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Magnetic Levitation Circuit System: An Experimental Study

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***Abstract*— This paper presents a fundamental levitation system in which hard magnetic material (permanent magnet or PM) is levitated in an air gap against the force of gravity. Although magnetic levitation systems are unstable and non-linear in nature therefore difficult to research, they are of interest in many applications. The levitation system basically consists of two parts: one is a fixed part in which an attractive force is produced, and the other is a movable part in which PM material is suspended in the air. The attractive force increases with a decreasing air gap and increases with increasing current in a stable, balanced system. Here, we present the experimental results of a balanced system with PM material (NdFeB) responding to direct current flux, and we focus on the relationship between the force, the air gap and the load line of the hard magnetic material. Optimal levitation is obtained with an optimal air gap by using the different load characteristics of hard magnetic material in a closed magnetic circuit and the results of the study are presented in detail. The study visualizes the relationship between theory, design and experimental verification, and the educational opportunities; therefore, it is highly suitable to encourage and motivate students to understand the effects of magnetic fields and magnetic theory.**

Keywords—Electromagnetism, Flux, Levitation, Hall Sensor, Material Science.

I. INTRODUCTION

Magnetic levitation systems and their applications (maglev transportation, magnetic bearings, vibration isolation etc.) have found wide-ranging implementation both in industry and in studies over the last decade. As a result, experimental studies and development of applications with magnetic levitation systems have been increased through a series of technical studies [1]-[3],[6]-[15]. However, theoretical calculations of performance have been limited by the complexities of nonlinear calculation [11]. Nevertheless, for the solution of nonlinear cases, a system model can be represented in a linear way around different operating points. In this study, the problem is solved by experimenting with a multi-position control system by considering the classical levitation electromagnetic conversion equations.

We can explain the implemented levitation system briefly in the following way: The attractive magnetic flux, or – in other words – the magnetic field force generated by a direct current (DC) source, is produced by a specific number of turns of wire in a coil surrounding the ferromagnetic material. When the moving object (ferromagnetic or PM material) is balanced by the opposing gravitational and magnetic field forces in the air, the effect is called levitation [1], [15]. Since there is no physical contact between the movable object and the fixed part of the system, there is no friction or loss associated with this technique; therefore, its application has been of increasing interest to various branches of industry. A levitation circuit produces a magnetic field force or magnetic flux to suspend an object in a desired position in the air. After experiments on levitation circuits by many researchers and lecturers, it has come to be understood that a levitation system is not a simple device [1]-[5]. When the air gap between the movable object and magnetic source is too long, the force of the magnetic field is inadequate to sustain the mass of the object. If it is placed too near to the magnetic source, the force of the magnetic field becomes very strong and the magnetic field can easily attract the object until it is in direct contact with the magnet [3] – [4]. As previously mentioned in brief, it is clear that a levitation device has a long transient regime. By controlling the current exerted on the object and developing a stabilizing controller, one can systematically measure the position of the mass and speed from the feedback parameters caused by the flux changes to favor a balanced position for a PM (NdFeB) sphere, as seen in Fig.1. Actually there are very few levitation systems using PMs, mostly because permanent magnets have not previously been very reliable in high-temperature environments, and their strength has been weak. Large magnets are required to provide sufficient levitation force. However, recent advances in high-energy rare earth permanent magnet technology has overcome these problems. These magnets, such as NdFeB magnets, usually have high residual induction and coercive force, and are very stable under higher working temperatures [14]. In this experiment, PM material has been preferred because it can supply a stronger attractive force compared to ferromagnetic materials.

A magnetic levitation system consists of a control panel which has two inputs and one output: voltage, current and position of the sphere, respectively, plus an electromagnetic unit on which a coil is mounted and controlled by the current. Here, a ferromagnetic material is used as an electromagnetic unit core. A Hall Effect sensor is attached with a plastic cover to the electromagnetic unit core to detect the position of the suspended object.

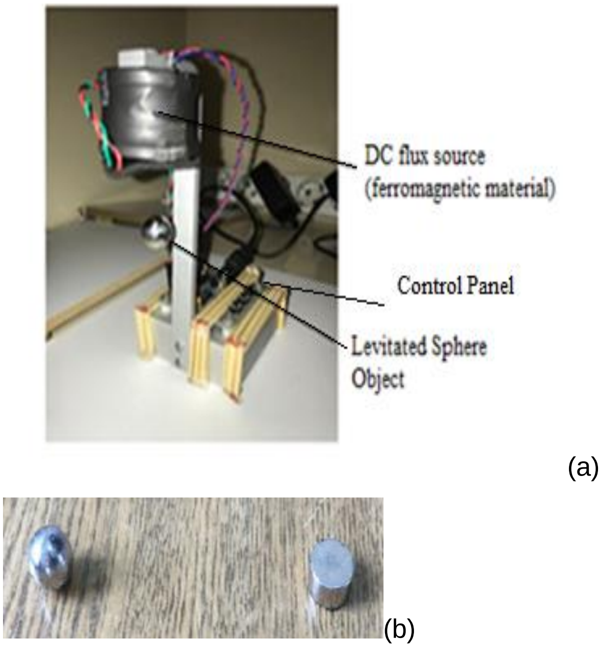

Fig.1 *Photograph of experimental magnetic levitation system (a) and PM materials (b).*

This paper is organized in the following way: The first part describes the problem in detail, by providing an explanation of the topic. The second part explains the mathematical model of the problem, while the third part is showing the experimental study and the results.

II. MAGNETIC LEVITATION SYSTEM DESCRIPTION

A. *Problem description*

This study mainly deals with the dynamic analysis of a magnetic levitation system; therefore, it is related to basic electromagnetism and the electromechanical conversion system. From this point of view, a magnetic levitation system experiment is very useful to show students the power of magnetism [4]-[6]. Also, underpinning this experimental study there is a strong link between control, magnetic circuits, power electronics and electromechanical energy conversion that encourages students to learn more complex subjects.

Fig. 2 shows a mechanical schematic diagram of the experiment. It shows a coil fixed on an L-shaped aluminum base, and with a Hall Effect sensor placed under the coil to detect the systematic flux changes. The distance is 0.12 m from the top of the L-shaped section to the base. The Hall Effect sensor is protected by a plastic cover to prevent damage to the sensor [7].

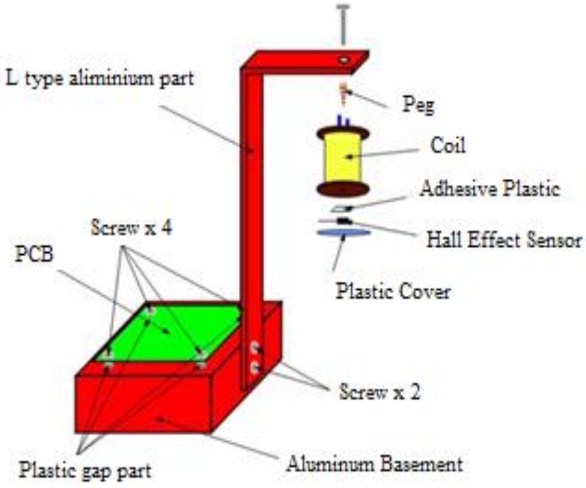

Fig.2 *Mechanical schematic diagram of levitation.*

Fig. 3 shows the control panel electronic circuit components. The input DC voltage is 7.5 V. This model contains a Hall Effect sensor, an LED, three switches, a micro-controller and an electromagnet (coil).

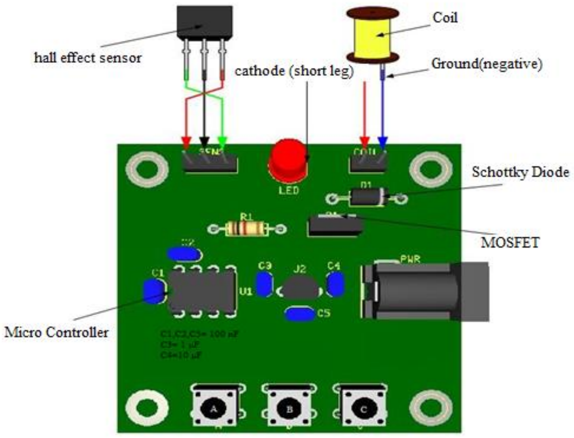

Fig.3 *The control panel electronic circuit components.*

The levitating object is repulsed and attracted to an electromagnet, so a controlled magnetic field is needed. A control unit adjusts the current in the electromagnet and hence the magnetic force acting on the levitating body, so that the body is held in a stable position.

The control system requires feedback signals of a certain kind from the positional sensor. In this case, the Hall Effect sensor located on the bolt head (the pole horn) is used to measure the Hall voltage and provide a proportional output that determines the amount of magnetic flux affecting the sensor.

The “A” button, which is the first button on the control panel, behaves as a recorder, so it helps to keep the last recorded position in the system, and the next experiment starts with that amount of air gap. The B and C buttons on the control panel allow the suspended object in the magnetic field to move upwards and downwards respectively, so the current and air gap spacing decreases and increases by affecting the applied magnetic force F (in Equation 4).

The signal from the Hall Effect sensor is processed by an amplifier with adjustable gain, and it controls the Pulse Width Modulator (PWM). As soon as the levitating object moves further away from the bolt, the output signal of the Hall Effect sensor increases. It makes the duty cycle of the PWM higher and the electromagnet attracts the levitated object – and vice versa.

The PWM signal drives the MOSFET which has a greater power-handling capacity and faster switching response in the cut off and saturation region of the transistor [13].

The experiment was conducted with different two geometrical shapes but with the same mass of PM material (see figure 1). The behavior of the magnetic circuit and the magnetic field on the differently shaped hard magnetic materials (PM materials) are compared in detail, using the experimental results in the following sections.

B. Mathematical model of the system

Considering Figures 1 to 3, the magnetic circuit steady-state levitation mathematical equation is based on the following simplified formulas [1], [2]:

$$N I = H_m l_m + H_g g \qquad (1)$$

where denotes the number of turns; is the current value, are PM field (A/m) and length (m) of PM, respectively; and are magnetic field (A/m) and length (m) of air gap between the fixed part and the suspended mass, respectively. From the properties of the series magnetic circuits, and using the fundamental formulas of magnetic fields, such as, the following equation can be derived:

$$B_m = \frac{F}{S_m}\ , \quad B_g = \frac{F}{S_g} \qquad (2)$$

where S_m *and* S_g are the PM cross section, and the cross section of the air gap through which flux $\Phi(Wb)$ is passing. B_m *and* B_g (Wb/m^2) are the magnetic induction for the PM and the air gap, respectively. Using equation 1, and rearranging the equations, the following is obtained:

$$N I = B\left(\frac{l_m{}'\ S_g}{m_m{}'\ S_m} + \frac{g}{m_0}\right) \qquad (3)$$

Where, $m_m(H/m)$ is the PM permittivity, which is directly dependent on the load line, and $m_0(H/m)$ is the air gap permittivity; by combining equations (1) to (3), and using Newton’s second law, equation (4) represented in linear terms is obtained as follows [2], [4].

$$M\ G = \frac{B^2}{m_0} S_g\ \ (N) \qquad (4)$$

Here, $M\ (kg)$ is the mass of the PM levitated material. The values for the material properties are shown in Table 1 below:

TABLE 1. THE PARAMETERS OF MAGNETIC LEVITATION SYSTEM.

M	Mass of Steel Ball	0.009 kg
G	Gravitational acceleration	9.82 m/s
μ_0	Magnetic permeability	$4\pi \times 10^{-7}\ H/m$
N	Number of Turns	370

C. Experimental results

Experiments were performed to compare the performance of the different shaped PM materials (see Fig. 1. (b)). The cylindrical shape is 1 cm in height and 0.5 cm in diameter and the sphere is 1 cm in diameter. In Fig. 4 the comparison of the PM materials is presented; the blue drawing symbolizes the cylindrical material and the green drawing function symbolizes the spherical material. The calculation of the PM mass is studied by equations (1) to (4) by considering the nonlinear system to be stabilized [3], [8].

After the experiments, in terms of stability, it was found that the cylindrical magnet is better than the spherical magnet. The reason for this is that the cylindrical magnet distributes the magnetic field less than the spherical magnet.

In Fig. 4. At that compares the air gap values to the current, we can see the effect of having different geometrically shaped PM materials. To levitate the PMs suspended in the air, for an increasing air gap, the current must be increased too. The spherical PM mass is levitated with a smaller air gap than the cylindrical PM mass. It means that larger levitation forces are needed to levitate the spherical PM mass. In Fig. 4. (b) and (c) , the effect on the system is seen. Fig. 4.(c) also indicates the load line graphics of the PM materials; the experimental measurements are emphasized with bold black dots. The results of the three figures were compared and evaluated against the theorical explanation and studies, and found to be in good agreement with published literature[1], [3], [12][13].

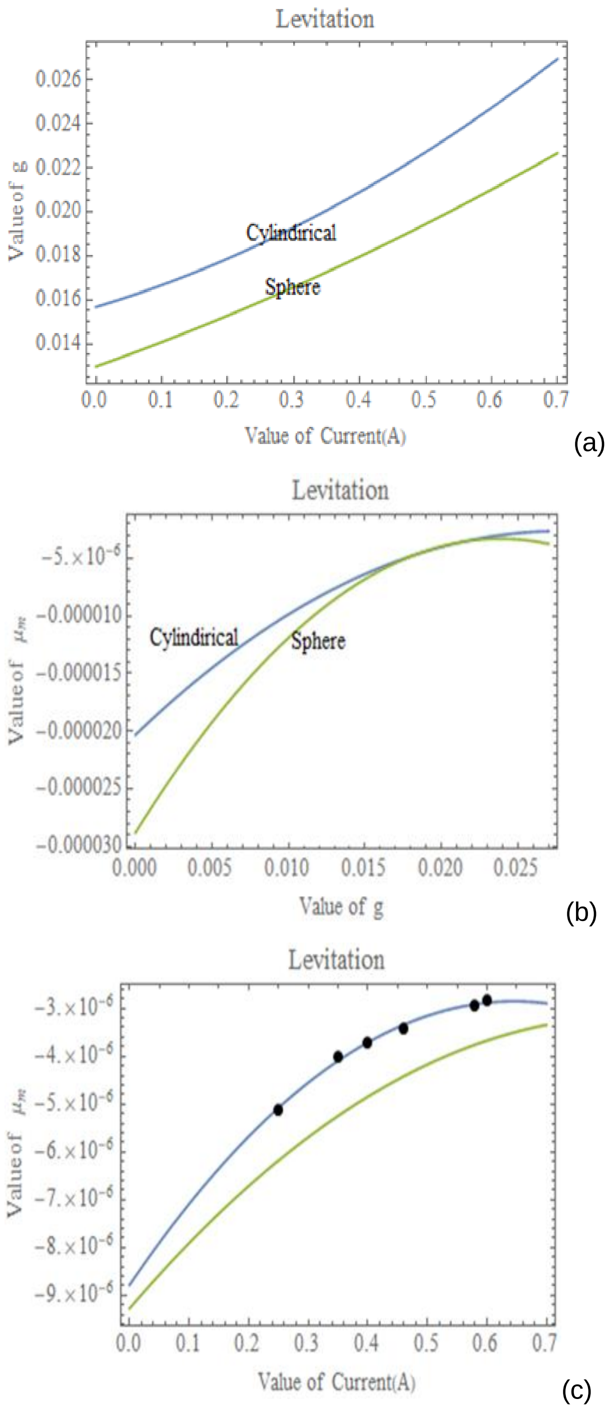

Fig.4 *Comparison of the effect of different geometrically shaped PM materials on the system (a) air gap versus current, (b) μ_m versus air gap and (c) μ_m versus current.*

As seen in the Fig. 4 graphics, the cylindrical PM material results match the experimentation data better than the spherical shaped PM. In the first experimentation (Fig 4(a)) the cylindrical PM's result is 70% higher than the other. It shows that the circuit system produces more magnetic force with drawing lower current.

III. CONCLUSION

This study introduces and studies the effect of a magnetic field on levitation, uses fundamental theoretical and practical basics, and encourages advanced approaches in electromagnetic fields and physics. This experimental research includes the identification, analysis and determination of the effects of levitation on various shaped objects with the same material mass. The most important factors affecting the power of the magnetic suspension system are the number of coil windings which form the magnetic force component, the applied current, the air gap, the cross sections and relative permeability of the permanent magnets. The experiment is completed by the loading effect of different shaped masses on the system. Initially it was difficult to control the current for system stabilization. We think that better control of the Hall Effect sensor may solve this problem effectively. Also, various observations could be made to improve the system's success in achieving current control and stabilization. Furthermore, in this study we did not just focus on improving the science and technology research, but also on the educational side to motivate and encourage students. In the future, we are going to develop the results of our research by controlling and measuring better-developed systems.

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REFERENCES

[1] Wong T.H., Design of magnetic levitation control System- An Undergraduate Project, IEEE Tra. on Education vol E-29 No.4, 1986, pp.120-124

[2] Valluvan M., Ranganathan S., Modelling and Control of magnetic Levitation system, International Conf.on Emerging Trends in Science Eng. and Tech., 2012, pp.545-548.

[3] S.Kurtulmuş, I. Kıvanç, Oyman Serteller N. F, 2007,Levitasyon Sistemlerinde Magnetic Kuvvet analizi ve bir Uygulama, UMES-2007 National Young Investigators Symposium,

[4] Sadiku Matthew N.O. Elements of Electromagnetic Theory, 3rd Edition,Oxford Uni. Press, 2001.

[5] Fitzgerald A.E, H. Kingsley, Stephen D.Umans, Electric Machinery,5th Edition, Mc.Graw Hill Comp.,1992.

[6] Naumovic M. B.,Modelling of a Didactic Levitation Sys. For Control Education, Telsiks,2013.

[7] A.A.,Sickafoose and J. E. Colwel, Experimental Levitation of Dust Grains in a Plasma

Sheath, Journal of Geophysical Research, Vol. 107, no. a.11, 2002, pp.1408,.1412.

[8] Ghodsi M.,Ueno T.,Higuchi T., Improvment of magnetic circuit in levitation system using HTS and Soft magnetic material, IEEE transaction on magnetics 41(10),2005, pp.4003-4007.

[9] Mundher H.A., Yaseen,Haider J. Abd, Modeling and Control for a Magnetic Levitation System Based on SIMLAB platform in real time,Results im Pysics Elsevier, 8, 2018., pp.153-159.

[10] F.Feichtinger, S. Clara, A. O. Niedermayer, T. V.Brunnmaier, B.Jakoby, Active magnetic levitation and 3-D position measurement for a ball viscometer , 2016, J. Sens. Sens. Syst.,5.

[11] R. R. Gomes, G. G. Sotelo, and R. M. Stephan, Comparação de configuraçõ espara um levitador eletromagnético pelo método dos elementos finitos," presented at the Congresso Brasileiro Eletromagn., São Paulo, 2004, Brazil,.

[12] Valle R.,Andrade R., Stephan R.M., Electromagnetic Levitation of a Disc, IEEE Transaction on Education Vol.55, No.2, 2012,May, pp.268-272.

[13] https://pdfs.semanticscholar.org/cea.pdf, T. Hron, "Model Of The Electromagnetic Levitation Device", CZECH TECHNICAL University in Prague Faculty of Electrical Engineering Department of Electrotechnology Lecture notes,2019.

[14] I.-Yann, A. Wang, I. Busch-Vishniac, A New Repulsive Magnetic Levitation Approach Using Permanent Magnets and Air-Core Electromagnets, IEEE Transactions on Magnetics, vol. 30, No. 4, 1994, pp.1422-1433.

[15] R. Bassani, Permanent Magnetic Levitation and Stability, Proceedings of the NATO Advanced Study Institute on Fundamentals of Tribology and Bridging the Gap Between the Macro- and Micro/Nanoscales Keszthely, Hungary ,August13-25, 2000, pp. 899-913.