An Analytical Research on Control Strategy in Magnetic Levitation

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Abstract-

This research provides a twin control technique with the goal of realizing levitation for a revolutionary permanent magnetic levitation system. First, a linked dynamic model comprising of two subsystems was created. Four joint control schemes of rotation angle and air gap length were developed based on the research of stable levitation. Next, the adjustment of the controller's parameters was applied using the non-linear inertia weight version of the enhanced PSO (particle swarm optimization) method. Finally, step-Experiments and response simulations were run to evaluate the effectiveness of the four suggested control techniques. The outcomes show that PSO is a valid method for adjusting proportional-integral-derivative (PID) parameters. Furthermore, although the cascade double PD controller and parallel double PD controller have larger steady-state errors, they both perform better dynamically. The mistake could be removed by employing PID control for the air gap. The cascade control approach outperforms the parallel PID-PD control strategy in terms of 0.03 s rising time, 4.3 s settling time, and 24% peak overshoot.

Keywords— *Revolutionary, Permanent Magnetic Levitation System, Stable Levitation, Integral-Derivative (PID) Parameters.*

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INTRODUCTION

With the use of levitation force and no mechanical contact, things can be suspended or supported by maglev (magnetic levitation) technology. Many specific applications, such as those requiring lubrication, frictionlessness, and pollution control, cannot be met by standard technologies; this one can. Applications for the maglev technology include multi-DOF actuators, trains, bearings, and gears. Research on the controller design of the maglev system is difficult because of the substantial non-linearity of the magnetic force. As the strong non-linearity of magnetic force, controller design and performance optimization are challenging tasks. Based on the first-order Taylor series expansion, the linearized dynamic model of maglev systems could be established. Hence it is regarded as a control problem of the linear system. The PID (proportional-integral-derivative) controller provides a generic and efficient control solution for the maglev system. Bojan–Dragos C designed a PID controller with state feedback for an EML (electromagnetic levitation) system, which successfully stabilizes a ferromagnetic ball without the steady-state air gap error. Zhao C proposed a zero-power strategy based on PD control and applied it for a hybrid magnetic levitation system. The inductance effect in the EML system may cause a problem of time delay. Jaeyoung K proposed a combined levitation control strategy consisting of a current and air gap controller for a high accuracy maglev tray system. The inner loop for current utilizes a PI controller, while the outer loop for an air gap applies a PID controller. Yang D designed an adaptive back stepping controller for the active magnetic bearing to reduce the uncertainties of system parameters. Also, modern control methods are applied to maglev systems, such as the H-infinity control method, the fuzzy control method, and the sliding model control method. Sun proposed a permanent magnetic levitation (PML) system with the variable magnetic flux, which could avoid adhering by adjusting to zero levitation force. The PML system consists of two coupled second-order subsystems; hence, it must adopt a double control strategy. Tuning controller parameters are critical when applying a PID control strategy. The traditional Z-N tuning method is challenging to achieve good control performance. Besides, the method of setting parameters by experiment depends on the engineering experience of technicians and takes a long time The parameter tuning of double PID controllers could be treated as a practical multi-optimization problem. The swarm-based metaheuristics algorithms could approach optimal solutions by imitating the collective intelligence of social behavior. The representative algorithms are GA (Genetic Algorithm), PSO (Particle Swarm Optimization), ABC (Artificial Bee Colony), GWO (Grey Wolf Algorithm), ant colony optimization, and cuckoo search. The above metaheuristics algorithms and newly developed methods have been applied to solve reliability-based design optimization in mechanical engineering. Panagant N investigated the comparative performance of new and established multi-objective metaheuristics when solving truss optimization problems. Yildiz A R used the hybrid Harris hawks simulated annealing algorithm to optimize design parameters for highway guardrail systems. Besides, metaheuristics algorithms are also applied to the optimal design of planetary gear train, aerial vehicle, automobile components, and machining parameters of milling operations.

SYSTEM OVERVIEW AND ARCHITECTURE

(i) System description- The PML prototype mainly consists of a levitation and rotation system, as shown in Figure 1. The levitation system includes a PM (permanent magnet), a pair of permalloy cores, and a ferromagnetic target object. The diameter and thickness of the PM are 30 mm and 10 mm, respectively. Figure 2 shows magnetic flux in the levitation system. There is no flux passing through the target object at 0°. When the diametrically magnetized PM rotates to a certain angle, a part of magnetic flux flows through the target object, providing an attractive force. The magnetic force increases with the increase of rotational angle and reaches the maximum when the rotational angle of PM is 90°. At the initial state, the magnetic force is approximately zero. Therefore, it avoids the adhere problem that traditional PML system cannot return to equilibrium position by self-regulation once the levitated target contacts with the PM or cores.

(ii) The dynamic model of permanent magnetic levitation system- In the PML system, the magnetic flux between the target object and the permalloy core will generate an attractive force. Meanwhile, the magnetic force between the PM and the permalloy core provides magnetic torque when rotating the PM. The mathematical model of magnetic force and the magnetic torque are established according to the equivalent magnetic circuit method and the principle of virtual work. When structural dimensions of the prototype are determined, the attractive force and magnetic torque are both related to air gap length and rotational angle

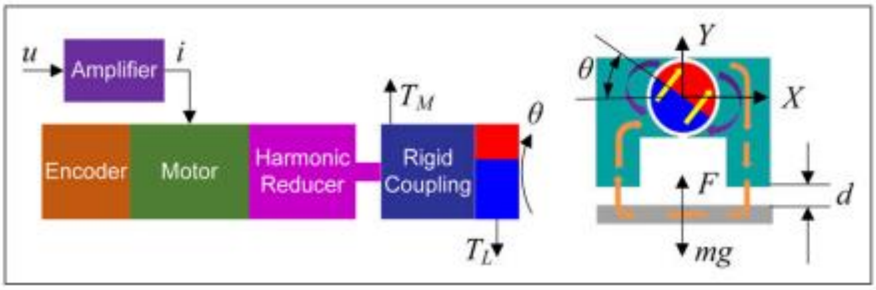

Figure 1- Model diagram of permanent magnetic levitation system

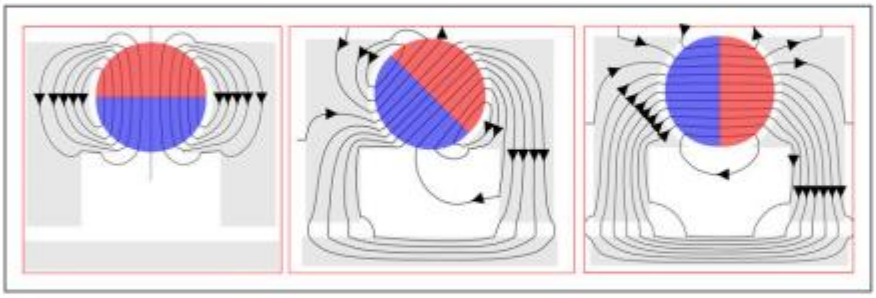

Figure 2- Diagram of magnetic flux in the levitation system

(iii) Design of control strategy- In the PML system, the ferromagnetic object is levitated when the magnetic force balances the gravity. The magnetic force relates to the air gap length and the rotation angle. When air gap control is applied only, the system cannot achieve expected stability performance. There is a minor angle adjustment near the equilibrium position due to the absence of active control for the angle.

(iv) Cascade control strategy- The cascade control strategy is proposed based on changing the connection mode of two controllers. The inner loop is for the rotational angle of the PM, which is driven by the rotary actuator, while the outer loop is for air gap length determined by force balance state. The input of the outer loop controller is the air gap error, and the output control signal is solved as angle compensation and transmitted to the inner loop.

PARAMETER TUNING WITH I-PSO

The PSO will randomly generate a particle swarm in the feasible solution space, and each particle represents a possible solution. The motion of each particle is represented by position, velocity. defines the j^{th} particle using the PID controller parameters.

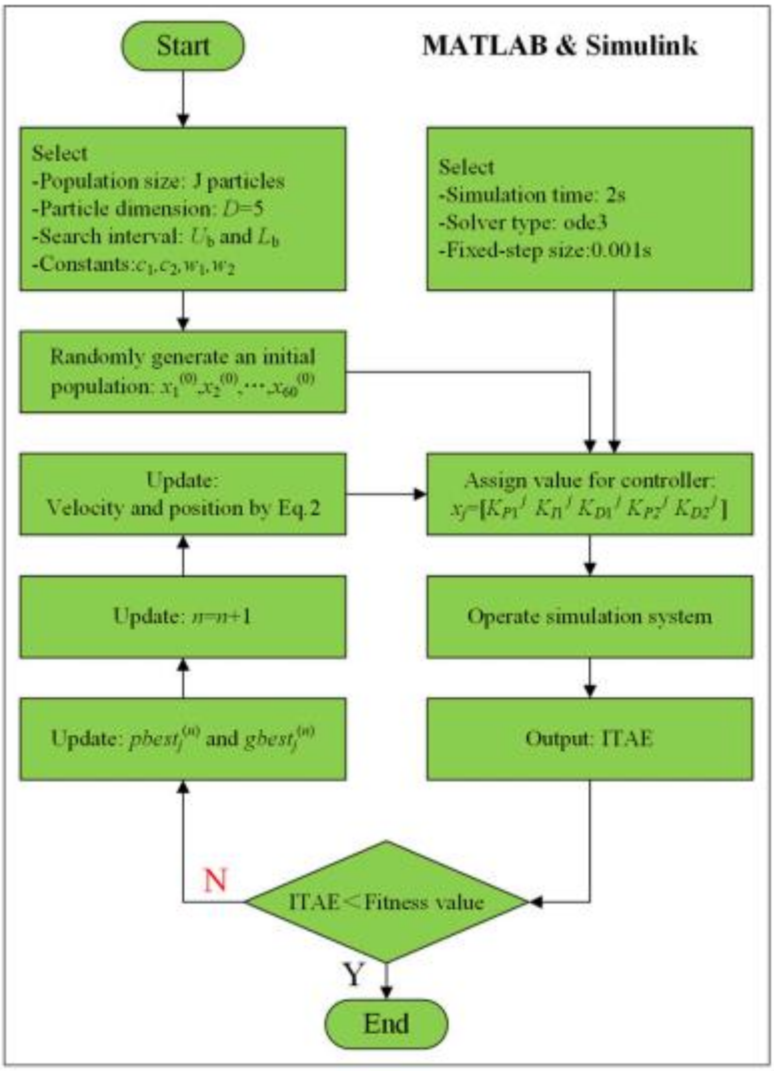

Figure 3- The flowchart of particle swarm optimization tuning proportional-integral-derivative controller

TEST SYSTEM RECOMMENDED

PID controller uses feedback control mechanism, in this mechanism the difference between the obtained variable and the desired set value is calculated. The difference can be minimized by using PID controller using feedback control system design. Gain of three basic controllers; proportional, derivative and integral is adjusted to get desired output response. Block diagram of the system is shown in the Figure 4. Without any compensator the response of system will be unstable. Controller design is necessary to make system stable and to achieve the required output response. Proportional-Derivative (PD) control is used for stabilization of the system, but it contains a little steady state error. Steady state error can be removed by adding Integral control is added [15]. Design of PID controller is considered to achieve the required transient response using MATLAB tools. Physical realization of feedback Sensor, actuator and design of feedback controller is explained below.

(i) Feedback Sensor- Light Emitting Diode (LED), Infrared (IR) sensor and photo detectors are used to detect the actual position of object. Detection ranges are limited, it can be around 20-30 mm beneath the poles of electromagnet. Beyond these limits, the sensor is not able to detect the correct position of the object. Surrounded ambient light may cause false detection when wide distances are involves. Proper covering of sensor can reduce this effect.

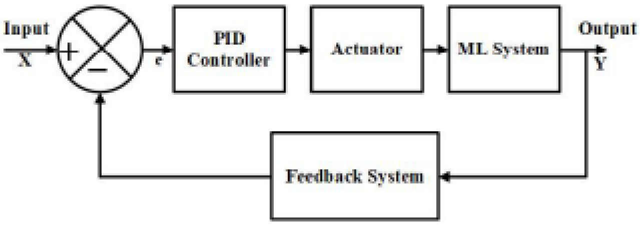

Figure 4 - Feedback control system

(ii) Actuator- Actuator is used to control the amount current passing through electromagnet with respect to applied control signal. If a small change occurs in applied voltage of the controller, input terminal can produce a very large current change in electromagnet. Figure 5, shows the basic model of an actuator.

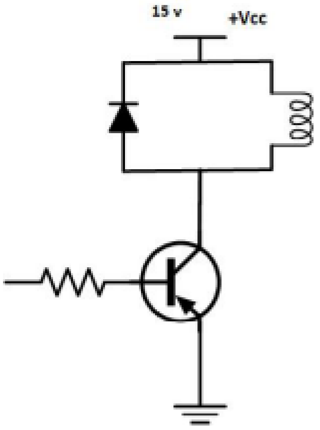

Figure 5-Circuit Model of actuator

CONCLUSION

A double PID control approach for a PML system made up of two connected second-order subsystems is presented in this work. Parameter tuning for the twofold control strategy is realized by an improved PSO approach with non-linear changing inertia weight. Both the cascade and parallel PD-PD strategies have outstanding dynamic performance. The relative setting times are 0.08 and 0.12 seconds. Levitation with zero static-state error might be achieved by the parallel PID-PD and cascade PID-PD; nevertheless, overshoot and response time are more important than double PD control. For vibration isolation in the future, the double PD control PML system that is being suggested offers an option. If the dynamic performance can be enhanced, cascade PID-PD control for precise placement will be possible.

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