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PSO Tuned PID Controller for Magnetic Ball Levitation System

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Abstract-The control of a magnetic ball levitation system using PSO tuned proportional integral derivative (PID) controller is proposed in this paper. Though PID controller produces a controlled output for stable and unstable systems, the performance of the system in terms of overshoot, settling time, Integral Square Error (ISE) and Integral Absolute Error (IAE) are poor. To solve this problem, PSO tuned PID controller is designed based on the system open loop transfer function. The performance of the proposed controller is demonstrated via simulation study of a magnetic ball levitation system. The results are compared with the classical PID controller.

Keywords: *PID controller; Compensator; PSO tuned PID controller; Magnetic Ball Levitation System*

I. INTRODUCTION

Magnetic levitation is the process by which a ferromagnetic object is suspended in the air against gravity with the help of a magnetic field generated by a coil. This process presents many practical applications such as: active magnetic bearings, vibration damping, suspension of wind tunnel models, transportation systems (e.g high speed passenger trains) etc [1]. In majority of the cases the control system and energy supply desires to levitate the object have a large level of intricacy. The nonlinear nature of the system dynamics coupled with the nonlinear characteristics of the actuators which cause difficulties in the controller design. For such a nonlinear system, it is required to propose an appropriate controller for positioning a ball in the air space with the help of an electromagnetic force on that iron ball. In the ideal condition, the weight of the metallic iron ball is balanced by the magnetic force produced by the current from an electromagnet [2]. PID Controllers have been widely used for speed and position control of various applications. For a wide range of practical processes, this tuning approach works quite well. To enhance the capabilities of traditional PID parameter tuning techniques, several intelligent approaches have been suggested to improve the PID tuning, such as those using the particle swarm optimization (PSO). These parameters can be optimally obtained via Particle swarm Optimization (PSO) [3]. PID with PSO is found to be easy to implement, and has stable convergence and good computational efficiency. [4].

II. SYSTEM DESCRIPTION

The schematic of magnetic ball levitation system is shown in *Fig. 1*. It consists of an electromagnet screwed to the support block. The current (i) passing through the electromagnet produces a magnetic force (F) which levitates the steel ball in air. The light sources and the photo sensors are used to determine the actual displacement of the ball. The actual position is compared with the desired position. Based on the error signal (e), the controller generates the necessary control voltage signal (c), which is fed to the current driver circuit. The driver circuit regulates the current through the electromagnetic coil, thus producing the necessary attractive force to achieve the desired position of the steel ball.

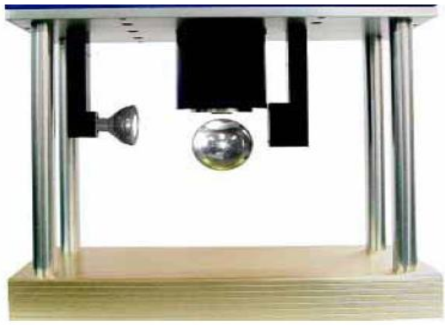

Figure 1: Schematic of Magnetic Ball Suspension System

The controller plays an important role in the improvement of production quality and accuracy, thus reduces the production costs. Intelligent controllers have remarkable success in research for more than two decades. However, PID controllers have widespread acceptance for variety of processes in industries. More than 97% of the regulatory controllers utilize the PID algorithm. The main reason for their versatility is their relatively simple structure and good cost/benefit ratio. The performance of the controller is much dependent on tuning of the PID parameters. Though, application of tuning rule proposed by several authors for stable and unstable processes produce controlled output, the performance of the controller shows deterioration in the quality of the system performance. Separate techniques have been developed for systems which are stable, unstable and integrating in open loop to improve the performance of the closed loop systems with PID controller. The main drawback of these methods is the tedious analytical design which prevents the operators from use in real time applications. PID controllers produce a controlled output for stable and unstable systems, the performance of the system in terms of overshoot, settling time, Integral Square Error (ISE) and Integral Absolute Error (IAE) are poor.

III. DYNAMICS OF MAGNETIC BALL LEVITATION SYSTEM

The magnetic force produced by the electromagnet is opposite to gravity and it maintains the suspended steel ball in a levitated position. The magnetic force depends on the electromagnet current and the air gap between the steel ball and the electromagnet.

The transfer function of the magnetic ball levitation system is

$$\frac{X(s)}{I(s)} = \frac{-C\left(\frac{2i_0}{x_0}\right)}{ms^2 - C\left(\frac{2i^2{}_0}{x^2{}_0}\right)} \quad (1)$$

TABLE I summarizes the variables and parameters used in this problem.

Table I Parameters of Magnetic Ball Levitation System

Parameters	Description	Value
M	Mass of the ball (kg)	0.021
X_0	Nominal air gap (mm)	22.5
I_0	Equilibrium current (A)	2.75
G	Gravitational acceleration (m/s^2)	9.82
C	Magnetic constant (Nm^2/A^2)	$1.477x10^{-4}$

Operating region is 18 – 27 mm from electromagnet.

Hence, the transfer function of the nominal plant based on the parameters in Table 1 leads to,

$$G_p(s) = \frac{X(s)}{I(s)} = \frac{1.60}{(0.001s^2 - 1^2)} \quad (2)$$

Hence, Magnetic ball levitation system is second order unstable system.

IV. CONVENTIONAL PID CONTROLLER

In the PID control structure shown in *Fig. 2*, $G_p(s)$ is the plant and $G_c(s)$ is the PID controller. y is actual output of the system and y_d is the desired output.

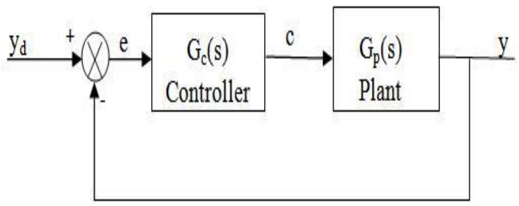

Figure 2: Conventional PID Controller

From the system transfer function given in equation 2, the parameters of the PID controller such as proportional gain (K_p), integral gain (K_i) and derivative gain (K_d) are computed based on the tuning method devised by manual tuning method.

TABLE II Conventional PID Controller Parameters for Magnetic Ball Levitation System

PID Parameters	K_p	K_i	K_d
Manual Tuning Method	5.0175	194.5950	0.1646

V. PSO TUNED PID CONTROLLER FOR THE SYSTEM

PSO is a robust stochastic optimization technique based on the movement and cooperation of swarms. It applies the concept of social interaction to problem solving. It was first developed in 1995 by J. Kennedy and R. Eberhart. It uses a number of particles that constitute a swarm moving around in the search space looking for the best solution. The basic concept of PSO lies in accelerating each particle towards its „pbest" and the „gbest" locations, with a random weighted acceleration at each time step. Each particle tries to modify its position using the information such as the current positions, the current velocities, the distance between the current position and „pbest", the distance between the current position and the „gbest". *Fig. 3* shows the flow chart for PSO algorithm.

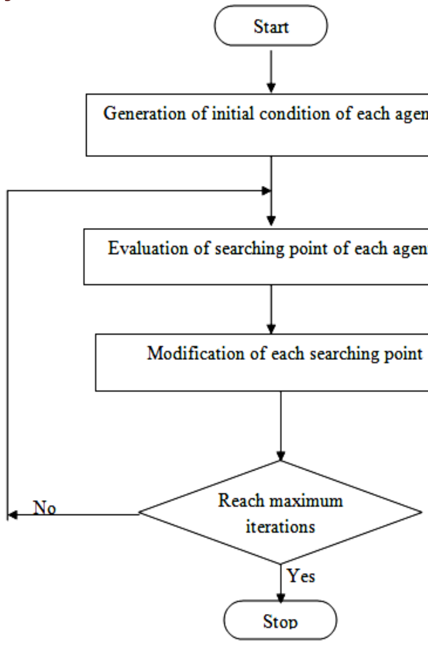

Fig.3 Flow Chart for PSO algorithm

PSO tuned PID controller improves the performance of the system by reducing the errors. The parameters Kp, Ki and Kd are chosen from the PSO algorithm tuning of PID controller for magnetic levitation system is shown in TABLE III.

TABLE III PSO tuned PID Controller Parameters for Magnetic Ball Levitation System

PID Parameters	K_p	K_i	K_d
PSO tuned PID Controller	5.625	76.21	0.1025

VI. RESULTS AND DISCUSSION

To illustrate its superiority, PSO tuned PID controller is compared with conventional PID controllers. The performance and robustness of the control system are evaluated based on the performance measures such as overshoot, settling time, ISE and IAE.

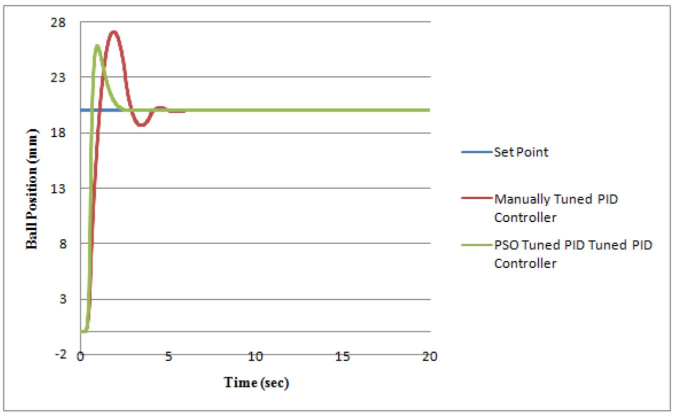

Fig. 4 Performance of conventional PID and PSO tuned PID controller at the Operating point of 20mm

A step change of 20mm is introduced in the set point. *Fig. 4* compares the set point responses obtained from the conventional PID controllers and the PSO tuned PID controller. The proposed controller shows reduce in overshoot. The closed loop performance indices listed in TABLE IV confirms the superior response of the PSO tuned PID controller for the same set point.

Table IV: Performance Analysis of Controllers

Tuning methods	Performance measures			
	Overshoot (%)	**Settling time (sec)**	**ISE**	**IAE**
Manual Tuning Method	35.72	4.140	8828.37	724.2212
PSO tuned PID Controller	29	2.46	6648.461	467.0682

VII. SERVO RESPONSE OF PSO TUNED PID CONTR-LLER WITH CONVENTIONAL PID CONTROLLER

Closed loop simulated transient responses obtained at different operating points are shown in Figure 5. The figure reveals that the performance of PSO tuned PID controller provides better performance with the same settings for different operating points. Among the controller tuning rules, PSO tuned PID controller tolerates the perturbations in the model parameters and provides the most consistent and robust response when the operating point changes.

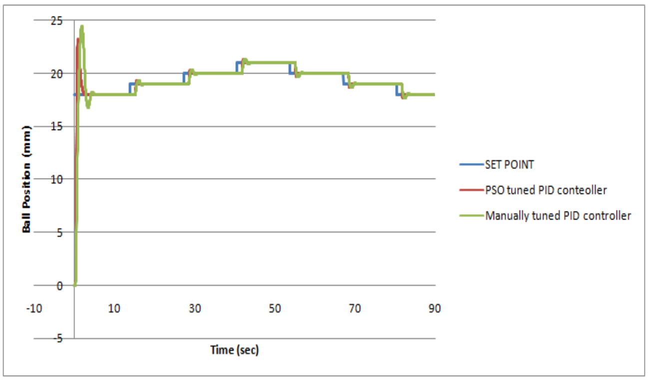

Fig. 5 Servo Response of PSO Tuned PID Controller with Conventional PID Controller

CONCLUSION

In this paper, PSO tuned PID controller is developed based on the process model. The magnetic ball levitation system is considered in the simulation study in order to demonstrate the superiority of the proposed method. A closed loop response of magnetic levitation system tuned by the proposed method is compared with the existing conventional PID controller. The results show that the performance of PSO tuned PID controller is superior to the conventional PID controller.

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