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Optimal Tuning of PID Controller for a Linear Brushless DC Motor using Particle Swarm Optimization Technique

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***Abstract*— This Paper presents a novel Cultural Algorithm based particle swarm optimization (PSO) technique which is intended to assist in converging to a accurate solution in the control of Linear Brushless Direct Current motor (LBLDC). With the novel PSO-based approach the optimal Proportional-Integral-Derivative (PID) controller parameters are deduced for efficient speed control of Linear Brushless DC motor. In the present paper, an modern heuristic algorithm based on the behavior of organisms, such as bird schooling has been implemented in MATLAB and Linear Brushless DC motor modeled in Simulink. The proposed approach has efficient features including stable convergence characteristic and good computational efficiency, reducing the steady-state error (Ess), rise time (Tr), settling time (Ts) and maximum overshoot (Mp) in speed control of a Linear Brushless DC motor. The experimental results implicate the effectiveness of the approach.**

***Keywords*--Proportional-Integral-Derivative Controller, Cultural Algorithm, Particle Swarm Optimization, Linear Brushless DC motor.**

I. INTRODUCTION

AMONG the different motors configurations available, Linear Brushless DC (LBLDC) motor has considered to be strong contender. This is due to several reasons, including higher efficiency, robust operation, lower maintenance, and higher mechanical reliability, since the permanent magnets provides the necessary air gap flux instead of wire-wound field poles[1]. In addition, Linear Brushless DC motor has the following advantages such as smaller volume, better velocity capability, high force and simple system structure. Hence, these motors can be applied widely in diversified fields where high performance drives are needed [2].

Coming to the control point of view, the decoupled nature of field and armature mmf helps in exhibiting sustainable control characteristics [1]. Recently many tools have been evolved to facilitate optimized solutions for the problems that were previously difficult or impossible to solve [3],[4],[5],[6]. These tools include complex theoretical basis such as evolutionary computation, simulated annealing, particle swarm and so forth [7]. These new heuristic tools have been joined together with knowledge elements as well as traditional approach to efficiently control various parameters.

The Proportional-Integral-Derivative (PID) controller is the most common form of feedback and also a requisite element of early governors. It has become the standard tool when process control emerged in the 1940s. At present, more than 95% of the controllers are of PID type; most of the industries employ Proportional-Integral-Derivative (PID) controllers because of their simple structure. PID control with its three term functionality covering both transient and steady-states response, offers the simplest and the most efficient solution to many real world control problems [8]. Yu et al. have presented a LQR method [9] to optimally tune the PID gains. In this method, the response of the system is near optimal but it requires mathematical calculation and solving equations.

Particle Swarm Optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality [8]. PSO was first introduced by Kennedy and Eberhart based on the behavior of organisms, such as fish schooling and bird flocking. Generally, PSO is characterized as a simple concept, easy to implement, and computationally efficient [14]. Compared to other techniques, PSO has a well-balanced mechanism to enhance the global and local exploration abilities [15].

This paper has been organized into following sections i.e. in section 2 the Linear Brushless DC motor (LBLDC) is described and the speed model of it is shown. In section 3, the Particle Swarm Optimization (PSO) method is reviewed. Section 4, describes how PSO is used to design the PID controller optimally for a Linear Brushless DC motor. A brief overview of the results has been obtained by the proposed method via simulation the DC motor is presented in section 5. The paper is concluded in section 6.

II. LINEAR BRUSHLESS DC MOTOR

Generally, a Permanent magnet synchronous motor that converts electrical energy to mechanical energy uses an inverter corresponding to the brushes and commutators. The Brushless DC motor adopts Hall Effect sensors instead of mechanical commutators and also the rotors are the permanent magnets, and stator of BLDC motors are the coils which make the rotor rotating [17]. The Hall Effect sensors detect the rotor position as the commutating signals. Hence, BLDC motors use permanent magnets instead of coils in the armature avoiding brushes in the configuration. In this paper, a three-phase and two poles BLDC motor is studied.

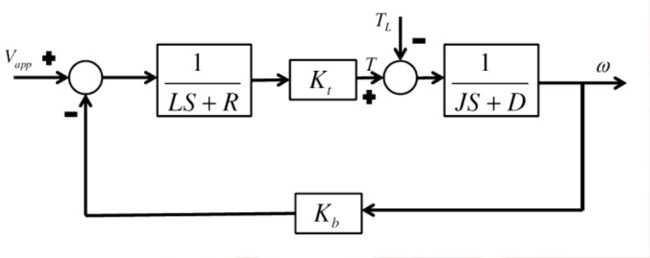

Fig.1 Block diagram of BLDC Motor.

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 follows [18]:

$$V_{app}(t) = L\frac{di(t)}{dt} + R.i(t) + V_{emf}(t)$$

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

$$T(t) = K_t.i(t)$$

$$T(t) = J\frac{d\omega(t)}{dt} + D.\omega(t)$$

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, $V_{emf}(t)$ is the back electromotive force, T is the torque of motor, D is the viscous coefficient, J is the moment of inertia, K_t, is the motor torque constant, and K_b is the back electromotive force constant. Fig. 1 shows the block diagram of the BLDC motor. From the characteristic equations of the BLDC motor, the transfer function of speed model is obtained.

$$\frac{\omega(s)}{V_{app}(s)} = \frac{K_t}{LJS^2 + (LD + RJ)S + K_tK_b}$$

The parameters of the motor used for simulation are as follows

TABLE 1. PARAMETERS OF THE MOTOR

Parameters	Values and Units
R	21.2 Ω
K_b	0.1433 $Vs.rad^{-1}$
D	$1*\ 10^{-4}\ Kg-ms/rad$
L	0.052H
K_t	0.1433 $Kg-m/A$
J	$1*\ 10^{-5}\ Kgm.s^2/radU$

III. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

PSO is one of the optimal technique and a 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 [13]. 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). 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 [16]. The velocity of each particle, adjusted according to its own flying experience and the other particle's flying experience. For example, the ith particle is represented as xi =(x i,1, x i,2 ,, x i,d) in the d-dimensional space. The best previous position of the ith particle is recorded and represented as [13]:

$$V_i(t+1) = W_i V_i(t) + C_1 rand(P_{best_i} - X_i(t)) + C_2 rand(g_{best_i} - X_i(t))$$

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

$$w = w_{Max} - [(w_{Max} - w_{Min}) iter]/Max_{iter}$$

Where

Vi (t) =Current velocity of agent i at iteration t

Vi (t+1) =Modified velocity of agent i

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

WMax = initial weight, WMin = final weight

MaxIter = 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) that can be evaluated analytically in the frequency domain[19],[20]. These three integral performance criteria in the frequency domain have their own advantage and disadvantages. For example, disadvantage of the IAE and ISE 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 [21]. The IAE, ISE, and ITSE performance criterion formulas are as follows:

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

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

Integral of time multiplied by Absolute Error

(ITAE) = $\int t.e(t).dt$

Integral of time multiplied by squared error

(ITSE) = $\int t.\{e(t)\}^2.dt$

The fitness function is reciprocal of the performance criterion [13], in the other words:

$$f = \frac{1}{W(k)}$$

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.

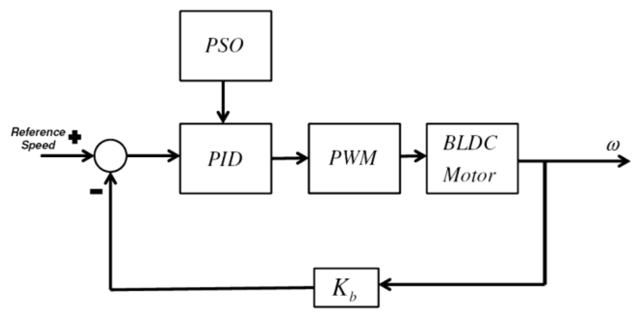

Fig.2 Block diagram of Proposed PSO-PID Controller.

The flow chart of PSO-PID controller is shown in Fig.3

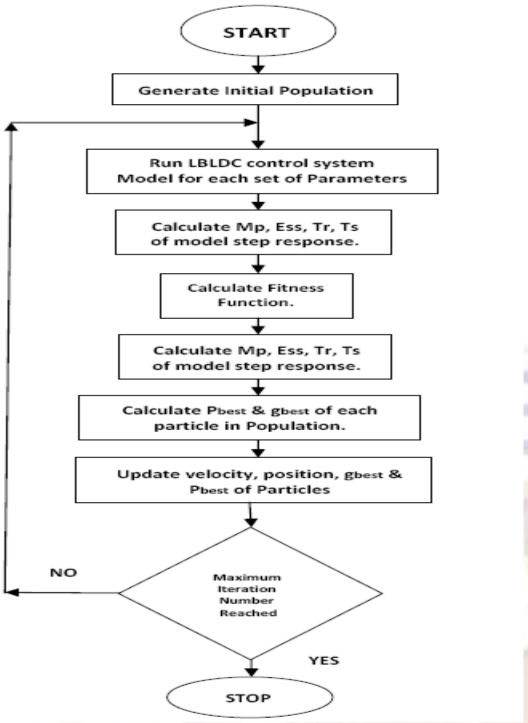

Fig.3 Flow Chart of PSO-PID Controller.

V. SIMULATION AND RESULTS

A. *Optimal PSO-PID Response*

To control the speed of the LBDC motor at 1000 rpm, 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;

[P I D]	[190.0176,50,0.0397]
Rise time(ms)	0.3038
Max overshoot (%)	0
Steady States error	0.77186
Settling time(ms)	0.60116

Fig.4 List of the Performance of PSO-PID Controller.

The optimal response of the PID controller is shown in Fig. 4.

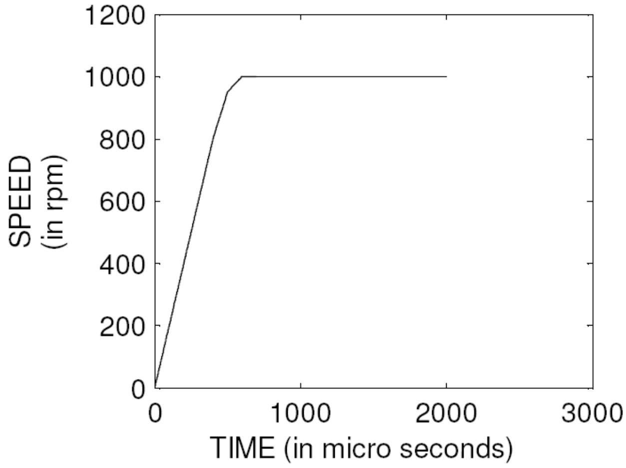

Fig.5 Speed curve attained using PSO-PID Controller.

The below figure illustrates about the convergence between the Maximum Fitness function and the Mean Fitness Function Respectively

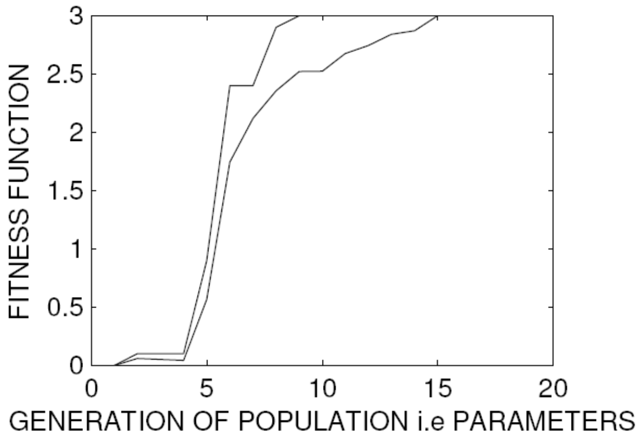

Fig.6 Fitness Function used in PSO-PID Controller.

VI. CONCLUSION

In this paper novels design method to deduce PID controller parameters as shown in Fig 3. using the PSO method is obtained. The obtained results through the simulation of BLDC motor shows that the proposed controller can perform an efficient search for optimal PID controller and can improve the dynamic performance of the system in a better way.

REFERENCES

[1] V. Tipsuwanporn, W. Piyarat and C. Tarasantisuk, “Identification and control of brushless DC motors using on-line trained artificial neural networks,” in Proc. Power Conversion Conf., pp. 1290-1294, Apr. 2002.

[2] X.Li Q.Zhang and H.Xiao, “The design of brushless DC motor servo system based on wavelet ANN, “in Proc. Int. Conf. Machine Learning and Cybernetics, pp. 929-933, 2004.

[3] N. Hemati, J. S. Thorp, and M. C. Leu, “Robust nonlinear control of Brushless dc motors for direct-drive robotic applications,” IEEE Trans. Ind. Electron., vol. 37, pp. 460–468, Dec 1990.

[4] P. M. Pelczewski and U. H. Kunz, “The optimal control of a constrained drive system with brushless dc motor,” IEEE Trans. Ind. Electron., vol. 37, pp. 342–348, Oct. 1990.

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

[6] E. Cerruto, A. Consoli, A. Raciti, and A. Testa, “A robust adaptive controller for PM motor drives in robotic applications,” IEEE Trans. Power Electron., vol. 10, pp. 62–71, Jan. 1995.

[7] C.-L. Lin, and H.-Y. Jan, “Evolutionarily multiobjective PID control for linear brushless DC motor, ”in Proc. IEEE Int. Conf .Industrial Elect. Society, Nov. 2002, pp.39-45.

[8] K. Ang, G. Chong, and Y. Li, “PID control system analysis, design, and technology,” IEEE Trans.Control System Technology, vol. 13, pp. 559- 576, July 2005.

[9] G. Yu, and R. Hwang, “Optimal PID speed control of brush less DC motors using LQR approach,” in Proc. IEEE Int. Conf. Systems, Man and Cybernetics, 2004, pp. 473-478.

[10] C. L. Lin, and H. Y. Jan, and N. C. Shieh, “GA-based multiobjective PID control for a linear brushless DC motor,” IEEE/ASME Trans. Mechatronics , vol.8, No. 1, pp. 56-65, 2003.

[11] D. B. Fogel, Evolutionary Computation toward a New Philosophy of Machine Intelligence: New York: IEEE, 1995.

[12] R. C. Eberhart and Y. Shi, “Comparison between genetic algorithms and particle swarm optimization,” in Proc. IEEE Int. Conf. Evol. Comput., Anchorage, AK, May 1998, pp. 611–616.

[13] Z.-L. Gaing, “A particle swarm optimization approach for optimum design of PID controller in AVR system,” IEEE Trans. Energy Conversion, vol. 19, pp. 384-391, June 2004.

[14] J. Kennedy and R. Eberhart, “Particle swarm optimization,” in Proc. IEEE Int. Conf. Neural Networks, vol. IV, Perth, Australia, 1995, pp. 1942–1948.

[15] M. A. Abido, “Optimal design of power-system stabilizers using particle swarm optimization,” IEEE Trans. Energy Conversion, vol. 17, pp.406- 413, Sep. 2002.

[16] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi, “A particle swarm optimization for reactive power and voltage control considering voltage security assessment,” IEEE Trans. on Power Systems, Vol. 15, No. 4, Nov. 2000, pp. 1232 – 1239.

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

[18] Chee-Mun Ong, Dynamic Simulation of Electric Machinery, Prentice Hall, New Jersey, 1998.

[19] R. A. Krohling and J. P. Rey, “Design of optimal disturbance rejection PID controllers using genetic algorithm,” IEEE Trans. Evol. Comput., vol. 5, pp. 78–82, Feb. 2001.

[20] Y. Mitsukura, T. Yamamoto, and M. Kaneda, “A design of self-tuning PID controllers using a genetic algorithm,” in Proc. Amer. Contr. Conf., San Diego, CA, June 1999, pp. 1361–1365.

[21] R. A. Krohling, H. Jaschek, and J. P. Rey, “Designing PI/PID controller for a motion control system based on genetic algorithm,” in Proc. 12th IEEE Int. Symp. Intell. Contr., Istanbul, Turkey, July 1997, pp. 125–130.

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