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Conference Paper · July 2019

DOI: 10.1109/ICECCE47252.2019.8940711

8 authors, including:

Ali Abbas
University of Al-Qadisiyah

Syed Ali Zulqadar
Soil and Water Testing Laboratory for Research, Bahawalpur

Syed Zulqadar Hassan
Chongqing University

Abdullah Mughees
National University of Computer and Emerging Sciences

Proc. of the 1st International Conference on Electrical, Communication and Computer Engineering (ICECCE)
24-25 July 2019, Swat, Pakistan

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Ali Abbas, Syed Zulqadar Hassan*,
Tasawar Murtaza, Abduallah Mughees
Department of Electrical Engineering
National University of Computer and Emerging Sciences
Chiniot-Faisalabad Campus, 35400 Chiniot, Pakistan
nfc.aliabbas@gmail.com, f180861@nu.edu.pk,
abdullahmughees@ieee.org

Tariq Kamal
Department of Electrical and Electronics Engineering
Sakarya University, Faculty of Engineering, 54050
Serdivan/Sakarya, Turkey
tariq.kamal.pk@ieee.org

Muhammad Abbas Khan
Department of Electrical Engineering
Balochistan University of Information Technology
& Engineering Management Sciences, Airport Road Baleli
87650 Quetta, Balochistan, Pakistan
engineerabbaskhan111@gmail.com

Q. D. Memon
Department of Electrical Engineering
NFC IEFR Faisalabad
qamaruddin2k2@gmail.com

***Abstract*—Magnetic levitation systems find their applications in many systems and are very have practical importance. Because of their practical applications such systems are gaining much attraction. This research paper dealing with the design and implementation for controlling magnetic levitation system. A non-linear behavior model representation for Magnetic Levitation System (MLS) is designed initially using Simulink as a modeling tool. The system considered consists of a ferromagnetic ball having some specific amount of mass. The object is suspended in the air gap using the force exerted by magnetic field whose strength can be controlled through applied voltage – known as the Magnetic Levitation System. This levitation system can be used to adjust the position and to lift the ball in air gap. These systems are highly nonlinear and that is why are highly unstable. It is therefore required that a system must be there to achieve linearization and highly precise positioning of the ferromagnetic ball. For that purpose, a Proportional-Integral-Derivative (PID) controller and state space analysis technique is adopted to design a linear feedback control system. In this paper the mathematical modeling and simulations have been done on a magnetic levitation system that is dynamically non-linear. State space modeling has been done to get linearized output response and precise position of object.**

***Index Terms*—Magnetic Levitation system, Feedback Controller, PID Controller, linearization/non-linearity, stability.**

I. Introduction

Electro-mechanical system used to suspend an object in free space without using any physical support is called Magnetic levitation system. These systems are gaining attention and are becoming famous because of their contactless and frictionless properties. These properties make them are beneficial as losses due to friction and mechanical movements can be avoided [1]. These properties increase the efficiency, reduces mechanical wear out and maintenance costs, that results in the much accurate position control of objects with effective cost and lower energy losses. The magnetic levitation systems can be used efficiently in various industrial applications [2].These systems are practically much important in many engineering system applications like high-speed passenger trains, magnetic suspension systems, frictionless magnetic bearings, wind tunnels levitation and isolation of vibrational sensitive machinery [3].

The maglev systems are classified according to the types of magnetic force and can be either attractive behavior or repulsive magnetic levitation systems. Such kinds of systems usually show a nonlinear behavior and are unstable open-loop systems. Complex and highly nonlinear differential equations are used to describe the behavior of such systems. These systems have highly nonlinear behavior and the mathematical equations add additional difficulties during the designing of systems. It is therefore, required to design a feedback controller having high efficiency so that they can be used to regulate the position of levitated object [4].

Linearization can be done using different techniques, usually two approaches have been reported in literature for better performance. Gain scheduling is one of the approaches; the nonlinear behavior of parameters like force and current or magnetic suspension airgap can be linearized successively for various operating conditions. Such types of controllers are designed specifically to get linearization of each of these operating conditions [5]. These gain scheduling techniques are in use since years back for dealing control problems of aircrafts. Any small change in flight condition can cause a severe instability in output of controller's gain. To obtain better tracking performance over long travel ranges, the operating ranges of gain scheduling controllers are required to be broken into large number of short intervals and are then stored in gain lookup tables of controllers [6].

An alternative approach is the feedback linearization approach [7]. In this technique feedback linearization approach, complete description is used for nonlinear electromagnetic

*Corresponding Author: Email: zulqadar.hassan@nu.edu.pk

field is used that gives consistent performance independent of air gap. Feedback linearization is a topic of most concern and many efforts has been done by researchers to find the ultimate solution [8]. Many of them has been implemented for successful control of flight control systems. To control the MLS different feedback linearization techniques have developed and implemented [9]. For simplicity PID controllers can also be used for design of feedback systems. Since many years, research has been done to find the methods that can improve the performance of PID against the robustness. These methods can be Ziegler-Nichols method and Coon-Cohen method, etc. [10]. These methods have limitation and correct auto tuning is not possible because they carry a limited information of system behavior. Therefore, it is required to develop control systems for controlling system's robustness. Model Reference Adaptive Control (MRAC) approach is used for auto tuning of PID control parameters [11], [12]. However, such techniques are only limited to nonlinear systems having first order and cannot be use to control nonlinear systems of higher. The highly nonlinear system behavior, uncertainty of parameters and systems instability are the factors that makes it difficult to accurately control the systems having higher orders via MRAC technique [13].

In this research work a D.C electromagnet is used to levitate the object. Also, we can use permanent type magnets for controlling the position of object.it is also required that there must have a mechanism to control the strength of magnetic force and it can be done using electromagnets. That's why mostly electromagnets are used for controlling the levitation of the Maglev system applications.

This paper consists of seven sections; Section-II describes a typical magnetic levitation system. Third Section describes dynamics and modeling (mechanical and mathematical) of MLS. Section IV is about the PID controller. section V describes the physical realization of the system. Section VI shows the results of simulations for non-linear and linearized system. Section VII contains the conclusion of entire work.

II. MLS Dynamics and Modeling

Figure 1 represents a typical magnetic levitation system. It consists of a suspended mass i.e. ferromagnetic ball that is levitated in the vicinity of a magnetic field controlled by voltage. It comprises of IR sensor used to sense the position, an actuator for switching control and a supply system.

Electromagnet, is the main component it component it has an I- shape. To make system simpler a round face bolt is used for core as shown in Figure 2. For large systems, materials having High permeability or cast iron is used to design the core. Such type of cores provides more magnetic strength and improved efficiency [11]. The other factor that can improve the performance is the stacking of the wire, good stacking will improve the performance greatly. Good stacking is used to concentrate the more flux under the poles.

Electromagnetic force is dependent upon the current passing through the magnetic coil it can be calculated using

$$V(t) = V_R + V_L \tag{1}$$

Fig. 1. A Typical Magnetic Levitation System [14]

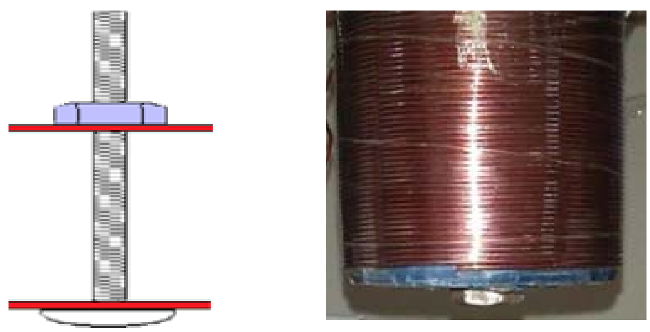

Fig. 2. (a) Core design (b) Stacking of wire

$$V(t) = R_i + \frac{d[L(x)i]}{dt} \tag{2}$$

where,
V=voltage Applied
i = Current through Coil
R = Resistance of Coil
Object becomes suspended in the air when the net force on the object is zero [15]–[17]. That is when gravitational fore becomes equal to the applied force.

$$F_{net} = F_{gravity} + F_{em} \tag{3}$$

$$m\frac{d^2x}{dt^2} = mg - f(x,i) \tag{4}$$

where,
m = Mass of object
k = Ponstant of magnetic force
x = Position of object

$g =$ Gravitational constant

$$\begin{vmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \end{vmatrix} = \begin{vmatrix} x_2 \\ g - \frac{kx_3^2}{mx_2^1} \\ -\frac{Rx_3}{L} + \frac{2kx_2x_3}{Lx_1^2} \end{vmatrix} \begin{vmatrix} x_1 \\ x_2 \\ x_3 \end{vmatrix} + \begin{vmatrix} 0 \\ 0 \\ \frac{1}{L} \end{vmatrix} \tag{5}$$

$$Y = \begin{vmatrix} x_1 \end{vmatrix} \begin{vmatrix} x_1 \\ x_2 \\ x_3 \end{vmatrix} = \begin{vmatrix} u \end{vmatrix} \tag{6}$$

III. Proposed Control System

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 3.

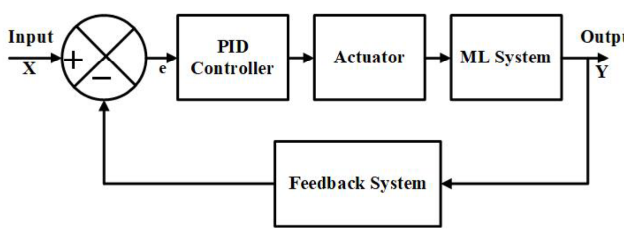

Fig. 3. Feedback control system

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.

A. Magnetic Levitation control Model

Figure 4, represents the modelling and structure of a Magnetic Levitation System.

B. Feedback Sensor

Figure 5 shows the basic structure of feedback sensors. 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.

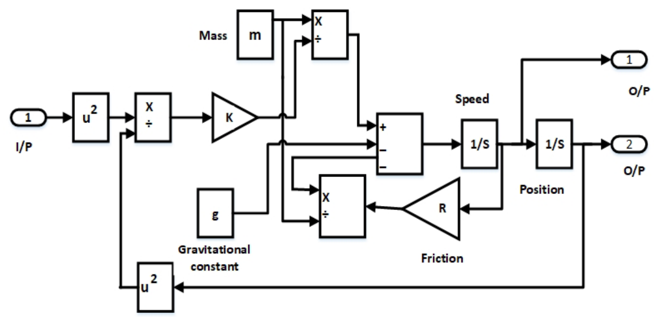

Fig. 4. Magnetic Levitation Model

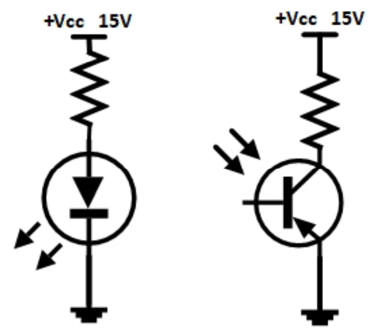

Fig. 5. (a) Light Emitting Diode (b) Photo detector

C. 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 6, shows the basic model of an actuator.

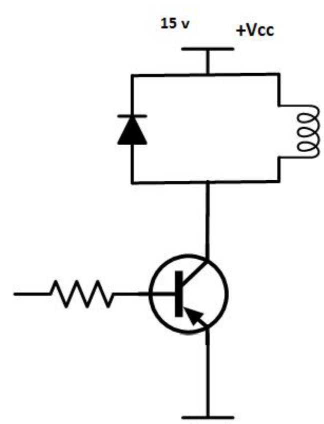

Fig. 6. Circuit Model of actuator

IV. Simulation Results and Discussion

Simulations results of non-linear are shown in Figure 7. It shows the position of object with respect to time for a non-linear system. The mean position of object is at 0.7, after 4 seconds the object has got the mean position the system has stopped levitating and it gets levitated as shown below.

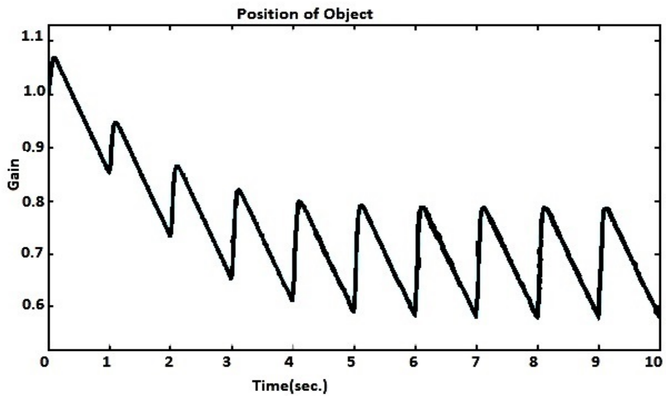

Fig. 7. Position of object with respect to time for a non-linear system

Table I represents the physical parameters of a magnetic levitation system.

TABLE I
PARAMETERS USED FOR DESIGNING MLS

Parameters	Values
m	0.6 Kg
R	18 Ω
L	0.16 H
g	9.8 ms^{-2}
k	0.08
i	1.4 A

Validation of the parameters calculated can be done by comparing the values of parameters with Table II [18].

TABLE II
PARAMETERS USED FOR DESIGNING MLS

Parameters	Values
m	0.04 Kg
R	1.2 Ω
L	0.0092 H
g	9.8 ms^{-2}
k	0.0001
X_{01}	0.012 m
X_{02}	0 ms^{-1}
X_{03}	0.75 A

The linearization of the system using state space equations can be done using matrices.

$$A = \begin{vmatrix} 0 & 1 & 0 \\ \frac{kx_3^{*2}}{mx_1^{*3}} & 0 & \frac{-2kx_3^*}{mx_1^{*2}} \\ 0 & \frac{2kx_3^*}{Lx_1^{*2}} & -\frac{R}{L} \end{vmatrix} B = \begin{vmatrix} 0 \\ 0 \\ \frac{1}{L} \end{vmatrix} C = \begin{vmatrix} 1 & 0 & 0 \end{vmatrix} D = \begin{vmatrix} 0 \end{vmatrix} \tag{7}$$

Using the vales of calculated parameters from Table I [A], [B], [C], [D] matrices can be calculated.

$$A = \begin{vmatrix} 0 & 1 & 0 \\ 272.25 & 0 & -69.583 \\ 0 & 7.821 & -111.5 \end{vmatrix} B = \begin{vmatrix} 0 \\ 0 \\ 6.25 \end{vmatrix} C = \begin{vmatrix} 1 & 0 & 0 \end{vmatrix} \tag{8}$$

$$D = \begin{vmatrix} 0 \end{vmatrix}$$

Using state space block of Simulink and putting the parameters linear response of the system can be found and shown in Figure 8.

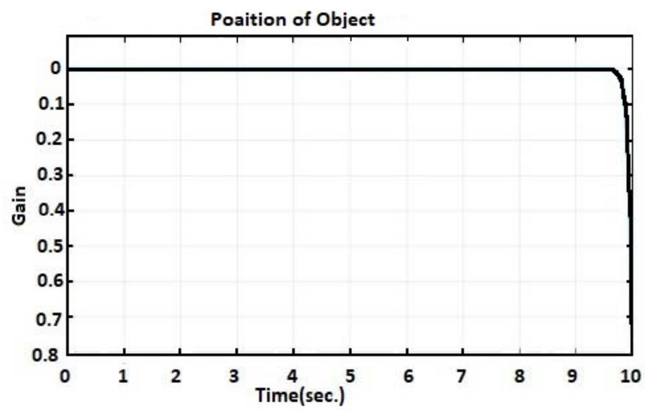

Fig. 8. Linear MLS model Simulation

V. CONCLUSION

This paper describes feedback control system implemented using PID Controller for adjusting the position of the metallic ball in free space. Analysis was done on a nonlinear and dynamically unstable magnetic levitation system in this research paper. To compensate for the instability and to done linearization modeling was done using state space model. Simulations were done to check the non-linear and linear behavior of the system. The modelling of system was done using the state space equations and state space variables were calculated to form the system matrices. The obtained modified matrices of the system were used to get the linear response and simulation results were observed. From the position vs. time plots it was observed that the position of metal object can be adjusted more precisely by linearization of feedback control system for Magnetic Levitation System.

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