method. It can be easily seen from the simulation results that the proposed method will have better performance than those presented in other studies.**

Keywords- PID controller; evolutionary programming; optimization problem; PM dc motor position control

I. INTRODUCTION

Today, with the development of the rare-earth magnet, the PM (permanent-magnet) dc motors are becoming more and more popular in control system applications, i.e. automobile industry (electric vehicle), weak power using battery system (motor of toy), and the electric traction in the multi-machine systems, etc. From the control point of view, dc motor exhibit excellent control characteristics because of the decoupled nature of the field. Recently, many modern control methodologies such as nonlinear control, optimal control [1], variable structure control [2] and adaptive control [3] have been extensively proposed for DC motor. However, these approaches are either complex in theoretical bases or difficult to implement [4]. So, a great majority of DC motor are still controlled by means of the PID controllers because it is simple and robust.

The implement a PID controller, three parameters (the proportional gain, *Kp*; the integral gain, *Ki*; the derivative gain, *Kd*) must be determined carefully. Many approaches have been developed to determine PID controller parameters for single input single output (SISO) systems. The tuning methods of Cohen-Coon (C-C) and Ziegler and Nichols (Z-N) have been frequently used [5]. However, the conventional tuning methods for PID controller design might fail to achieve satisfactory performance when the plants are of high order, have long time delay, are nonlinear and so on.

The typical specifications on DC motor control applications are attenuation of load disturbance and setpoint following. Thus, the criterion IAE is in many cases a natural choice because it represents the specifications in the time domain, including peak overshooting, rise time, and steady-state error. In this paper, our main object is to propose a new tuning method to obtain optimal or near-optimal PID controller gains such that the value of IAE is as small as possible and to achieve satisfactory performance for DC motor position control systems.

As we know, the evolutionary programming (EP) has been considered as an useful and promising technique for deriving global optimization solutions of complex functions, and also has been applied to solve difficult problems in the field of control engineering. Generally, the EP for global optimization contains four parts: initialization, mutation, competition, and reproduction. However, standard EP converges slowly and may not be directly applicable to practical problems. So, during the last decade, new techniques of EP have emerged to speed up convergence and improve solution quality. Yao [6] proposed the fast EP (FEP) and improved fast EP (IFEP) techniques based on the Cauchy distribution, and Lee [7] further generalized them into a Lévy distribution-based adaptive fast EP (AFEP) technique. In this paper, the AFEP algorithm is used for determining the optimal control gains of a PID controller. An optimization problem is then well defined and an AFEP algorithm is presented to solve the optimization problem such that the IAE performance index of the system is minimized. Detailed descriptions will be stated in the following sections.

II. MODEL OF PM DC MOTOR

The PM dc motor can be represented by the equivalent circuit diagram in Fig.1. The Symbols, Designations and Units are publicized in Table 1.

978-1-4244-9600-6/11/$26.00 ©2011 IEEE

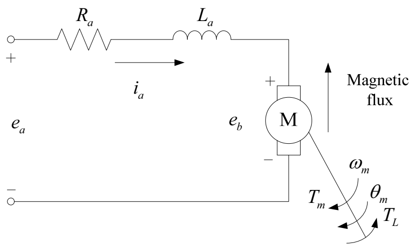

Figure 1. Equivalent circuit of PM dc motor .

TABLE I. USED SYMBOLS

Symbols	Designations	Units
R_a	Armature resistance	[Ω]
L_a	Armature inductance	[H]
i_a	Armature current	[A]
e_b , e_a	Back emf, Applied voltage	[Volt]
K_b	Back-emf constant	[V/rad/sec]
T_L,T_m	Load torque, Motor torque	[N·m]
ω_m	Rotor angular velocity	[Rad/sec]
θ_m	Rotor displacement	[Rad]
J_m	Rotor inertia	[Kg·m2]
K_i	Torque constant	[N·m/A]
B_m	Viscous-friction coefficient	[Kg·m2/sec]

The armature is modeled as a circuit with resistance R_a connected is series with an inductance L_a and a voltage source e_b representing the back emf in the armature when the rotor rotates. The dynamics of the PM dc motor drive system can be described by the following equations [8]:

$$\frac{di_a(t)}{dt} = \frac{1}{L_a}e_a(t) - \frac{R_a}{L_a}i_a(t) - \frac{1}{L_a}e_b(t) \quad (1)$$

$$T_m(t) = K_i i_a(t) \quad (2)$$

$$e_b(t) = K_b\frac{d\theta_m(t)}{dt} = K_b\omega_m(t) \quad (3)$$

$$\frac{d^2\theta_m(t)}{dt^2} = \frac{1}{J_m}T_m(t) - \frac{1}{J_m}T_L(t) - \frac{B_m}{J_m}\frac{d\theta_m(t)}{dt} \quad (4)$$

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts if possible. True-Type 1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

III. REALIZATION OF A PID-AFEP CONTROLLER TUNING OPTIMAL PARAMETERS

A. Realizetion of a PID-AFEP Controller Tuning Optimal Parameters

The continuous-form of a PID controller can be described as [5]:

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}\right) \quad (5)$$

Where *u(t)* is the control variable and *e(t)* is the control error. The controller parameters are proportional gain K , integral time T_i, and derivative time T_d. We can also rewrite (5) as:

$$u(t) = K_p e(t) + K_i\int_0^t e(\tau)d\tau + K_d\frac{de(t)}{dt} \quad (6)$$

Where $K_i=K_p/T_i$ is the integral gain and $K_d=K_pT_d$ is the derivative gain.

In PID controller design methods, the most common performance criteria are integrated absolute error (IAE), and integrated of squared error (ISE) under step testing input. IAE represents the specifications in the time domain, including peak overshoot, rise time, and steady-state error, so in this study, the IAE index is used as the objective function, which is given as:

$$IAE = \int_0^\infty |e(\tau)|d\tau \quad (7)$$

With this control objective, we now develop a tuning method is developed for a PID controller based on using AFEP algorithm.

B. Scheduling AFEP for PID Controller parameters

The structure of the PID controller with AFEP algorithms is shown in Fig. 2, where ysp is the desired output, y is the plant output(position of PM dc motor), and u is the control input generated by the PID controller as defined in (6). The PID controller is proposed with the optimal parameters derived from the AFEP algorithm such that the value of IAE in (7) is minimized.

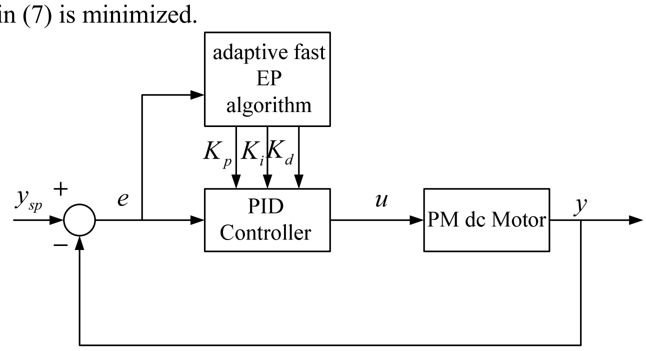

Figure 2. The block diagram of proposed PID Controller with AFEP algorithms .

The optimum problem is formulated as follows: Let z be the continuously differentiable matrix-valued function defined for $z \in S$, where

$$S \in \{z \in R^3 \mid 0 \le z_i \le \infty, i = 1,2,3\}$$

,then to find $z^* = [K_p^*, K_i^*, K_d^*] \in S$ such that IAE performance index of the PM dc motor position control system is minimized. More accurately, the optimum problem is stated mathematically as:

To find $z^* \in S$ such that for

$$IAE = \int_0^{\infty} \left| e(\tau) \right| d\tau \quad for \quad z \in S \tag{8}$$

is minimized.

Based on the results shown by Lee [7], the AFEP algorithm for solving the above optimization problem is described as follows:

Step 1) Randomly generate the initial population consisting of N individuals, each of which can be represented a set of real vectors,(x_i, σ_i), i=1,2,···,N. Each x_i and σ_i has 3 independent components

x_i={ $x_i(1), x_i(2), x_i(3)$ }

σ_i={ $\sigma_i(1), \sigma_i(2), \sigma_i(3)$ }

Where, x_i are control variables and σ_i are strategy parameters. In this paper, one individual of the initial population is given as the initial operating state, i.e. its control variables are set to the values they take in the initial operating state of the position control system.

Step 2) For each parent(x_i, σ_i), create an offspring (x'_i, σ'_i) as follows: for j=1, 2, 3

$$\sigma_i' = \sigma_i(j)\exp\{\tau' N(0,1) + \tau N_j(0,1)\}$$

$$x_i'(j) = x_i(j) + \sigma_i'(j) L_j(\alpha)$$

Where, Lj (α) is a random number generated anew for each j from the Lévy distribution with the parameter α. N(0,1) stands for a standard Gaussian random variable fixed for a given i and $N_j(0,1)$ a newly generated Gaussian random variable for each component j . The Parameters τ and τ' are defined as $\tau = \frac{1}{\sqrt{2\sqrt{N}}}$ and $\tau' = \frac{1}{\sqrt{2N}}$

We generate four candidate offspring with α=1.0, 1.3, 1.7, and 2.0 from each parent and select the best one as the surviving offspring. This scheme is adaptive because which to use is not predefined and is determined by evolution.

Step 3) From N parents and their N offspring, calculate their fitness values based on the objective function (7), f_1, f_2,···,f_{2N}. Where

$$f(x_i) = \int_0^{\infty} |e(\tau)| d\tau \quad , \quad x_i = [K_p, K_i, K_d] \in S$$

Step 4) Define and initialize a "winning function" for every parent and offspring as w_i=0, for i=1,2,···,2N. For each i , select one fitness function, say f_j ($j \neq i$) and compare the two fitness values. If f_i is less than f_j, the winning function for individual i increases by one, $w_i = w_i+1$. Perform this procedure q times for every parent and offspring. Where q is called the tournament size. In this paper, tournament size is set to 0.9N.

Step 5) According to the winning function w_i , i=1,2,···,2N, select N individuals that have the largest winning values to be the parents for the next generation. Let the individual with the minimum fitness value in the winners be x_1.

Step 6) If the sum of all next generation's fitness values converges to a minimum value, then $z^*=x_1$, is the global optimum value and $z^* = [K_p^*, K_i^*, K_d^*]$ is such that the IAE performance index of the system is minimized as possibly. Otherwise, return to step 2.

IV. Simulation Results

In this section, we applied AFEP to SYL-5 PM dc motor position control system. The various parameters of the PM dc motor are shown in Table 2. From the state equations (1), (2), (3), (4) previous, the transfer function of the electric DC motor is written as follows:

$$\frac{\theta_m(s)}{E_a(s)} = \frac{0.2866}{0.0281s^2 + 0.0913s} \tag{9}$$

TABLE II. Parameters of the DC Motor

R_a=13[Ω]	L_a=0.0312[H]
K_b=0.2731[V/rad/sec]	K_i=0.2866[N·m/A]
J_m=0.002158[Kg·m2]	B_m=0.001[Kg·m2/sec]

We construct the PM dc motor position control system model with the environment MATLAB 7.4 (R2007a) in Simulink version 6.6. The model of the system in Simulink is shown in Fig. 3.

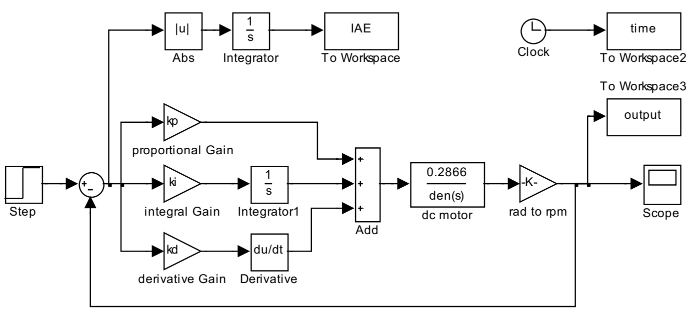

Figure 3. Model of the DC Motor position control system in Simulink .

A unit step reference input is applied into the above position control system and parameters are set for AFEP in the study is as in Table3.

TABLE III. AFEP Parameters Setting

Parameter	Value
population size N	60
tournament size q	54
initial standard deviation σ	3.0
maximum number of generations	120
Ranges of PID gain	0~50

After a series of AFEP algorithm manipulations, the convergence curve of IAE value versus iteration is depicted in Fig. 4. It can be easily observed from Fig. 4 that it converges after about 100 iterations and its final value of IAE is about $f(z^*)$=0.016 .

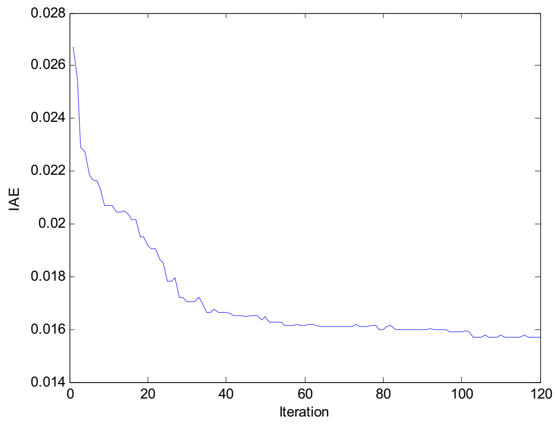

Figure 4. Convergence curve of IAE .

To show the effectiveness of the proposed approach, a comparison is made with AFEP tuned controller, conventional EP tuned controller and Ziegler Nichols tuned controller. The step response of the three controllers is shown in Fig 5. Table 4 lists the performances of these controllers. It can be seen that AFEP tuned PID controller reveals shorter settling time. Moreover the overshoot is considerably lower than that obtained via the Z-N tuned controller and conventional EP tuned controller.

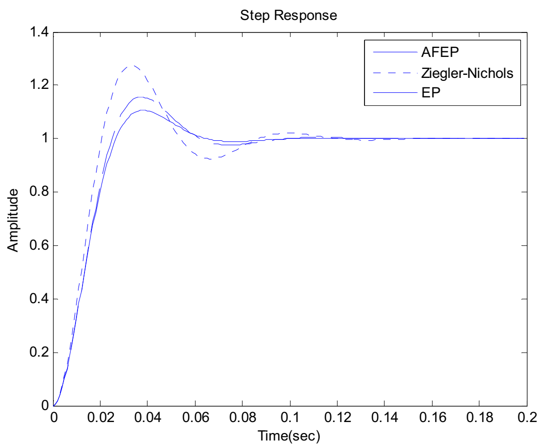

Figure 5. step response of AFEP tuned controller vs. Z-N and EP tuned controller .

TABLE IV. PERFORMANCE COMPARISION

Item	AFEP	EP	Z-N
IAE	0.016	0.020	0.021
Peak amplitude	1.106	1.156	1.275
Overshoot (%)	10.6%	15.6%	27.5%
Rising time (sec)	0.0265	0.025	0.0206
Settling time (sec)	0.058	0.081	0.101
P gain	16.842	15.89	17.6
I gain	0	0.632	0.25
D gain	0.1881	0.16	0.125

V. CONCLUSIONS

In this paper, a new design method to determine optimal PID controller parameters using the AFEP method is presented. Three PID controller gains can be directly obtained by solving certain optimization problems as defined above by performing Step 1-6 .To demonstrate the effectiveness of the proposed algorithm, a PM dc Motor position control system is illustrated under the reference input being unit step function. The results show that the proposed controller can perform an efficient search for the optimal PID controller. Finally by comparison with Z-N and EP tuned controller, it shows that this method can improve the dynamic performance of the system in a better way.

ACKNOWLEDGMENT

I would like to thank my advisor, Prof. Liang ,who has given me numerous instructions about this paper.

REFERENCES

[1] Reyer J. A., Papalambros P. Y., An Investigation into Modeling and Solution Strategies for Optimal Design and Control, ASME Design Engineering Technical Conferences, Las Vegas, Nevada, Sep, p. 10 – 13, 2000.

[2] Lin F. J., Shyu K. K., Lin Y. S., Variable structure adaptive control for PM synchronous servo motor drive, IEE Proc. IEE B: Elect. Power Applicat., vol. 146, Mar., p. 173 – 185, 1999.

[3] Rubaai A., Kotaru R., Online identification and control of a DC motor using learning adaptation of neural networks, IEEE Trans. Industry Application, Vol. 36, p. 935 – 942, 2000.

[4] Lin C. L., Jan H. Y., Evolutionarily multi-objective PID control for linear brushless DC motor, in Proc, IEEE Int. Conf .Industrial Elect. Society, Nov., p. 39 – 45, 2002.

[5] Åström,K.J. & Hägglund, T., PID Controllers: Theory, Design, and Tuning, Instrument Society of America,2nd ed.,1995.

[6] Yao, X., Liu, Y., and Lin, G.M.: 'Evolutionary programming made faster', IEEE Trans. Evol. Comput., 1999, 3, (2), pp. 82–102.

[7] Lee, C.Y., and Yao, X.: 'Evolutionary programming using mutations based on the Levy probability distribution', IEEE Trans. Evol.Comput., 2004, 8, (1), pp. 1–13

[8] Benjamin C. Kuo, Farid Golnaraghi, Automatic Control Systems, John Wiley&Sons, 8th ed.,2003.