International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-3, Issue-1, March 2014

Fuzzy Logic Controller and LQR for Magnetic Levitation Syste

Arjun C Unni, A.Junghare

***Abstract:** Magnetic suspension systems have been successfully implemented for many applications such as frictionless bearings, high-speed maglev passenger trains, and fast-tool servo systems. Due to the features of the instability and nonlinearities of the magnetic suspension system, the design of a high-performance controller for the position control of the levitated object is very import. This paper presents the modelling of the system and control of the same.*

***Key words:** Magnetic levitation system, Fuzzy, LQR*

I. INTRODUCTION

A Maglev is a system that uses magnetic fields to levitate an object in a particular position. If an object is placed too far away from the magnetic source, the magnetic field is too weak to support the weight of the object. If placed too close to the magnetic source, the magnetic field becomes too strong and causes the object to move towards the source until it makes physical contact with the magnet. Maglev device is an example of an inherently unstable system.

Magnetic levitation system can be categorized based on whether the force of attraction or repulsion is used for the levitation of the ball. Here the force of attraction of the electromagnet in the maglev is used to balance against the gravity.

The main components of the magnetic levitation ball system are shown in Fig. 1.

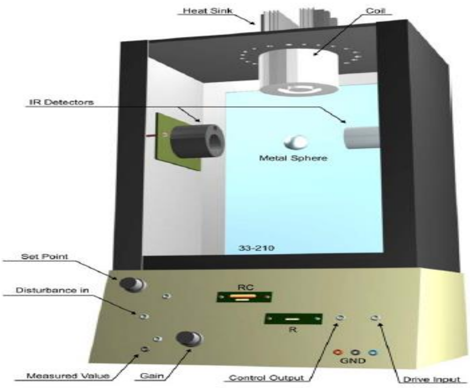

Fig.1 Magnetic levitation system

Revised Manuscript Received on 30 March 2014.
* Correspondence Author
Arjun C. Unni*, Department of Electrical, National Institute of Technology, Nagpur, India.
Dr. A.S. Junghare, Department of Electrical, Visvesvaraya National Institute of Technology, Nagpur, India.

The working of magnetic levitation system is as the following. Voltage is applied to the electromagnet. Then current flows through it. This current magnetizes the electromagnetic coil which produces a magnetic force in the steel ball. The ball is attracted towards the electromagnet. This force when becomes equal to the force of gravity the ball is successfully suspended in the required position. Theoretically it seems very easy. Because it is just a problem of finding out how much is the gravitational force on the ball at a particular point. But without the help of a controller it cannot be done. Before designing the controller modeling of the system is done.

II. MODELING

The magnetic levitation system can be categorized into

1) Electrical system

2) Mechanical system

The ball position in the mechanical system can be controlled by the current through the electromagnet where the current through the electromagnet in the electrical system can be controlled by applying controlled voltage across the electromagnet terminals.

The magnitude of force f(x,i) exerted across an air gap h by an electromagnet through which a current i flows can be described as

$$f(h,i) = -\frac{i^2}{2}\frac{dL(h)}{dh} \qquad (1)$$

The total inducatance L is a function of the distance and given by

$$L(h) = L_1 + \frac{L_0 H_0}{h} \qquad (2)$$

Where L1 is the inductance of the electromagnet coil in the absence of levitated object L0 is the additional inductance contributed by its presence,and X0 is the equilibrium position .The parameters are determined by the geometry and construction of electromagnet ,and can be determined experimentally.

Substituting equation (2) in (1) yields

$$f = \frac{L_0 X_0}{2}\left[\frac{i}{h}\right]^2 = \beta\left[\frac{i}{h}\right]^2 \qquad (3)$$

$$\beta = \frac{L_0 H_0}{2} \qquad (4)$$

By using Taylors theorem,the equation of the force is linearised.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

$$f = f_0 + \left(\frac{\partial f}{\partial L_0}\right) \Delta L_0 + \left(\frac{\partial f}{\partial H_0}\right) \Delta H_0 + \left(\frac{\partial f}{\partial i}\right) \Delta i + \left(\frac{\partial f}{\partial h}\right) \Delta h \quad (5)$$

Eliminating the higher order terms give

$$f = f_0 + \left(\frac{\partial f}{\partial i}\right) \Delta i + \left(\frac{\partial f}{\partial h}\right) \Delta h \qquad (6)$$

Evaluating equation (6) using (4) and (5) yields

$$f = \beta \left(\frac{I_0}{H_0}\right) + \frac{2\beta I_0}{{H_0}^2} \Delta i \Delta h \qquad (7)$$

Where I0 is the equilibrium value. At equilibrium,the weight of the object is suspended by the electromagnet force f0 .The force required to maintain equilibrium f1 is

$$f_1 = f - f_0 \qquad (8)$$

Combining equations (7) and (8) gives

$$f_1 = \left(\frac{2\beta I_0}{{H_0}^2}\right) \Delta i - \left(\frac{2\beta {I_0}^2}{{H_0}^3}\right) \Delta h \qquad (9)$$

Now we are considering the electrical system.The voltage equation of the electromagnetic coil is

$$V = iR + L(h)\frac{di}{dt} \qquad (10)$$

Assuming that the suspended object remains close to its equilibrium position

$$L(h) = L_1 + L_0 \qquad (11)$$

Also assuming L1 is very large compared to L0 equation (10) can be simplified as

$$V = iR + L_1\frac{di}{dt} \qquad (12)$$

By taking Laplace transform we get

$$\frac{I(s)}{V(s)} = \frac{1}{L_1 s + R} \qquad (13)$$

Now, the main equation of the suspended object comes by applying Newton's second law of motion. For this one degree of freedom system,a force balance taken at the centre of gravity of the object yields

$$M\frac{d^2h}{dt^2} = -f_1 \qquad (14)$$

Applying Laplace transform,we get

$$\frac{H(s)}{I(s)} = \frac{-K_1 I(s)}{Ms^2 - K_2} \qquad (15)$$

Where

$$K_1 = \frac{2\beta I_0}{{H_0}^2}$$

and

$$K_2 = \frac{2\beta {I_0}^2}{{H_0}^3}$$

There is a sensor in the model of the system.It can be modeled as

$$V_s = K_s h \qquad (16)$$

The overall transfer function of the plant is

$$G(s) = \frac{V_s(s)}{V(s)} = \frac{\frac{-K_s K_1}{M L_1}}{\left(s + \frac{R}{L_1}\right)\left(s^2 - \frac{K_2}{M}\right)} \qquad (17)$$

Real time system is designed in such a way that, the current produced in the electrical system is proportional to the voltage given.(It is experimentally verified that the proportionality constant is 1).Also, sensor gain is not there since voltage to position and vice-versa is done in input and output sides.

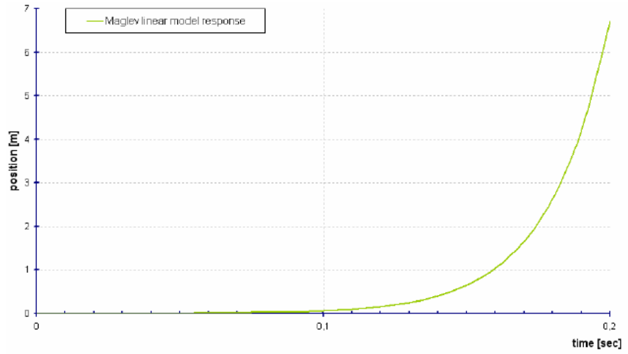

Fig 2 response of the linear Maglev model when no control voltage is applied.

III. CONTROLLER DESIGN

Without a controller when we give voltage to the electromagnet the steel ball will either fall down or go and stick to the electromagnet. So here we use a PID controller, fuzzy logic controller and LQR controller which successfully control the voltage given to the electromagnet and thereby controlling the ball in steady state after the transient time.

A. Fuzzy logic controller

Fuzzy logic systems are one of the main developments and successes of fuzzy sets and fuzzy logic. A FLS is a rule-base system that implements a nonlinear mapping between its inputs and outputs.

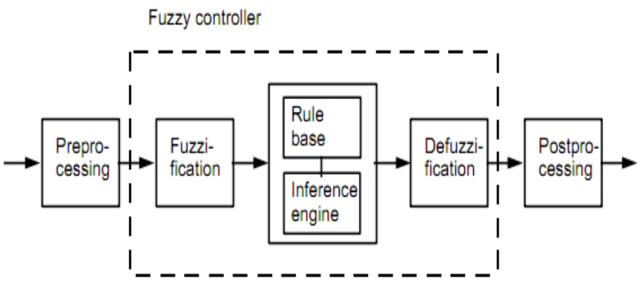

Fig.3 structure of a fuzzy logic system

Error in position and change of error in position are the two inputs taken as the input to the controller, whereas voltage is taken to be the output of the controller. The membership functions of the input and output are taken as triangular type whose range can be decided by observing the response of the system on varying the range of each membership function.fig 4 gives the membership plot of the input variable 'error', fig 5gives the membership plot of input variable 'change of error' and fig 6 gives the membership plot of output variable 'output'.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

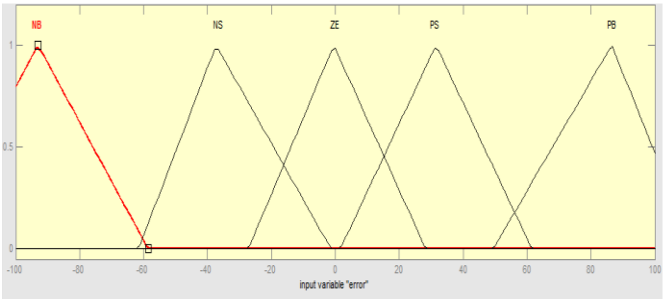

Fig 4 membership plot of input variable 'error'

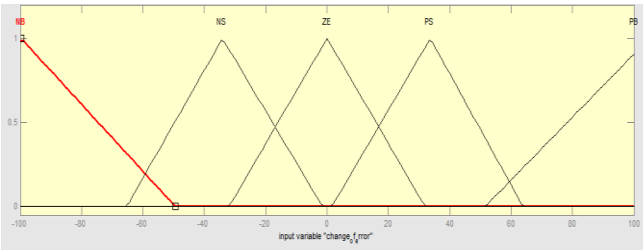

Fig 5 membership plot of input variable 'change of 'error'

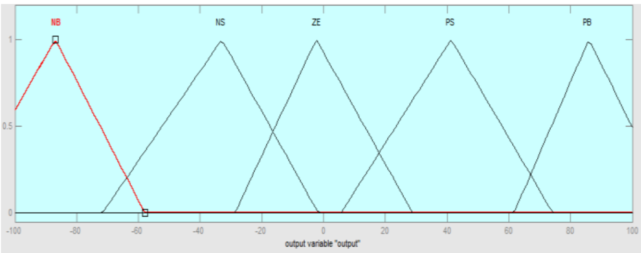

Fig 6 membership plot of output variable 'output'

The rule base is shown in table 1

Table 1 Rule base

e / de/dt	NB	NS	Z	PS	PB
NB	PB	PB	PB	PS	Z
NS	PB	PB	PS	Z	NS
Z	PB	PS	Z	NS	NB
PS	PS	Z	NS	NB	NB
PB	Z	NS	NB	NB	NB

Simulation result of the the step response of maglev with fuzzy logic controller is given in fig 7.

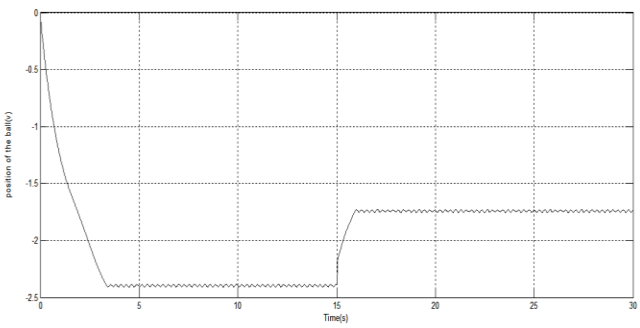

Fig 7.position of the ball of maglev using Fuzzy Logic Controller

Fig 8 gives the real time step response of maglev using Fuzzy Logic Controller.

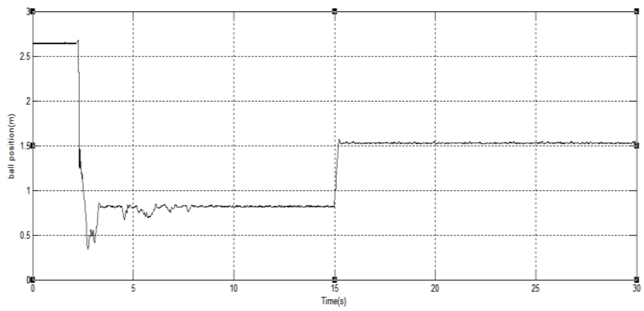

Fig 8 The real time step response of maglev with fuzzy logic controller

IV. LINEAR QUADRATIC REGULATOR(LQR)

A system can be expressed in state variable form as,

$$\dot{x} = Ax + Bu \qquad (1)$$

with $x(t)\in Rn$, $u(t)\in Rm$. .

Assuming here that all the states are measurable and seek to find a state-variable feedback (SVFB) control,

$$u = -Kx + v \qquad (2)$$

gives desirable closed-loop properties. The closed-loop system using this control becomes

$$\dot{x} = (A - BK)x + Bv = A_c x + Bv \qquad (3)$$

With the closed-loop plant matrix and the new command input.

To design a State Variable Feed Back(SVFB) that is optimal, performance index (PI) is defined as

$$J = \frac{1}{2}\int_0^{\infty} (x^T Qx + u^T Ru)dt \qquad (4)$$

Substituting the feedback control into thisyields is assumed to be zero since only internal stability properties of the closed loop system is considered.

$$J = \frac{1}{2}\int_0^{\infty} x^T (Q + K^T RK)x \, dt \qquad (5)$$

The objective of optimal design is to select the feedback gain K that minimizes the performance index J. Depending on the design parameters of the two matrices Q (n n matrix) and R (m m matrix) , the closed-loop system will exhibit a different response.Q should be always positive semi-definite and R to be positive definite. Since the plant is assumed to be linear and the performance index PI is quadratic, the problem of determining the feedback gain K to minimize J is called the Linear Quadratic Regulator (LQR).

To find the optimal feedback K, a constant matrix P is selected such that,

$$\frac{d}{dt}(x^T Px) = -x^T(Q + K^T RK)x \qquad (6)$$

Substituting (6) into (5) yields,

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

$$J = \frac{1}{2}\int_0^{\infty} \frac{d}{dt}(x^T P x)dt = \frac{1}{2}x^T(0)\,Px(0) \quad (7)$$

J is made independent of K. It is a constant that depends only on the auxiliary matrix P and the initial conditions.

Solving all the above equations (3),(5) and (7), following equation can be obtained,

$$A^T P + PA + Q + K^T RK - K^T B^T P - PBK = 0 (8)$$

f it is selected as,

$$K = R^{-1} B^T P$$

$$A^T P + PA + Q - PBR^{-1} B^T P = 0 \qquad (9)$$

This equation (9) is known as the ***algebraic Riccati equation(ARE).***

The simulation result of the step response of maglev with LQR is given in fig 9

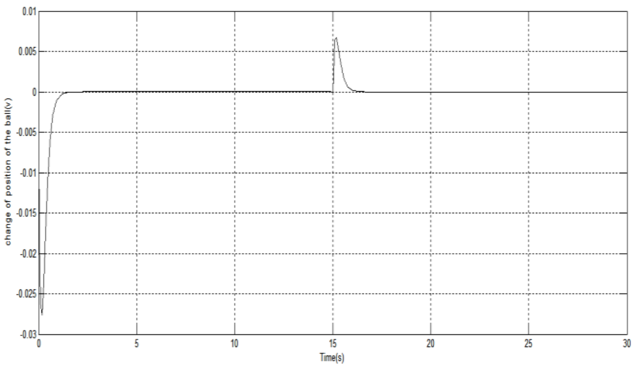

Fig 9.simulation result of error in position of the ball for a step input using LQR.

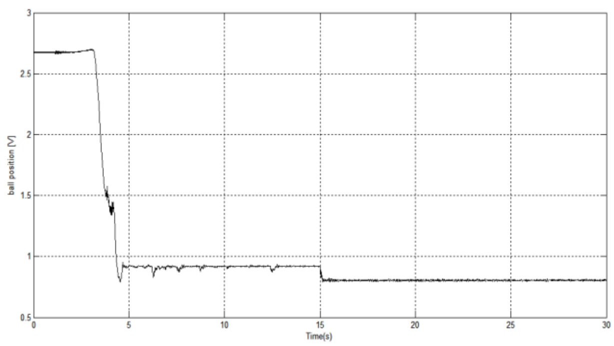

Fig 10 The real time step response of maglev using LQR

V. CONCLUSION

Magnetic levitation system is modelled.PID controller,LQR and Fuzzy logic controller is applied successfully to control the ball position in the magnetic levitation system in real time.

Three different parameters of PID controller,Fuzzy logic controller and LQR are compared. The parameters compared are rise time ,percentage peak overshoot and settling time. Comparison of the simulation of the test bed model is given in table 2 and comparison of the real time response is given as shown in Table 3

Table 2

Controller	**Rise time(s)**	**Peak overshoot %Mp**	**Settling time(s)**
LQR	.09	.4%	.5
Fuzzy Logic	.52	.1%	1.7

Table 3

Controller	**Rise time(s)**	**Peak overshoot %Mp**	**Settling time(s)**
LQR	.166	3.1%	.166
Fuzzy Logic	.166	.005%	1.16

Comparing the real bed results of both the controllers, from the Table 2 and 3, it is seen that, for both simulation and real time results, rise time is almost equal, Percentage peak overshoot is less in fuzzy logic controller and settling time is less in LQR control.

FLC is having an extra advantage that the exact model of the system is not required whereas LQR requires a thorough understanding of of the mathematical model. And it is very easy to tune FLC since it deals with linguistic variables.

REFERANCES

1. K. Ishaque, Y. Saleem, S. S. Abdullah, M. Amjad, M. Rashid, S. Kazi, Modeling and control of magnetic levitation system via fuzzy logic controller, IEEE 4th International Conference on in Modeling, Simulation and Applied Optimization, 2011, pp.1–6.
2. P. Suster , A. Jadlovska, Modeling and control design of magnetic levitation system, 2012 IEEE 10th International Symposium on Applied Machine Intelligence and Informatics, 2012, pp. 295–299.
3. A. Ahmad, Z. Saad, M. Osman, I. Isa, S. Sadimin, S. Abdullah, Control of magnetic levitation system using fuzzy logic control, IEEE Second International Conference on Computational Intelligence, Modeling and Simulation, 2010, pp. 51–56.
4. D. L. Trumper, S. M Olson, P. K Subrahmanyan, Linearizing control of magnetic suspension systems, IEEE Transactions on Control Systems Technology, vol. 5, no. 4, pp. 427–438, 1997.
5. C.-F. Juang, J.-Y. Lin, C.-T. Lin, Genetic reinforcement learning through symbiotic evolution for fuzzy controller design, IEEE Transactions on Systems, Man, and Cybernetics, vol. 30, no. 2, pp. 290–302, 2000.
6. K.Ogata, Y.Yang, Modern control engineering.
7. F. Lewis, Linear quadratic regulator (LQR) state feedback design, 1998.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)