DESIGN AND MODELING OF A MAGNETIC LEVITATION SYSTEM

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Abstract: ***The maglev system is one of the most powerful techniques which are widely used to propel the objects in many control applications. This paper deals with the design and modeling of a magnetic levitation system. The system is described with closed loop. Model linearization is carried out at equilibrium. The performance of the system is analyzed using pole and zero maps and root locus method. The effect of controller parameters is discussed.***

Key words : Maglev, Controller, Modeling, Root locus, Hall Sensor

I. INTRODUCTION :

Magnetic levitation system has been receiving incredible interest because of its advantage of almost negligible frictional loss. It is an emerging technology having potential applications [1] which includes transportation (High speed Maglev Train), Household fixtures, aerospace shuttles,magnetic bearings, Flywheels, Levitation melting etc. However, currently this technology is expensive.Surely in future the research in developing low cost techniques will change the corporate life. Maglev systems also known as Magnetic levitation systems are electromechanical devices that propel magneticobjects with the help of electromagnetism without any noise or use of any kind of fuel.

The idea of the maglev is to take in to account the magnetic force which is produced by electromagnet[2]. This avoids the effect of gravity exerting on a ball. Hence, when these two forces are balanced, there is apoint of equilibrium.Mathematical modeling is an important concept to analyze the performance of any system.The aim of this work is to design and model a laboratory developed magnetic levitation system.

System transfer function is obtained in this case. Suitable control algorithms can be applied to compensatefor the nonlinearity and instability present in system. For linearizing the system, various linear control methods are adopted.The magnetic levitation system consists of electromagnet, magnetic ball, pair of Hall sensors and simple controller circuit.

II.SYSTEM MODELING:

The objective of this paper is to derive a mathematical model, the concepts of which are applied to design the control circuits to stabilize the ball and tracking of reference signal.[3]

Figure 1 shows the free body diagram of magnetic ball under suspension.

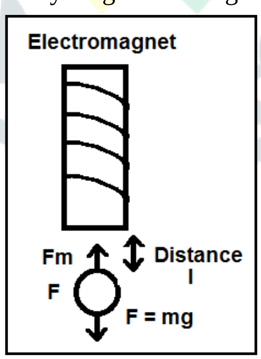

Fig. 1 Free body diagram of magnetic ball under suspension

The suspension system of magnetic ball is classified as electrical system and mechanical system[4,5].The total force in vertical direction is given by

m.l = mg-fm ------- (i)

and v=i.R + Lc.di/dt ------- (ii)

we can say if the position of the ball changes, the coil inductance changes.

Therefore, Total Inductance L = Lc +2c/l

Where, x = position of ball

C= coil constant ($N.m^2A^{-2}$)

Lc= Inductance of the coil.

Now the coil magnetic energy is given by

$$\omega_m = \frac{1}{2} L.i^2$$

And levitation force is changed with the distance $Fm=-\partial\omega_m/\partial l$
U
$F_m = -\partial/\partial l \ (½ \ L.i^2)$
$= -\partial/\partial l \ (½ \{ Lc+2c/l.\ i^2\} .\ i^2)$
$= -\partial/\partial l \ (½ \ Lc+c/l .\ i^2)$
$F_m=c.1/l^2 .\ i^2$
$F_m=c(i/l)^2$-------(iii)

Therefore, magnetic force is
$m.l = mg - c (i / l)^2$ --------(iv)
Thus, it is observed that nonlinear term is present which should be linearized.
Fig.2 shows Magnetic levitation system with the attachment of Hall sensor. Hall sensor is attached at the top and bottom of an electromagnet.

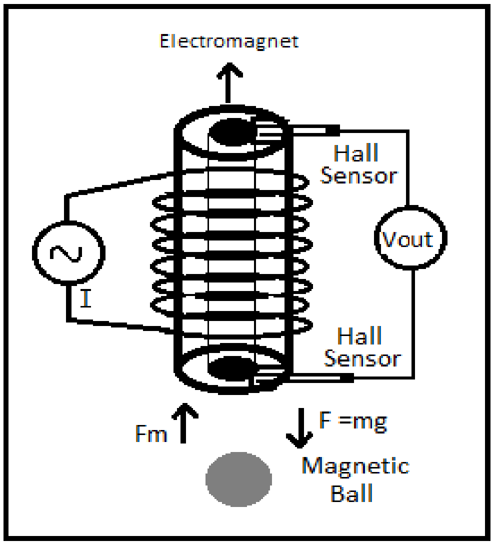

Fig.2 Magnetic levitation system with the attachment of Hall sensor.

From the force balancing equation we can also write,
$m.d^2/dt^2. [d(t)] = mg-fm$
The electrical dynamics of an electromagnet can be represented as,
$$v (t) =R.i(t) + L.\ di(t) /dt \text{ ----------(A)}$$
Therefore, $V(s) = R.I(s) + L.\ s.I(t)$
$$V(s) = (R + L.s) \ I(s)$$
$$I(s) = V(s) / R + L.s$$
$\Delta I(s) = \Delta v(s) / (R + L.s)$ ------------ A (i)
Where, L is inductance of an electromagnet.
$I(t) =i._e + \Delta\ i(t)$
$$v(t) = v_e + \Delta v(t)$$
$$d(t) = d_e + \Delta d(t)$$
With this, dynamics of eqation A can be linearized around and operating point (i.e, de,ve) as
$d\Delta i / dt = - R/L .\ \Delta i + 1 / L .\ \Delta v$
The Hall sensor has an output voltage of the form as,
$Z(t) = \alpha + \beta / d^2 + \gamma i (t)$ -------(B)
A linearization of (B) around $dZ(t) = Ze + \Delta Z$ gives
$$\Delta Z = - 2\beta / de^3\Delta d + \gamma.\Delta i \text{ -------- (C)}$$
The block diagram of system is as shown in Fig . 3

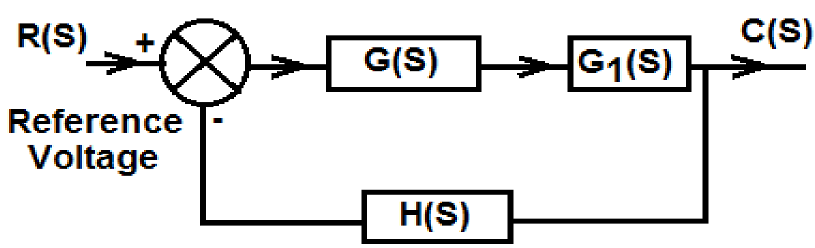

Fig . 3 Block diagram of Maglev system

The Laplace transform of above block diagram [6,7] is given by
$G(s)H(s) = \Delta z(s) / \Delta v(s) = -2\beta / de^3. \Delta d + \gamma. \Delta i / \Delta I(s) (R + L.s)$
Where, G (S) is For Electromagnet, G1(s) is For levitating Ball and H(S) for Hall Sensor.

III.DESIGN OF CONTROLLER CIRCUIT:

Figure 4 shows the controller circuit designed and developed for maglev system. The completecircuit consists of Dual Power supply, operational amplifiers,Top and Bottom Hall sensors,Electromagnet etc.Here the combinationof Proportional and Derivative controller are used to controlthe voltageofthe electromagnet.

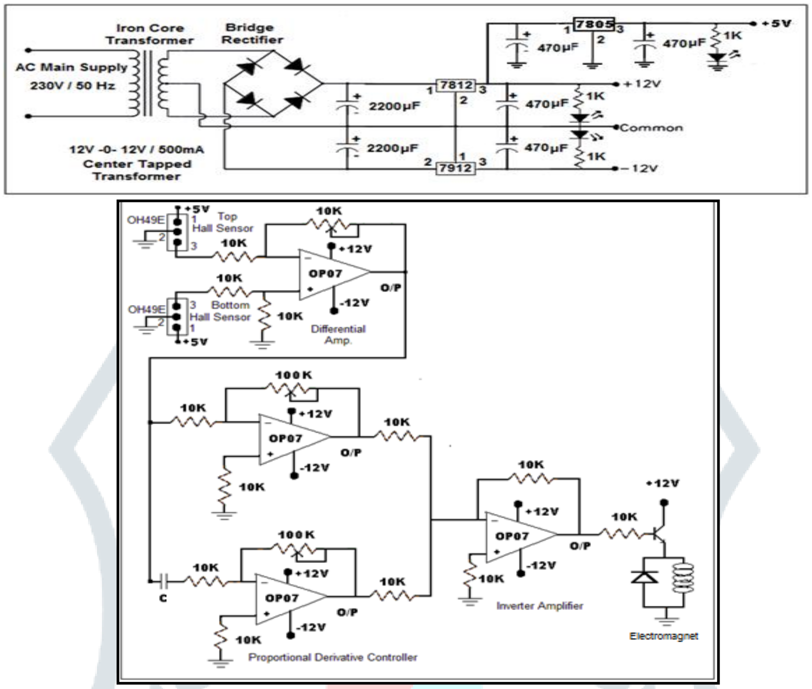

Fig. 4 Controller circuit for maglev system

IV.EXPERIMENTAL AND OBSERVATION:

The values of feedback resistors(Rf) and Capacitor C plays an important role to change the controller parameters.Also, the position of levitating magnet ball can be raised or lowered by changing the referencevoltage with a potentiometer.

Table.1 shows the system parameters which are substituted in loop transfer function.

	Parameter	**Value**	**Observation & Unit**
Electromagnet	K	$1.6X10^{-9}$	Kgm^5 /s^2A
	R	2.5	Ω
	L	$15.1X10^{-3}$	H
Sensor	β	2.92	V
Operating Point	Q ie	0.45	A
	Q de	25	mm
Mass of ball	m	0.1	Kg
Equilibrium Position	x	0.8	cm

By substituting these parameters in equation (D) loop transfer function is achieved.
Figure 5 shows the open loop Root locus obtained with these parameters.

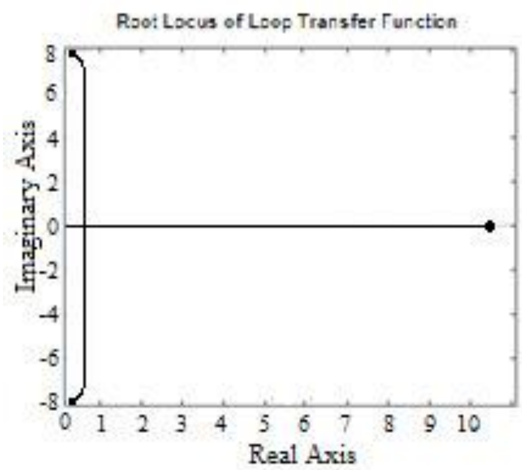

Fig 5 Root locus for open loop system

The transfer function of the proportional Derivative controller is given by
(Cs) = V(s) / (s) = - Rf/R (RCs+1)
With fixed values of C=10uF and R= 10K, output of PD controller is equal to –Kc(0.15 +1)
Where Kc is the controller gain.This is an important tuning parameter determined by feedback resistor.With this, the closed loop system root locus is determined which is as shown in Fig.6

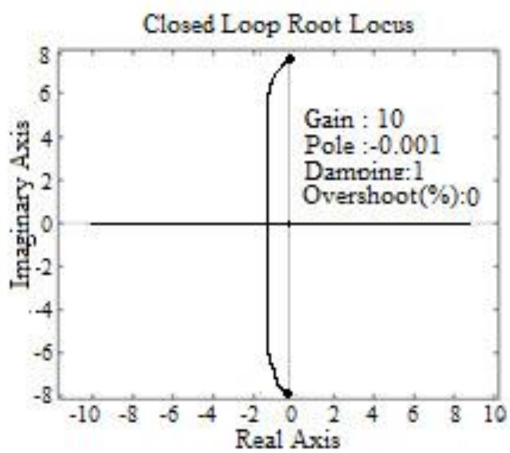

Fig 6 Root locus for closed loop system

The closed loop system is stable with Kc = 7.91

V.CONCLUSION:

The Magnetic Levitation system is designed and systematic Modeling of the system was carried out. Magnetic levitation system is connected with Hall sensor. The controller circuit for Maglev was developed with the help of OPAMP.The performance of the system was checked with root locus method. Magnetic levitation system remains stable with change in Rf and C within specified limits.Theposition of the levitating ball was increased or decreased with respect to equilibrium condition.

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