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Development of a Cost Effective Magnetic Levitation System Using PIC12F683 Microcontroller and Photo sensor

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Abstract:

This paper presentsthe development of an active magnetic levitation system using electromagnetand photo sensor. The developed system is capable to levitate a15gm steel ball associated with vertical translation i.e. single-degree-of-freedom motion (SDOF). In this paper, PD controller has been developed using MPLAB programming language for the system and the steel ball can levitate less than 1 mm in vertical motion.This paper also presents active feedback control system using PD controller which mainly suspends the mass of the object as well as control its direction of motion. Moreover, the developed system consumes very low power and can be operated by using USB power supply. However, photo sensor is used for input signal of feedback control which is very simple and cost effective and controller circuit has been designed in such a way that it would be able to precisely control the electromagnetic field to stabilize the position of the levitated object. This paper also shows that, at sensor offset 735 the steel ball is levitated and at sensor offset 740 the steel ball is not levitated.

Keywords —**Magnetic Levitation, Vertical Translation, Feedback Control, Magnetic Suspension, Photo sensor**

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I. INTRODUCTION

ThisMagnetic levitation, maglev, or magneticsuspension is a method by which an object is suspended with no support other than magnetic fields. Magnetic force is used to counteract the effects of the gravitational acceleration and any other acceleration. Maglev is one of the best recent technologies. It has no physical contact between the motion object and stable part of the system. So there is no friction and wear in such type of technique [1-3]. When the gap between the object and magnetic source is too long, then the strength of magnetic field will inadequate to sustain the weight of the object. By placing near to the magnetic source, the strength of magnetic field becomes very powerful and the magnetic field can easily attract the object till it makes direct contact with the magnet [4, 5].The initial application of magnetic actuation was in solenoid actuators, magnetic cranes and electrical switches [6]. Approximately three decades ago, the first magnetic levitation train was proposed and initialized as a high speed mass transportation vehicle [7, 8]. Various experimental and a large number of theoretical studies have been done in Japan, Germany and the United States and have resulted in interesting outcomes [8-10]. After several years, changing market requirements have forced manufacturers to develop new technologies of actuation. In the hightech industry, which increasingly relies on micro assembly, product requirements drive manufactures to change their production strategies. Magnetic levitation (maglev) technology is mostly used in different fields such as high speed trains [11-13]), magnetic bearings [14], and photolithography steppers for reducing friction due to mechanical contact, for low maintenance cost and reaching high precision positioning [15-16].

The researches on magnetic levitation and controlhave become a widespread and significant attention recently due to their broad and potential applications in many advanced fields including semiconductor manufacturing, precision measurement, space vehicle and many other applications. For steady state levitation, it is equally important to minimize several kinds of force such as acceleration force (disturbance), damping force, gravity force, magnetic force and feedback control force. An active feedback control system has been an unquestionable choice for magnetic levitation system.

Feedback control is the best way to take care of amagnetic levitation system but it does not guaranteed robustness in the presence of modelling error and disturbances. However, in active feedback control system using PID, LQR, H∞, PI control, repetitive control, pole placement are extensively used [4, 5]. The advanced technology of semiconductor devices and high density recording precise magnetic levitation systems has increasingly been demanded. Most of the active feedback control systems used high performance sensors, such as servo-type accelerometers [1-10]. Large amount of control current is consumed to drive the actuators for those high performance sensors. The system is very expensive for that. This is one of the most obstacles to expand the field of application of an active control system.

To overcome this, an active feedback control magnetic levitation system has been developed using MPLAB programming language and PIC12F683 microcontroller. PD controller has been used for its simplicity and low cost. Considering the object to move in vertical translation i.e. single-degree-of-freedom motion (SDOF), the controller has been made enable for this motion. A SFH 9206 Phototransistor is used as photo sensor for displacement feedback. The control current is very little for this system using low performance sensor. Therefore, USB power supply has been used to drive the actuator in the steady- state. The steady state condition has been realized in this control, in which the repulsive or attractive force produced by the electromagnet balance the weight of the suspended mass.

Therefore, the objective of this paper is to introduce an active feedback controlled magnetic levitation system which is very simple, low cost and consume very low power.

1.1. Basic Magnetic Suspension System

It has beena viable choice of active magneticsuspension system for many industrial machines and devices as a noncontact, lubrication free support [17- 20]. It would become an essential machine element from high speed rotating machines to the development of precision vibration isolation system. By using electromagnet and/or permanent magnet suspension can be achieved. Electromagnet or permanent magnet in the magnetic suspension system causes flux to circulate in a magnetic circuit and magnetic fields can be generated by moving charges or current. The attractive force of an electromagnet, F can be expressed approximately as

$$F= \mathbf{K}\frac{\boldsymbol{I^2}}{\boldsymbol{\partial^2}}(1)$$

Where K: attractive force coefficient for electromagnet, I: coil current and δ : mean gap between electromagnet and the suspended object. Each variable is given by the sum of a fixed component, which determines itsoperating point and a variable component. Such as

$$I = I_0 + i(2)$$

$$\delta = D_0 - x\ (3)$$

Where I_0: bias current, i: coil current in the electromagnet, D_0: nominal gap and x: displacement of the suspended object.

1.2. Zero PowerControlled Magnetic Suspension System

In order to reduce power consumption andcontinuous power supply, a position sensor isemployed in the suspension system to avoidproviding bias current. The position sensor is used for the purpose of providing bias flux [21 - 23]. This control realizes the steady states in which theelectromagnet coil current converges to zero and the attractive force produced by the position sensor balances the weight of the suspended object. Attractive force of the electromagnet F can be written as

$$F = k\frac{(I_0 + i)^2}{(D_0 - x)^2} \quad (4)$$

Where the bias current, I_0 is modified to equivalent current in the steady-state condition provided by the fixed current and nominal gap, D_0 is modified to the nominal air gap in the steady-state condition. For zero-power control system, the control current of theelectromagnetis converged to zero to satisfy the following equilibrium condition:

F_e= mg(5)and the equation of motion of the suspension system can be written as

$$m\ddot{x} = F - mg \quad (6)$$

From eqs. (5) and (6)

$$m\ddot{x} = k_i i + k_s(x + p_2x^2 + p_3x^3 + ...) \quad (7)$$

This is the fundamental equation for describing the motion of the suspended object.

1.3. Model

A basic control model is designed based on linearized equation of motionwith the assumptions that the displacement of the suspended mass (m) is very small, moving in the verticaldirection as shown in Fig.1 [24 - 27]. The block diagram of the maglev system using PD controller is represented in Fig. 2. The equation of motion is given by

$$m\ddot{x} = k_s x + k_i i + w \quad (8)$$

Where x: displacement of the suspended object from the equilibrium position, k_s: gap- force coefficient of the electromagnet, k_i: current-force coefficient of the electromagnet, *w:* disturbance acting on the suspended object, *i*: control current. The coefficients k_s and k_i are positive. Denoting each Laplace transform variable by its capital and the initial values are assumed to be zero for simplicity, the transfer function representation of equation (8) become

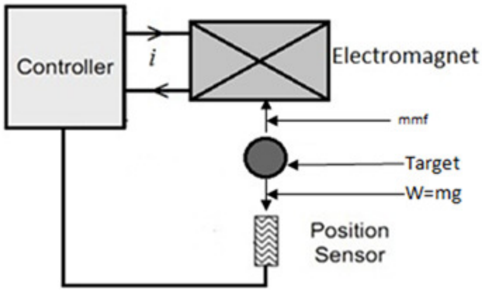

Fig.1 Basic model of a magnetic levitation system

$$mX(s)s^2 = k_s X(s) + k_i I(s) + W(s) \quad (9)$$

$$(ms^2 - K_s)X(s) = k_i I(s) + W(s) \quad (10)$$

$$X(s) = \frac{1}{ms^2 - k_s}(k_i I(s) + W(s)) \quad (11)$$

$$X(s) = \frac{1}{s^2 - \frac{k_s}{m}}\left(\frac{k_i}{m} I(s) + \frac{1}{m} W(s)\right) \quad (12)$$

$$X(s) = \frac{1}{s^2 - a_0}(b_0 I(s) + d_0 W(s)) \quad (13)$$

Where, $a_0 = \frac{k_s}{m}, b_0 = \frac{k_i}{m}, d_0 = \frac{1}{m}$

By feeding back the velocity of the suspended object or by introducing a minor feedback of the integral of current in the PD (proportional-derivative) controlsystem zero-power may be achieved. In the current controlled magnetic levitation system, PD control

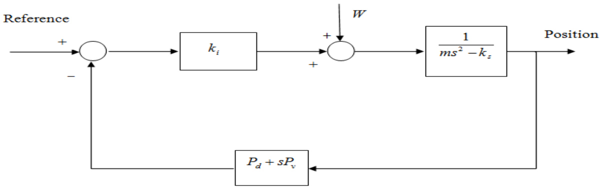

Fig.2 Block diagram of a magnetic levitation system with PD controller

The developed magnetic levitation system with PD controllercan be represented [26, 28] as

$$I(s) = -(P_d + P_v s)X(s) \quad (14)$$

Where, P_d Proportional control feedback gain, $P_v s$ Derivative control feedback gain

$$X(s) = -\frac{I(s)}{(P_d + P_v s)} \quad (15)$$

$$\frac{X(s)}{I(s)} = -\frac{1}{(P_d + P_v s)} \quad (16)$$

From this linearized system, *X(s)* and *I(s)* represent the change from the equilibrium values of position and current respectively. From Eq.(13) and Eq.(14)

$$I(s) = -(p_d + P_v s)\frac{1}{s^2 - a_0}(b_0 I(s) + d_0 W(s)) \quad (17)$$

$$I(s) = -(p_d + P_v s)\frac{1}{s^2 - a_0}(b_0 I(s)) - (p_d + P_v s)\frac{1}{s^2 - a_0}(d_0 W(s)) \quad (18)$$

$$I(s)(1 + (p_d + P_v s)\frac{1}{s^2 - a_0} b_0) = -(p_d + P_v s)\frac{1}{s^2 - a_0}(d_0 W(s)) \quad (19)$$

$$I(s)(s^2 + p_d b_0 + P_v s b_0 - a_0) = -d_0(p_d + P_v s)W(s) \quad (20)$$

$$\frac{I(s)}{W(s)} = \frac{-d_0(p_d + P_v s)}{s^2 + p_d b_0 + P_v s b_0 - a_0} \quad (21)$$

From Eq.(14) and Eq.(21)

$$\frac{-(P_d + P_v s)X(s)}{W(s)} = \frac{-d_0(p_d + P_v s)}{s^2 + p_d b_0 + P_v s b_0 - a_0}$$

(22)

$$\frac{X(s)}{W(s)} = \frac{d_0}{s^2 + p_d b_0 + P_v s b_0 - a_0}$$

(23)

To estimate the stiffness for direct disturbance, the direct disturbance, W(s), on the isolation table is considered to be stepwise, that is

$$W(s) = \frac{F_0}{s} \quad (F_0\text{constant})(24)$$

From eqs. (21) & (24)

$$\lim_{t \to \infty} i(t) = \lim_{s \to 0} I(s) = 0 \quad (25)$$

This indicates that control current always converges to zero in the basic zero power control for any load. The steady displacement of the suspension from eqs. (23) & (24)

$$\lim_{t \to \infty} x(t) = \lim_{s \to 0} X(s) = -\frac{d_0}{a_0} F_0 = -\frac{F_0}{k_s} \quad (26)$$

The negative sign in the right sight indicates that the new equilibrium position is in the direction opposite to the applied force. It means that the system realizes negative stiffness. If that stiffness of any suspension is denoted by k. The stiffness of the zero powercontrolled magnetic suspension is, therefore negative and given by

$K = -K_s$(27)

II. EXPERIMENTAL SETUP

The main component of the experimental setup is control circuit, sensor circuit, the body(plastic), clear plate, centre pole, yoke, electromagnet and floater ball. For its operation the other apparatus are an oscilloscope, PICK it 3 programmer/debugger, USB power supply, LAPTOP/desktop. It is used MPLAB X IDE software to write program in microcontroller. To make coil/electromagnet the outer and inner diameter of the bobbin is 14 mm and 6 mm respectively. The wire diameter is selected so that the resistance value of the coil becomes 10 to 15Ω. The coil is inserted into the yoke then the yoke is inserted into the upper side of the body. A M4 nut is used as center pole. The sensor circuit is placed into the lower side of thebody. A transparent thin plastic plate is placed slide upper the sensor so that thelevitated object cannot thrust the sensor. The control circuit is placed at the back side of the body. The sensor produces a voltage, $v_{s.}$ that is proportional to the position of the levitated object x (Fig.1), with a gain, say β, which is linear around the operating point, $v_s = x\beta$. The magnetic force developed is given by $F = Ni$. Where N is the number of turns and i is thecurrent flow through the winding. A steel ball of 1.4 cm diameter and 15gm mass is used as a levitated object. We can also use other ferromagnetic Magnetic materials ballsame size and mass of the steel ball. Fig.3 shows the Developed model of magnetic levitation system.

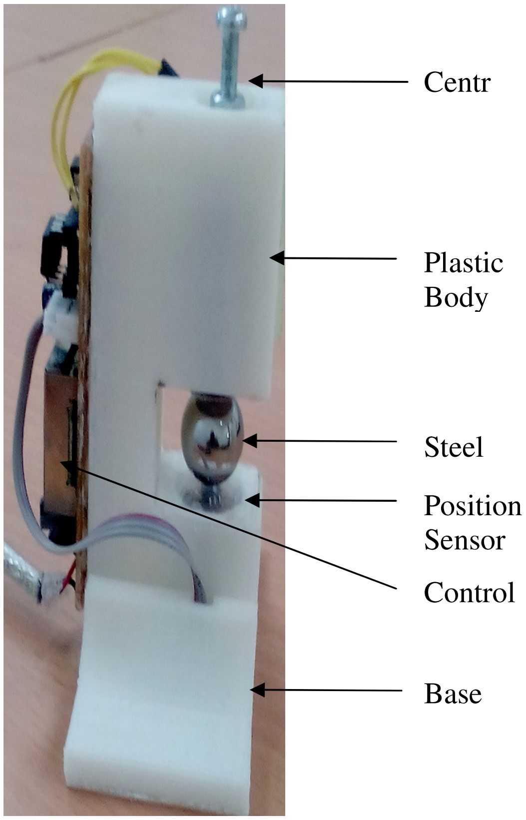

Fig.3 Developed model of magnetic levitation System

III. EXPERIMENTAL RESULT

In the experiment several results were foundwhich are accumulated. First we set the position sensor and center pole (M4 nut) at fixed position. Now to levitate the ball, in the program we have to change the sensor offset value (offs), proportional gain (dav), derivative gain (dav+) and current offset (pwmout). Following observations were found:

Observation 1: In 1st observation current offset (pwmout), sensor offset (offs) and derivative gain (dav+) values were fixed. It was only changed the proportional gain (dav) value. Fixed values are:
Current offset (pwmout) = 25 + dav
Sensor offset (offs) = 735
Derivative gain (dav+) = -((dv<<3)– (dv<<1))
Following results were found in table 1.

Table 1: proportional gain (dav) is variable

Sl no	proportional gain (dav)	Results
1	Dav = -((adv>>1) – (adv>>5))	then the ball was fully levitated.
2	Dav = -((adv>>1) – (adv>>0))	Attached the ball to electromagnet, more noise, more force.
3	Dav= -((adv>>0) – (adv>>4))	the ball levitate but more vibration.

Observation 2: In 2nd observation current offset (pwmout), sensor offset (offs) and proportional gain (dav) values were fixed. It was only changed the derivative gain (dav+) value. Fixed values are:
Current offset (pwmout) = 25 + dav, sensor offset = 735
Proportional gain (dav) = ((adv>>1) – (adv>>4))
Following results were found in table 2.

Table 2: derivative gain (dav+) is variable

Sl no	derivative gain (dav+)	Results
1	Dav+ = -((dv<<3) – (dv<<1))	the ball was fully levitated.
2	Dav+ = -((dv<<2) – (dv<<1))	the ball levitate but more vibration.
3	Dav+ = -((dv<<2) – (dv<<0))	the ball smoothly levitated.

Observation 3: In 3rd observation current offset (pwmout), derivative gain (dav+) and proportional gain (dav) values were fixed. It was only changed the sensor offset (offs) value. Fixed values are:
current offset (pwmout) = 25 + dav
derivative gain (dav+) = -((dv<<3) – (dv<<1))
proportional gain (dav) = ((adv>>1) – (adv>>4))
Following results were found in table 3.

Table 3: sensor offset (offs) is variable

Sl no	sensor offset (offs)	Results
1	735	the ball was fully levitated.
2	737	the ball was fully levitated.
3	740	the ball was not levitated, touch lower surface

3.1 System Realization

A stable maglev system is developedusing a microcontroller. At the same time the system is suitably controlled by the controller.From the experiment, it is observed that the powerconsumption of the system is approximately 3 watt. It is considerably low regarding the stability of the system. It is seen from Fig. 4 that the system is stable using PIC12F683 microcontroller.

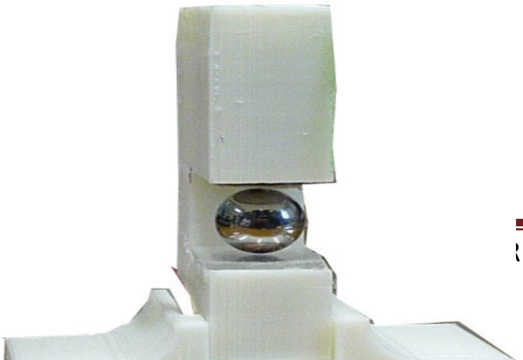

Fig.4 Realization of the Developed System

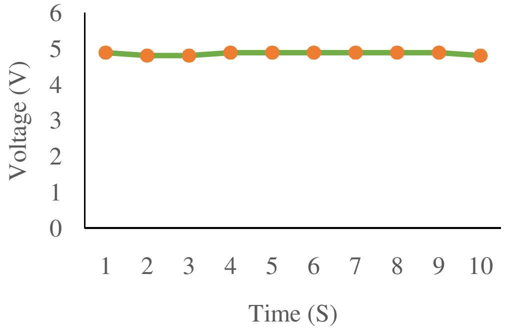

Fig. 5 Voltage VS Time curve from osciloscopereading at fully lavitated position

3.2 Characteristic Curve of the Developed System

Different characteristics of the developed magnetic levitation system has been found and demonstrated in figure. The vibration of the object is further reduced by aligning the object perfectly with the sensor and the electromagnet. Fig. 5 shows that voltage remains about 4.8 volt at fully levitated position of the ball. It is shown from the Fig. 6 that the current consumption is being stable for a certain time hence the stability of the system is established at a certain distance.

IV. CONCLUSIONS

A basic magnetic levitation system has been developed using microcontroller and photo sensor. It requires very little amount of power to operate the system. A constant small amount of power source has been used from USB port. To reduce reflection, the steel ball was colouredwhite and made its surface rough. The developed system was statically and dynamically stable. The steel ball can be levitated only in the vertical direction. At stable position the air gap of the steel ball from the electromagnet and the position sensor was 0.5 to 0 .8 mm. During the operation of the system input voltage should be kept 4 to 6 volt.

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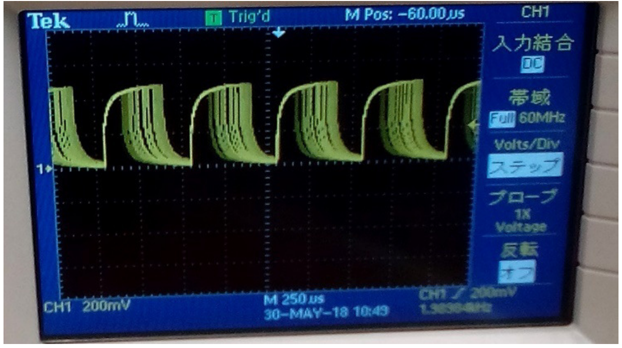

Fig.6 osciloscopereading at stable position

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