A comparative study of stabilizing control of a planer electromagnetic levitation using PID and LQR controllers

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Abstract

Magnetic levitation is a technique to suspend an object without any mechanical support. The main objective of this study is to demonstrate stabilized closed loop control of 1-DOF Maglev experimentally using real-time control simulink feature of (SIMLAB) microcontroller. Proportional Integral Derivative (PID) and Linear Quadratic Regulator (LQR) controllers are employed to examine the stability performance of the Maglev control system under effect of unbalanced change of load and wave signal on Maglev plane. The effect of unbalanced change of applied load on single point, line and plane are presented. Furthermore, in order to study the effect of sudden change in input signal, the input of wave signal has been applied on all points of the prototype maglev plate simultaneously. The results of pulse width modulation (PWM) reveal that the control system using LQR controller provides faster response to adjust the levitated plane comparing to PID controller. Moreover, the air gap distance that controlled using PID modulation (PWM) reveals that the control system using LQR controller provides faster response to adjust the levitated plane comparing to PID controller. Additionally, LQR controller is rather stable with little oscillation. Meanwhile, LQR controller provided more stability and homogeneous response.

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Introduction

Magnetic levitation or maglev is the suspension of an object with the help of magnets, without any physical contact. The purpose of doing so is to reduce maintenance cost and improve efficiency of systems [1]. Compared with traditional wheel-on-rail transportation systems, maglev systems promise reduced maintenance costs, less noise, much higher speeds and greater acceleration capacity without compromising safety and ride comfort. Especially electromagnetic suspension (EMS) maglev has appeared as the solution to the speed limit problem. It is well-known that EMS is inherently unstable, highly nonlinear and time-varying. Consequently active feedback control algorithms are needed to stabilize the system as suggested by [2,3].

The stabilization of the Quanser magnetic levitation system which consists of a levitated ball has been investigated by Kumar et al. [4], where the mathematical model of the system is developed, linearized, and then LQR based PID controller was implemented. While, a novel second-order sliding mode controller has been studied to serve the electromagnetic levitation grip control [5]. The results showed that the system achieved a faster response and strong robustness using slide model surface compared with traditional slide model and PID system control. Nevertheless, a comparative study of control system operations based on peak overshoot, rise time and settling time using PID, FUZZY and LQR control system has been achieved [6]. The systems implemented in real time using MATLAB software and the results proved that FUZZY control system provided more stable system followed by LQR controller. The restricted levitation gap causes critical problem of very high cost of construction of railroads. The railroads should be uniform unless the rough guide-way would evade levitation area and finally it causes severe obstruction to maglev operation. The levitation gap of the German high-speed Maglev (Transrapid 07) is 8–10 mm [7]. Furthermore, the uncertain disturbances that may occur in any maglev system has been examined [8]. Therefore, a self-tuning control for maglev systems for unknown mass variation was designed. The sensors employed in the research were inductive gap sensor, hall sensor for current measurement and an accelerometer to gauge the disturbances due to uncertain forces like impulse force. A nonlinear electromagnetic suspension system with single-axis was controlled based on nonlinear feedback linearizing technique [9], where the study indicated that the feedback linearization control supplies a wide variation of operation point comparing with the linear system. For a one-degree-of-freedom levitation system parameter estimation technique is employed to develop system parametric model [10]. The main purpose of using this technique is to make the output of the system independent of duty cycle and air gap and this lead to enhance the dynamic performance of the system. The results showed that a faster response and strong robustness using slide model surface compared with traditional slide model and PID system control. Nevertheless, a comparative study of control system operations based on peak overshoot, rise time and settling time using PID, FUZZY and LQR control system has been achieved [6]. The systems implemented in real time using MATLAB software and the results proved that FUZZY control system provided more stable system followed by LQR controller. The restricted levitation gap causes critical problem of very high cost of construction of railroads. The railroads should be uniform unless the rough guide-way would evade levitation area and finally it causes severe obstruction to maglev operation. The levitation gap of the German high-speed Maglev (Transrapid 07) is 8–10 mm [7]. Furthermore, the uncertain disturbances that may occur in any maglev system has been examined [8]. Therefore, a self-tuning control for maglev systems for unknown mass variation was designed. The sensors employed in the research were inductive gap sensor, hall sensor for current measurement and an accelerometer to gauge the disturbances due to uncertain forces like impulse force. A nonlinear electromagnetic suspension system with single-axis was controlled based on nonlinear feedback linearizing technique [9], where the study indicated that the feedback linearization control supplies a wide variation of operation point comparing with the linear system. For a one-degree-of-freedom levitation system parameter estimation technique is employed to develop system parametric model [10]. The main purpose of using this technique is to make the output of the system independent of duty cycle and air gap and this lead to enhance the dynamic performance of the system.
characteristics of the system. Nevertheless, Muhammad et al. [11] examined a one degree-of freedom electromagnetic levitation of a pivoted-free ferromagnetic rigid beam (PFB). The stabilizing of an open loop unstable PFB between the two electromagnets that were mounted above and below PFB with equal air gap was considered. A stabilizing classical (PID) controller was designed and implemented in real-time on a 1-DOF PFB test rig. The controller exhibits robust and effective disturbance rejection characteristics. Additionally, the actuator successfully achieving all the desired performance specification. Moreover, multi degree of freedom levitation system has been investigated with nonlinear and strong coupling multivariable control system [12]. The linearization and decoupling of the levitation force was the main objective to achieve control with high speed and high precision. The results showed that the employed control system provide high-speed response compared with given reference.

However, to the best of authors’ knowledge, little attention was paid to investigate the stability control of planar electromagnetic levitation model with four electromagnetic coils. As aforementioned, there are no sufficient information for closed loop control of 1-DOF Maglev under effect of unbalanced change of load and wave signal. Therefore, in this investigation, the main objective is to demonstrate stabilized closed loop control of 1-DOF Maglev experimentally. Where four parallel electromagnetic coils will be mounted below a fixed surface and above a free plane which tied with four magnetic disks, hence the weight of the plane with magnetic disks is 120 g. The plane enables movement in the vertical plane under the influence of electromagnets. A position sensor of (Allegro A1324 linear hall-effect sensor) is fixed at the bottom of the electromagnetic coil and used to detect the air gap distance. Therefore, the sensor operation principle is detecting the coils magnetic field, where this mechanism depends on the intensity of the magnetic field. Therefore, due to small amount of the generated output voltage, the hall elements combine the required electronics to increase the voltage amount and create the hall-effect sensor. However, the small region condition for hall-effect switch is the reason behind choosing (Allegro A1324 linear hall-effect sensor) [13].

The experimental setup as shown in Fig. 1 consists of four electromagnetic coils working together through a control logic in a differential mode. This configuration is amenable for design of a feedback control mechanism employing linear control theory. The system is built with proportional-integral-derivative controller (PID), then the same system is built with linear quadratic regulator controller (LQR). This is done in order to compare the ability of different control methods for building a suitable system. An important aspect of this study is to demonstrate stabilized closed loop control of 1-DOF Maglev through experiments. This is can be achieved by utilizing real-time control feature of simulink which supports the microcontroller (SIMLAB) employed here. Feedback control for this system is designed utilizing linear control theory [14,15]. The overall architecture comprising of data acquisition hardware (SIMLAB) sensor, electromagnetic coils and real-time operating environment is shown in Fig. 2. The (SIMLAB) platform is a versatile, complete and low-cost real-time package with 15.2 kHz sampling rates.

Furthermore, (SIMLAB) is fully integrated into MATLAB and simulink with highly intuitive usage. A conversion of displacement sensor signal to digitized value is first carried out using analog to digital (A/D) converter. The stability controller processed digitized value and send it through computer to digital to analog (D/A) port of the microcontroller. Microcontroller produces control current corresponding to coil magnetic field. The generated PWM value is then sent to current controller to produce corrective control current i.e., electromagnetic force. Therefore, since the load is varied and position has to be maintained, then feedback control will adjust the strength of the magnetic field to hold the suspended object in the desired position. The block diagram representation of overall control system is illustrated in Fig. 3, where the $X'$ is the desired output.

![Fig. 1. Schematic diagram of experimental setup.](image)
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