DESIGN OF PID CONTROLLER FOR A LINEAR BRUSHLESS DC MOTOR USING SOFT COMPUTING TECHNIQUES

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ABSTRACT

This Paper presents a particle swarm optimization (PSO) method for determining the optimal proportional-integral derivative (PID) controller parameters, for speed control of a linear brushless DC motor. The proposed approach has superior features, including easy implementation, stable convergence characteristic and good computational efficiency. The brushless DC motor is modeled in Simulink and the PSO algorithm is implemented in MATLAB. Comparing with Genetic Algorithm (GA) and Linear quadratic regulator (LQR) method, the proposed method was more efficient in improving the step response characteristics such as, reducing the steady-states error; rise time, settling time and maximum overshoot in speed control of a linear brushless DC motor.

Index words: — Brushless DC motor, Particle swarm optimization, PID Controller, Optimal control.

I. INTRODUCTION

There are mainly two types of dc motors used in industry. The first one is the conventional dc motor where the flux is produced by the current through the field coil of the stationary pole structure. The second type is the brushless dc motor (BLDC motor) where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles [1]. This kind of motor not only has the advantages of DC motor such as better velocity capability and no mechanical commutator, but also has the advantage of AC motor such as simple structure, higher reliability and free maintenance. In addition, brushless DC motor has the following advantages: smaller volume, high force, and simple system structure.

So it is widely applied in areas which needs high performance drive [2]. From the control point of view, dc motor exhibit excellent control characteristics because of the decoupled nature of the field and armature mmf's [1]. Recently, many modern control methodologies such as nonlinear control [3], optimal control [4], variable structure control [5] and adaptive control have been widely proposed for linear brushless permanent magnet DC motor. However, these approaches are either complex in theoretical bases or difficult to implement. PID control with its three term functionality covering treatment to both transient and steady-states response, offers the simplest and yet most efficient solution to many real world control problems. In spite of the simple structure and robustness of this method, optimally tuning gains of PID controllers have been quite difficult. Genetic algorithm is a stochastic optimization algorithm that is originally motivated by the mechanism of natural selection and evolutionary genetics. Though the GA methods have been employed successfully to solve complex optimization problems, recent search has identified some deficiencies in GA performance.

II. LINEAR BRUSHLESS DC MOTOR

Permanent magnet DC motors use mechanical commutators and brushes to achieve the commutation. However, BLDC motors adopt Hall Effect sensors in place of mechanical commutators and brushes [5].

The stators of BLDC motors are the coils, and the rotors are the permanent magnets. The stators develop the magnetic fields to make the rotor rotating. Hall Effect sensors detect the rotor position as the commutating signals. Therefore, BLDC motors use permanent magnets instead of coils in the armature and so do not need brushes. In this paper, a three-phase and two-pole BLDC motor is studied. The speed of the BLDC motor is controlled by means of a three-phase and half-bridge pulse-width modulation (PWM) inverter. The dynamic characteristics of BLDC

motors are similar to permanent magnet DC motors. The characteristic equations of BLDC motors can be represented as [1] follows:
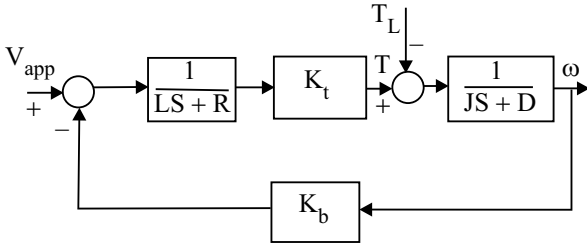

Fig. 1. The block diagram of BLDC motor

$$V_{app}(t) = L\,di(t)/dt + R \cdot i(t) + v_{emf}(t) \qquad ...(1)$$

$$V_{emf} = K_b\,\omega(t) \qquad ...(2)$$

$$T(t) = Kt \cdot i(t) \qquad ...(3)$$

$$T(t) = J\,d\omega(t)/dt + D \cdot \omega(t) \qquad ...(4)$$

where $V_{app}(t)$ is the applied voltage, $\omega(t$ is the motor speed, L is the inductance of the stator, $i(t)$ is the current of the circuit, R is the resistance of the stator, emf (t) is the back electromotive force, T is the torque of motor, D is the viscous coefficient, J is the moment of inertia, Kt is the motor torque constant, and Kb is the back electromotive force constant. Fig. 1 shows the block diagram of the BLDC motor. From the characteristic equations[6] of the BLDC motor, the transfer function of speed model is obtained the parameters of the motor used for simulation are as follows.

$$\omega(s)/V_{app}(s) = K_1/(L.J.S^7 + (l.D + RJ)\,S + K_1\,K_b) \qquad (5)$$

Table 1. The parameters of the motor used for simulation

parameters	Values and units
R	$21.2\ \Omega$
K_b	0.1433 Vs rad^{-1}
D	$1*10\text{-}4$ Kg-m s / rad
L	0.052 H
K_t	0.1433 Kg-m / A
J	$1*10^{-5}$ Kgm s^2 / rad

III. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

PSO is one of the optimization techniques and a kind of evolutionary computation technique. The method has been found to be robust in solving problems featuring nonlinearity and no differentiability, multiple optima, and high dimensionality through adaptation, which is derived from the social-psychological theory [7]. The technique is derived from research on swarm such as fish schooling and bird flocking. According to the research results for a flock of birds, birds find food by flocking (not by each individual). The observation leads the assumption that every information is shared inside flocking. Moreover, according to observation of behavior of human groups, behavior of each individual (agent) is also based on behavior patterns authorized by the groups such as customs and other behavior patterns according to the experiences by each individual. The assumption is a basic concept of PSO [8].The velocity of each particle, adjusted according to its own flying experience and the other particle's flying experience [9]. For example, the i_{th} particle is represented as $x_{i=}$ ($x_{i,1}$, $x_{i,2}$, $x_{i,d}$) in the d-dimensional space [10]. The best previous position of the i_{th} particle is recorded and represented as:

$$V_i(t+1) = W_iV_i(t) + C_1\text{rand}(Pbest_i - X_i)(t) + C_2\text{rand}(gbest - X_i(t))$$

$$X_i(t+1) = X_i(t) + V_i(t)$$

$$w = w_{Max} - [(w_{Max} - w_{Min})\ iter]/\ max_{Iter}$$

Where

$V_i(t) =$ Current velocity of agent i at iteration t

$V_i(t+1) =$ Modified velocity of agent i

$Xi(t) =$ Current position of agent i at iteration t

$W_{Max} =$ initial weight, $W_{Min} =$ final weight

$MAX_{Iter} =$ maximum iteration number,

iter $=$ current iteration number

IV. IMPLEMENTATION OF PSO-PID CONTROLLER:

A. Fitness Function

In PID controller design methods, the most common performance criteria are integrated absolute error (IAE)

The integrated of time weight square error (ITSE) and integrated of squared error (ISE) [10] that can be evaluated analytically in the frequency domain. These three integral performance criteria in the frequency domain have their own advantage and disadvantages. For example, disadvantage of the IAE and ISE [10] criteria is that its minimization can result in a response with relatively small overshoot but a long settling time because the ISE performance criterion weights all errors equally independent of time. Although the ITSE performance criterion can overcome the disadvantage of the ISE criterion, the derivation processes of the analytical formula are complex and time-consuming [11].

- Integral of absolute error (IAE) $= \int e(t).dt$

- Integral of squared error (ISE) $= \int \{e(t)\}^2 \cdot dt$

- Integral of time multiplied by absolute error (ITAE) $= \int t\, e(t).dt$

- Integral of time multiplied by squared error (ITSE) $= \int t\{e(t)\}^2 \cdot dt$

The fitness function is reciprocal of the performance criterion, in the other words:

$$f = 1/W(K)$$

B. Proposed PSO-PID Controller:

In this paper a PSO-PID controller used to find the optimal parameters of LBDC speed control system. Fig. 2 shows the block diagram of optimal PID control for **the BLDC motor**. In the proposed PSO method each particle contains three members P, I and D. It means that the search space has three dimension and particles must 'fly' in a three dimensional space. The flow chart of PSO-PID controller is shown in Fig. 3.
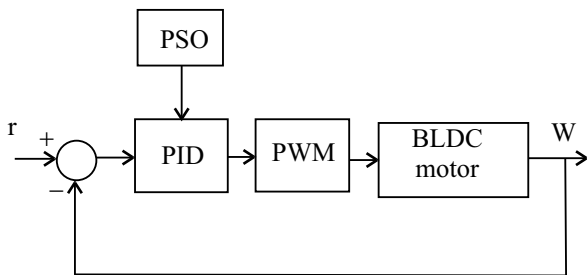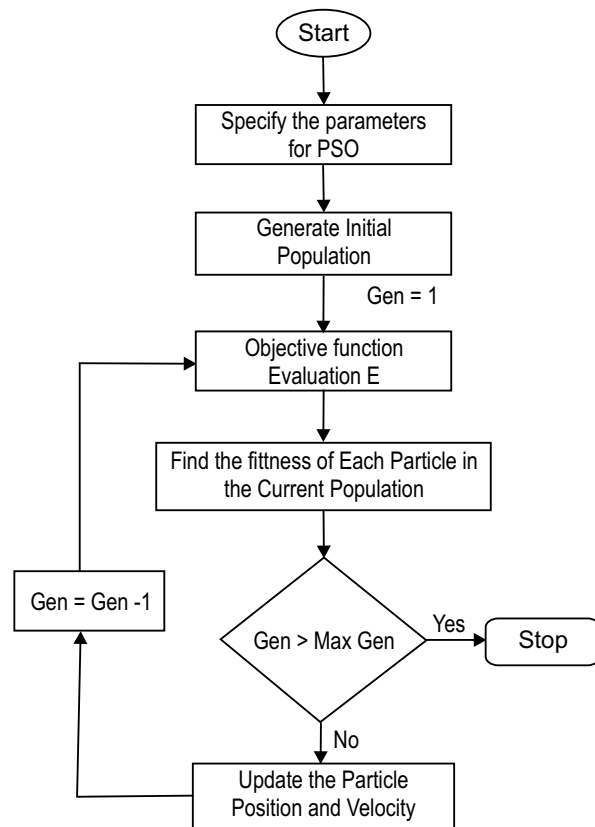

Fig. 2. Optimal PID Control

Fig. 3. Flow Chart of the PSO-PID Control System

V. NUMERICAL EXAMPLES AND RESULTS

A. Optimal PSO-PID Response

To control the speed of the LBDC motor at 1000 rmp, according to the trials, the following PSO parameters are used to verify the performance of the PSO-PID controller parameters:

Population size: 20;

Wmax = 0.6, Wmin = 0.1;

$C1 = C2 = 1.5$;

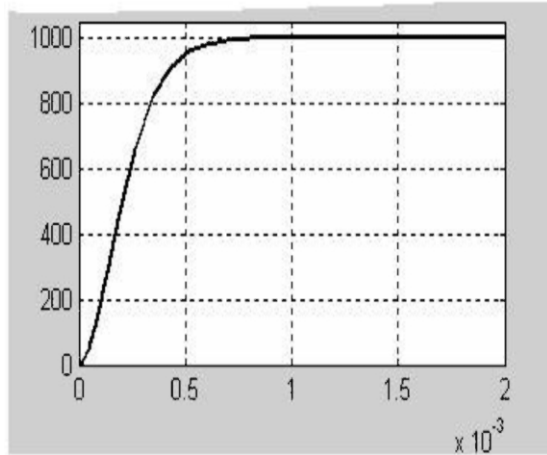Iteration: 20;

The optimal PID controller is shown in Fig. 4.

Fig. 4. Step response of BLDC motor in PSO based PID speed control

Table 2. Performance of the PSO-PID controller

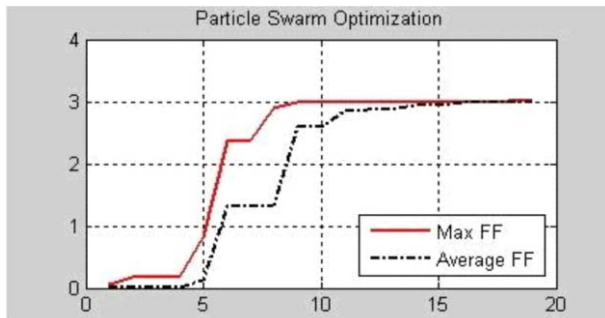| [P I D]	[190.0176, 50, 0.039567]
Rise time(ms)	0.3038
Max overshoot (%)	0
Steady States error	0.77186
Settling time(ms)	0.60116

Fig. 5. The convergence graph in the PSO method

B. Comparison of PSO-PID Method with LQR and GA Methods

To show the effectiveness of the proposed method, a comparison is made with the designed PID controller with GA and LQR methods. At first method, the PID controller is designed using LQR method and the values of designed PID Controller are 70.556, 10, and 0.0212. Also, GA method is used to tune the PID

controller. The following GA parameters which are used to verify the performance of the GA-PID controller parameters:

Population size: 30
Crossover rate: 0.9
Mutation rate: 0.005
Number of iterations: 30

The values of designed PID Controller are 93.1622, 38.6225, and 0.027836. Fig. 6 shows the convergence graph in the GA method, Fig. 7 shows the PSO response in comparison with GA and LQR methods and Table III lists the performance of the two methods.
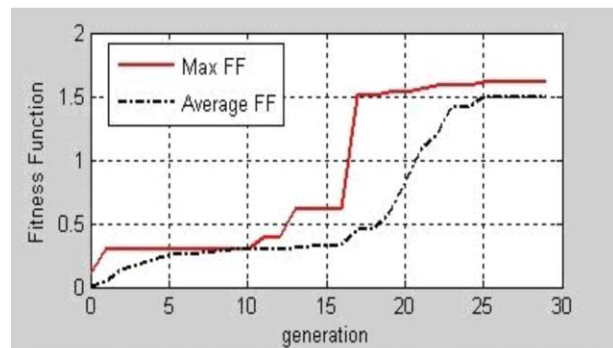

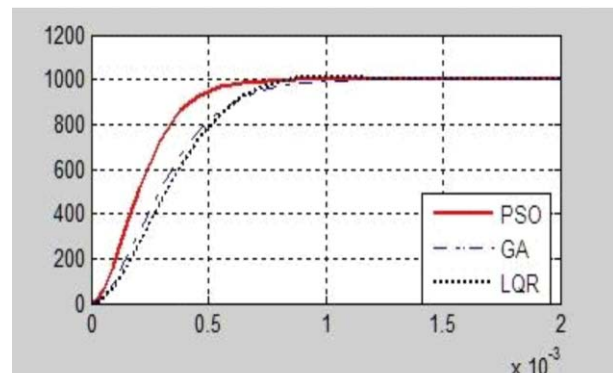Fig. 6. Convergence graph in the GA method

Fig. 7. Comparison between GA, LQR and PSO based PID control in speed control of LBDC motor

Table 3. LQR and GA Performance

	LQR	GA
P	70.556	93.1622
I	10	38.6225
D	0.0212	0.027836
Tr(ms)	0.46786	0.46127
MP%	1.4186	0
Ess	2.2513	1.5785
Ts(ms)	0.79368	0.87404

VI. CONCLUSION

In this paper a new design method to determine PID controller parameters using the PSO method is presented. Obtained through simulation of BLDC motor, the results show that the proposed controller can perform an efficient search for the optimal PID controller. By comparison with LQR and GA methods, it shows that this method can improve the dynamic performance of the system in a better way.

REFERENCES

[1]   Allan R. Hambley, Electrical Engineering: Principles and Application, Prentice Hall, New Jersey 1997.

[2]   J. Kennedy and R. Eberhart, "Particle swarm optimization," in Proc.IEEE Int. Conf. Neural Networks, vol. IV, Perth, Australia, 1995, pp.1942-1948.

[3]   Chee-Mun Ong, Dynamic Simulation of Electric Machinery, PrenticeHall, New Jersey, 1998

[4]   Mittal, A.K., Prasad R and Sharma S.P., Reduction of multivariable systems using stability equation method and error minimization technique. Proceedings of 27th National Systems Conference (NSC – 2003) on Control and Critical System, I.I.T. Kharagpur, December 17-19, 2003, 34-38.

[5]   S. Mukherjee, Satakshi and R.C.Mittal, "Discrete System Order Reduction Using Multipoint Step Response Matching", Journal of Computational and Applied Mathematics, Vol. 170, 2004, 461.

[6]   S. Mukherjee, Satakshi and R.C. Mittal, "Model Order Reduction using Response Matching technique", Journal of Franklin Institute, USA, Vol.342, Issue 5, Aug 2005, pp 503-519.

[7]   Satakshi, R.C. Mittal and S. Mukherjee, "Order Reduction of Linear Discrete Systems Using Genetic Algorithm", Applied Mathematics Modeling, Vol. 29, 2005, 565.

[8]   Mittal, A.K., Prasad, Rajendra and Sharma, S.P., "Model reduction Using Routh Hurwitz Array and Error Minimization Technique", 26th National System Conference (NSC 2002) Hyderabad, Nov 18-19, 2002

[9]   Devi, S. and Prasad, R., "Reduction of Discrete Time Systems by Routh Approximation", Proc. 27th National Systems Conference (NSC) during Dec 17-19, 2003. EE Deptt, IIT Kharagpur, pp 30-33, 2003.

[10] Mukherjee S., Satakshi and Mittal R.C., "Order Reduction of Linear Time Invariant Continuous Systems Using Genetic Algorithm", National System Conference held at Vellore Institute of Technology (VIT), Vellore, Tamilnadu, Dec 16-18, 2004.

[11] Mukherjee S., Satakshi and Mittal R.C., "Order Reduction of Linear Systems using point-to-point Step Response Matching", Wseas International Conference at Athens, Greece, July 2004.

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