Development of Magnetic Levitation System

Rajalakshmy .P, Subha Hency Jose .P, Thilagavathy.B

Abstract: ***A Magnetic Levitation System is considered to be a classical control problem due to its inherent non-linearity which makes it a bench mark to test the efficacy of any control algorithm. Hence, it is highly challenging to design a control system to maintain the system stable. Applications of these systems range from high speed rail transportation to various industrial applications like magnetically levitated wind turbines. Based on an extensive literature survey of the existing methodologies adopted to control such systems, an attempt to develop an embedded implementation of the system is proposed. In order to levitate an object of desired mass and at a desired distance an electromagnet with ample magnetizing force is designed. A driver board is used to drive current to the electromagnet based on the closed-loop feedback signal from a Hall Effect sensor through a microcontroller so as to levitate the object at a desired distance. The system is further stabilized using a lead compensator. Also a PID controller is implemented as an alternate method for achieving levitation.***

Keywords: Magnetic levitation, Hall Effect Sensor, PID Controller.

I. INTRODUCTION

The technology of Magnetic Levitation has been experimented by researchers all over the globe for the past thirty decades with great vigour. Magnetism has been an integral part of the earth since its inception. It is believed and has been proved by many a scientist that the phenomena of gravity and the earths spin exist due the magnetism property. Almost levitating systems primarily involve generation of magnetic forces, the basic principle of which is Faraday's Law. In order to achieve a stable levitating magnetic system, it is required to vary the magnetic field strength by changing the current. Magnetic Levitation Systems are increasingly gaining importance due to their practical applications in various engineering fields. The objective of the proposed system is to develop an electromagnetic levitation system and to ensure its stable operation by designing a PID controller with a compensator circuit.

II. LITERATURE REVIEW

An extensive literature review on the proposed system has been presented in this section. A comparator based analog electromagnetic levitation system and the circuit employed that uses a potentiometer to vary set point has been discussed. [1]. A non-linear dynamic model of a magnetic levitation system is developed and state space controllers are proposed. An elaborate research on the usage of Matlab as a programming tool for real time simulations is discussed. A comparative study of the performance of a Fuzzy Logic Controller and a Linear Quadratic Regulator (LQR) Controller is presented.[4]

III. METHODOLOGY

The experimental set up consists of a ferromagnetic object suspended in a magnetic field, generated by an electromagnet. The position of the object is tracked by a Hall Effect sensor that provides feedback to adjust the current to the electromagnetic field so as to maintain the object in a stable position. The representation of the proposed system is shown in Fig 1.

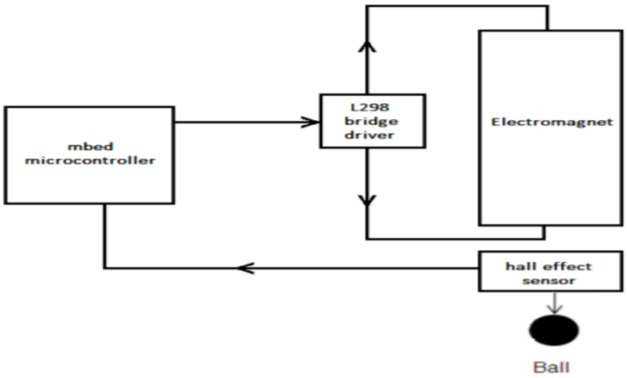

Fig. 1 Representation of Magnetic Levitation System

An Electromagnet with a high ampere turn value has been fabricated for the proposed system. This allows the possibility of changing the weight of the object and the levitation distance. The mbed LPC1768 acts as the controller that incorporates the PID controller. The L298 Bridge Board is used to drive a high current to the electromagnet.

Design of Electromagnet Coil

The primary objective in designing an electromagnet is to generate sufficient lifting power. In this work, cast steel has been selected since it has a narrow loop area which gives it a high permeability and fairly good coercivity, thus making it a suitable choice for the core of an electromagnet. Once, the core of the electromagnet is specified, the core area (shape), diameter, and the required length of the winding are then selected by estimating or calculating the amount of current expected to pass through when lifting the required load.

The various terms connected with circular coils are explained below:

Revised Manuscript Received on February 05, 2019.

Rajalakshmy .P, Assistant Professor, Department of Instrumentation Engineering, Karunya Institute of Technology and Sciences, Coimbatore,

Subha Hency Jose .P, Head of the Department, Department of Instrumentation Engineering, Karunya Institute of Technology and Sciences, Coimbatore,

Thilagavathy.B, Assistant Professor, Department of Instrumentation Engineering, Karunya Institute of Technology and Sciences, Coimbatore,

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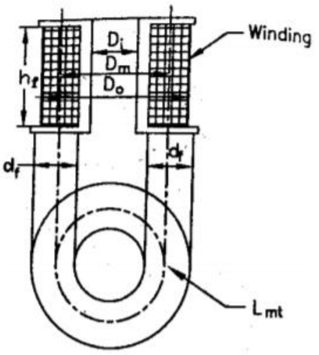

Fig.2. Electromagnet Coil

AT – mmf per coil, A
V - Terminal Voltage , V
ρ - Resistivity ohm/m/mm^2
δ - Current Density
L_{mt} - Length of Mean Turn, m
I - Current
T - No. of Turns
R - Resistance in ohms
A - Area of conductor mm^2

The Design Specifications of the Electromagnet are:

Area of Pole Face = 1.53 cm^2
Inside diameter of coil D_i = 8 mm
Mean Diameter D_m = $(D_i + D_o)/2$
= 18mm
Outside Diameter D_o = $D_i + 2D_i$
= 28 mm
Depth of winding d_f = $(D_o - D_i)/2$
= 10 mm
Axial length of coil h_f = 60 mm
Length of Mean Turn L_{mt}` = 56.5 mm

Design specifications of the electromagnet:

Let's assume,

Mass of object to be balanced = 30 g = 0.030 kg

Levitation distance (l_g) = 3 cm = 0.03 m

$$F = 0.051 \frac{B^2 A}{\mu_O} \text{ kg}$$

$$0.030 = \frac{0.051 \times B^2 \times 1.53 \times 10^{-4}}{1.265 \times 10^{-6}}$$

$$B^2 = \frac{0.030 \times 1.265 \times 10^{-6}}{0.051 \times 1.53 \times 10^{-4}} = 0.00482$$

$$B = 0.0694 \text{ Wb}/m^2 \text{ (Tesla)}$$

Mmf required for air = 80000 Blg

= 800000 × 0.0694 ×0.030

= 1665 AT

Mmf tolerance for iron parts = 0.1 × 1665

= 166 AT

Total mmf = 1831 AT

If I = 0.7 A = 700 mA

$$T = \frac{1831}{0.7} = 2616 \text{ turns}$$

Implementation

The Hall Effect Sensor MH481 is chosen to detect the position of the ferromagnetic object since these sensors are found to accurately track minute changes in the magnetic flux density. The values observed while testing the Hall Effect Sensor MH481 for linearity is tabulated in Table 1.

Table. 1 Ball position Vs Output Voltage

S.NO.	BALL POSITION(mm)	OUTPUT VOLTAGE(v)
1	0	4.24
2	2	4.10
3	4	4.04
4	6	3.89
5	8	3.65
6	10	3.33
7	12	3.11
8	14	2.78
9	16	2.65
10	18	2.58
11	20	2.57
12	22	2.56
13	24	2.55
14	26	2.52
15	28	2.50
16	30	2.49
17	32	2.45
18	34	2.45
19	36	2.45
20	38	2.45
21	40	2.45
22	42	2.45
23	44	2.45
24	46	2.45
25	48	2.45
26	50	2.45

The L298 Dual Full Bridge Circuit acts as a current driver circuit to provide sufficient current to the electromagnet proportional to the controller output. The Pin diagram of the L298 Bridge Driver Circuit is represented in Fig.3.

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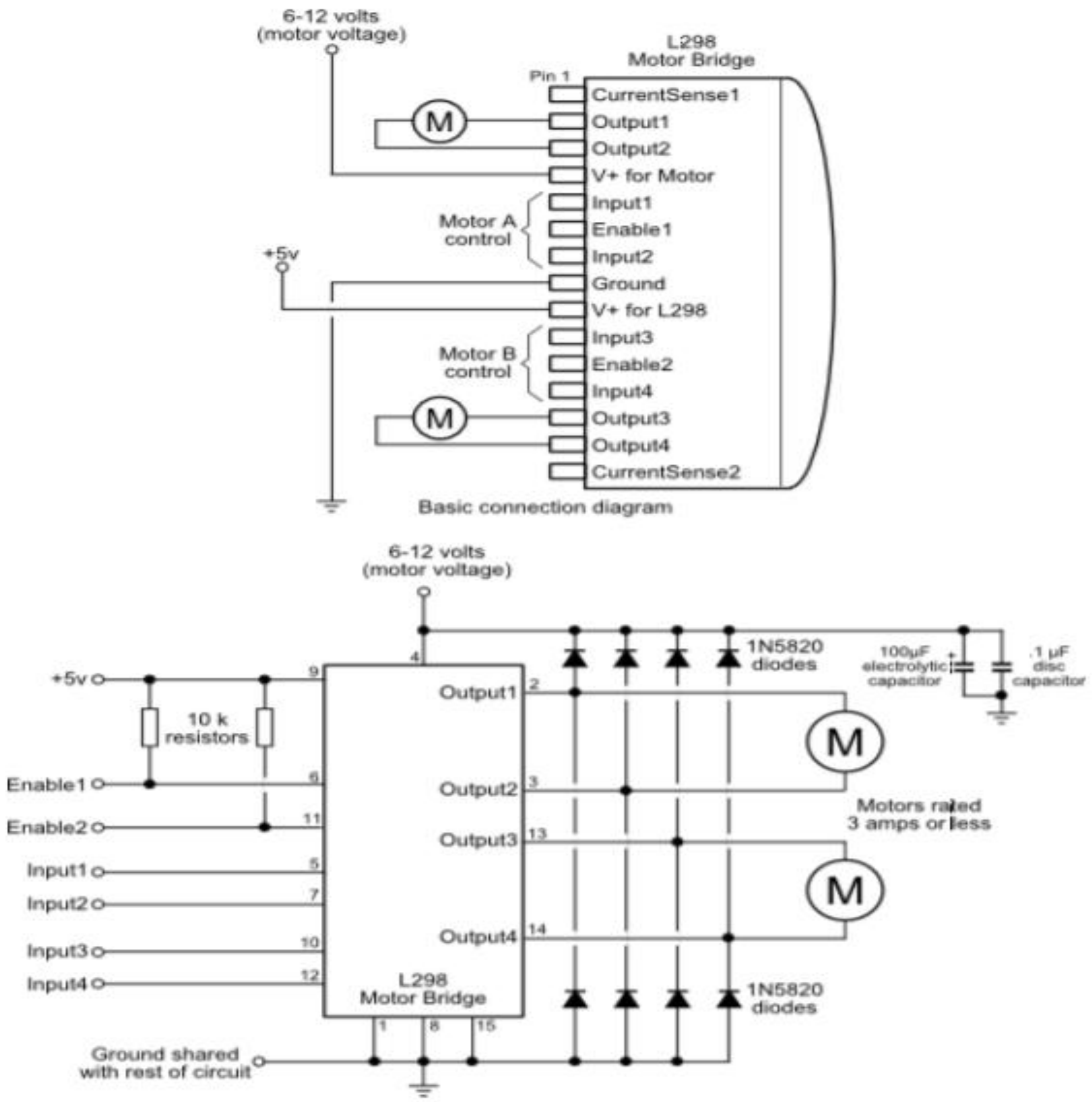

Fig. 3 Pin Diagram of L298 Bridge Driver

Lead Compensator

The output of the levitation circuit is unstable and the levitating object starts oscillating up and down and eventually falls or sticks to the bolt. While researching through methods to compensate for these oscillations a paper published by Adam Kumpf from MIT contained a clever solution for the problem. This circuit was used as a base to come up with a suitable compensation circuit to stabilize this system. Described below are the details of the methods employed in the paper to design the lead compensator. An adder has been incorporated as a sensor to provide feedback so that the system could be driven with an input and it can be characterized by its output. This was done by using an inverting adder that was built using one quarter of an operational amplifier in which one of the inputs was the voltage output from the Hall Effect sensor and the other was the voltage input used for testing. The system was excited by a low amplitude sinusoidal signal and the shift in gain and phase shift at the output were recorded.

The Real Time Environment Simulation techniques can be employed for future implementation [8]. It was observed that the phase of the output at the crossover frequency was slightly more than -180 degrees due to which the system is considered to be unstable.

If the phase margin at this frequency could be reduced by 2 degrees, it could gradually shift the system out of the control due to the sinusoidal amplitudes that exponentially increasing in nature.

The Compensator

The main cause for the unstable nature of the system is its negative phase margin. A lead compensator was implemented to drive the phase margin to the positive side and thereby increase the crossover frequency. In order to device the lead compensator, a 10kΩ resistor is associated in parallel with a 10uF capacitor followed by a 1kΩ resistor to ground.The main limitation is the attenuation factor. In order to cancel the effect of attenuation, a noninverting amplifier with a gain of 11 has been added to the output of the lead network. Additional unit of the LM348 OPAMP was used along with two more resistors to attain the anticipated gain. The compensator circuit is shown in fig.4.

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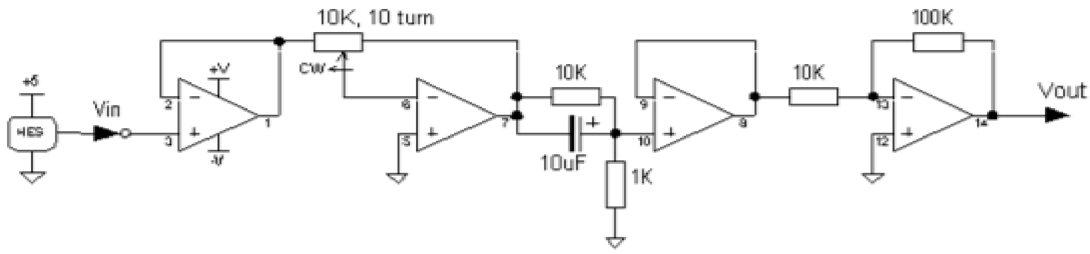

Fig. 4 Lead Compensator Design using Op-amp

IV. RESULTS AND DISCUSSION

According to the calculations made, a new electromagnet was designed with better magnetic characteristics like increased magneto motive force and magnetic flux density Also, the wire gauge value was changed to 28 SWG for the new coil so as to allow more current carrying capacity up to 0.5 A. Therefore by increasing the number of turns to 2800, its now possible to levitate an object of mass range 20-30g at a distance range of 1-2 cm. The table 2 below show the comparison of parameters of the two electromagnets and the variation in current for different voltage values.

Table. 2 Electromagnet Comparison

Parameter	Existing Electromagnet	Designed electromagnet
Magneto motive Force	432 AT	1200 AT
Magnetic Flux density (B)	0.05 T	0.07 T
Voltage (V)	10 V	20 V
Resistance (R)	60 Ohms	46 Ohms
Current (I)	0.16 A	0.42 A
No of turns	2700	2800
Wire Gauge	36 SWG	28 SWG

The designed electromagnet levitation system is able to levitate an object for a period of 2 hours and maintain the stability throughout using the ON-OFF control algorithm. The PID controller however can sustain levitation for a period of just a few seconds (10-20 s).

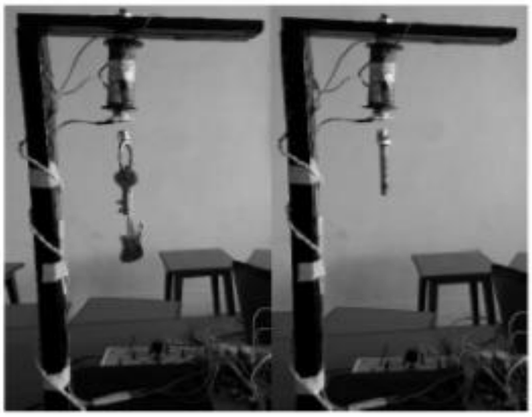

Fig. 4 Experimental Set up

V. CONCLUSION

An electromagnet with sufficient magnetizing force to levitate an object of up to 30 grams at a distance of about 1.5 cm was successfully designed. The driver circuit provides the required current to the electromagnet by the action of the pulse width modulation enable signal to the current driver based on the microcontroller output. The system proved to be unstable at the beginning and levitation of the object over a long duration of time was not possible. Therefore to stabilize the system a lead compensator was designed, implemented and the system was made stable for a longer period of time. The PID controller for automatically obtaining stabilized levitation is also implemented for different combinations of object mass and levitation distance. In the future the PID algorithm can be improved further by tuning the control parameters to sustain levitation for a longer duration.

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