Comparative Analysis of PID and Fuzzy Controller for Control of Magnetic Levitation System

Dhanraj Suman, Rajesh Bhatt

Abstract— This paper provides a comparative analysis of performance of different controllers for magnetic levitation system. Magnetic levitation system is a highly nonlinear and unstable system and it is very challenging to develop accurate controller for the same. This paper provides mathematical model of magnetic levitation system and develops controller for the same. Two different controllers such as PID controller and fuzzy controller have been designed and simulation results have been provided.

Index Terms*: *Magnetic levitation system; PID controller; Fuzzy controller

I. INTRODUCTION

Magnetic Levitation is a method by which an object is suspended in the air with no support other than the magnetic field. However difficulty in stably levitating an object by using inverse square law is studied by Samuel Earnshaw in 1842. Earnshaw's Theorem states that a point charge cannot have stable equilibrium position when a static force is applied following the inverse square law. This theorem is also applicable to the magnetic force of the permanent magnet. Werner Braunbeck extended the analysis to uncharged dielectric bodies in electrostatic fields and magnetic bodies in magnetostatic fields in 1939 and also by Papas (1977). It was observed that for diamagnetic material, super conducting body and conducting body with eddy current induced on them can have stable equilibrium point.

Magnetic levitation is an electromechanical coupling concept. The magnetic field is created by electromagnet coil which is electrical part attracts the magnetizable material or object. The magnetic force is controlled by controlling the current in the coil. When the object moves to close the magnet the current in the coil is decreased and vice versa. Magnetic Levitation is an open loop unstable system. The whole system is an electro-mechanical coupled system. Thus modeling of the system is difficult task which is first carried out. Since the system is nonlinear and unstable thus control problem is challenging.

This paper provides the comparative analysis of PID controller and fuzzy controller for control of magnetic levitation system. This paper is organized as follows. Section II provides the related work. Section III provides mathematical model of magnetic levitation system. Section IV provides details of PID controller. Section V provides details about fuzzy controller. Section VI provides details of results and discussion. Section VII concludes the paper.

Revised Version Manuscript Received on May 27, 2016.
Dhanraj Suman, Department of Electronics Engineering, University College of Engineering, Rajasthan University of Technology, Kota (Rajasthan). India.

Rajesh Bhatt, Department of Electronics Engineering, University College of Engineering, Rajasthan University of Technology, Kota (Rajasthan). India.

II. RELATED WORK

Reference	Year	Controller
[1]	2011	Nonlinear controller
[2]	2004	Reinforced neural network controller
[3]	2015	Output feedback control
[4]	2015	Robust Control
[5]	2014	Identification using ARX model
[6]	2013	Nonlinear model predictive control
[7]	2014	PID control
[8]	2013	LQR-PID
[9]	2016	Input-output feedback linearization
[10]	2016	PID control
[11]	2002	H-∞ control
[12]	2012	Multi-rate ripple free dead-beat control
[13]	2001	Adaptive control
[14]	1996	Linear and nonlinear control
[15]	2008	Adaptive output feedback control
[16]	2010	Total sliding mode and PSO
[17]	2005	Fuzzy sliding mode
[18]	2004	Dynamic surface control
[19]	2007	Adaptive backstepping
[20]	2004	Development of low cost kit for Maglev
[21]	2011	PID via PSO

III. MAGNETIC LEVITATION SYSTEM

Magnetic levitation system is a highly nonlinear and unstable system. Fig. 1 shows the control block diagram of magnetic levitation system and Fig. 2 shows the actual experimental setup of magnetic levitation system.

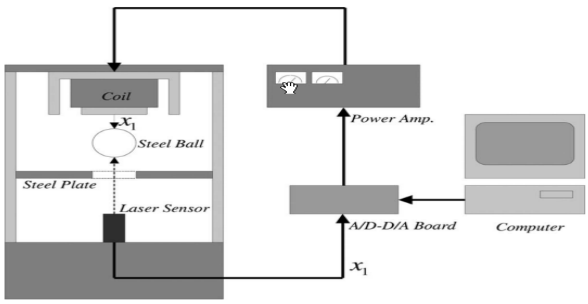


Fig. 1. Closed loop control of magnetic levitation system

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

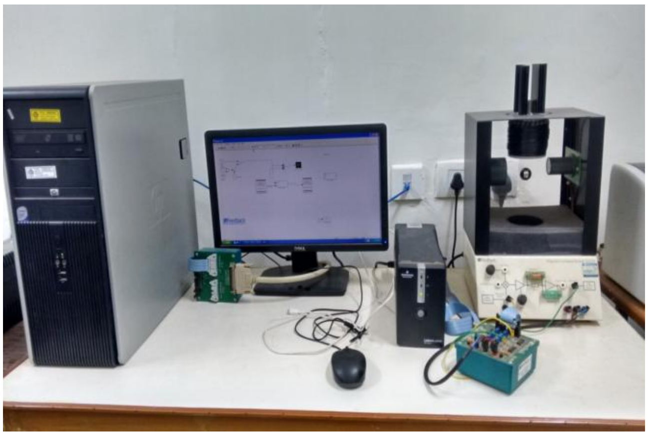


Fig. 2. Actual experimental setup

A. Mathematical Model

Fig. 3 shows the free body diagram of magnetic letivation system under study.

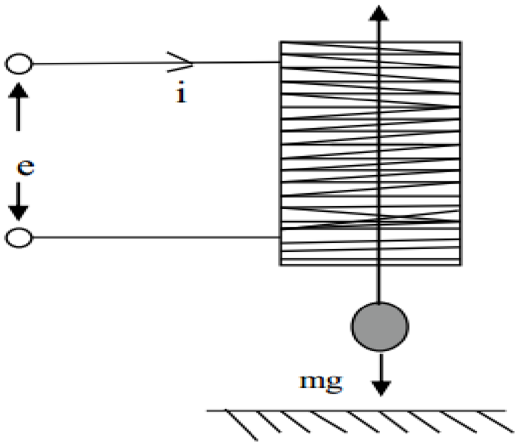


Fig. 3. Freebody diagram of magnetic letivation system

Using newton's law of motion, $F(x,i) - mg = ma$ (1)

Eq(1) can be rewritten as $F(x,i) - mg = m\dfrac{d^2x}{dt^2}$ (2)

Eq(2) can be rewritten as $m\ddot{x} = F(x,i) - mg$ (3)

Magnetic field due to small segment of wire can be represented as $dB = \dfrac{\mu_0}{4\pi}\dfrac{idlr}{r^3}$ (4)

From Eq(4) we can get $B = \dfrac{\mu_0 i}{2}\dfrac{a^2}{\left(a^2+d^2\right)^{1.5}}$ (5)

From Fig. 4, $\sin\theta_1 = \dfrac{r}{\sqrt{(l+x)^2 + r^2}}$

and $\sin\theta_2 = \dfrac{r}{\sqrt{r^2 + x^2}}$

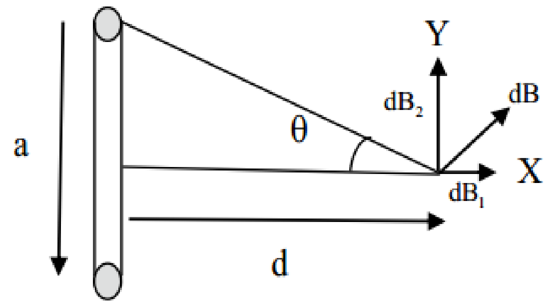


Fig. 4. Magnetic field countour

Magnetic flux can be calculated as

$$B = \frac{\mu_0}{2} nI \int \frac{r^2}{\left(r^2 + l^2\right)^{1.5}}$$

$$B = \frac{\mu_0}{2} nI \left(\cos\theta_1 - \cos\theta_2\right)$$

$$B = \frac{\mu_0}{2} nI \left[\frac{X+l}{\sqrt{r^2 + (X+l)^2}} - \frac{X}{\sqrt{r^2 + X^2}}\right]$$

The linearized model of magnetic levitation system can be found as $G_p(s) = \dfrac{-0.0025}{s^2 + 0.0075}$

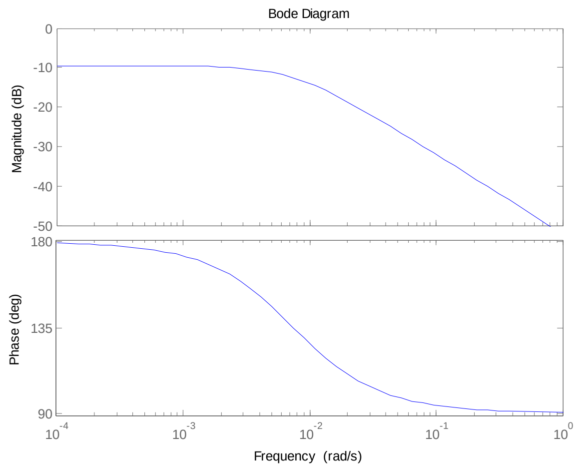


Fig. 5. Frequency response of magnetic levitation system

IV. DESIGN OF PID CONTROLLER

The transfer function of PID controller can be expressed as

$$G_c(s) = K_c\left(1 + \frac{1}{T_i s} + T_d s\right)$$

Here K_c is proportional gain; T_i is integral gain; T_d is derivative gain

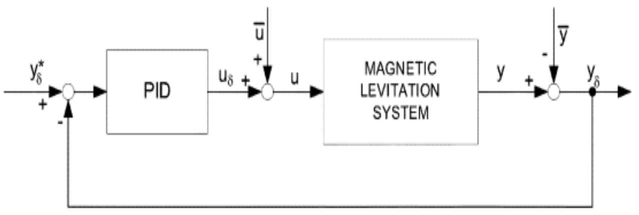


Fig. 6. Closed-loop control system of magnetic letivation system using PID controller

V. DESIGN OF FUZZY CONTROLLER

Fuzzy Logic is extension of Boolean logic which incorporates partial values of truth. Fuzzification is generalization of theory from discrete to continuous. Fuzzy logic is important to artificial intelligence. Fuzzy logic allows computers to answer 'to a certain degree' unlike Boolean logic (one extreme or the other). Computers are allowed to think more 'human-like'. Nothing in our perception is extreme. However, it is true only to a certain degree. In fuzzy logic, machines think in degrees. It can solve problems in the cases where there is no simple mathematical model. Fuzzy logic solves highly nonlinear processes. Fuzzy logic uses expert knowledge to make decisions. To design a fuzzy controller; fuzzy inference system is developed. The schematic diagram of fuzzy inference system is shown in fig. 7.

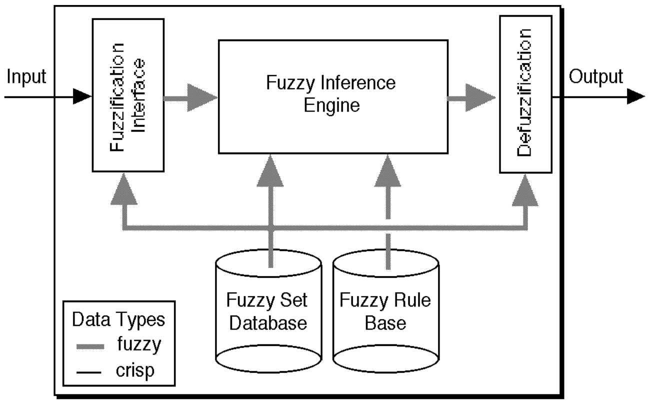
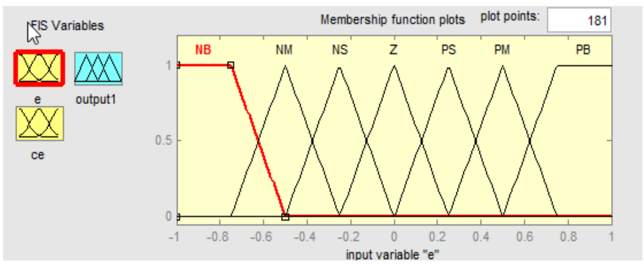
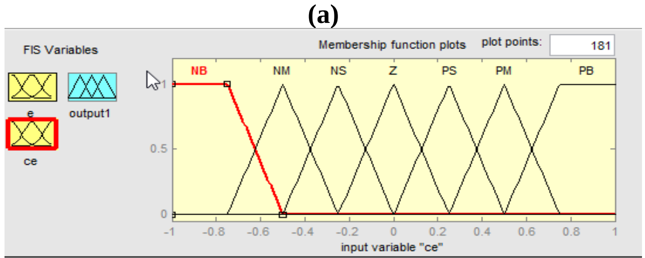


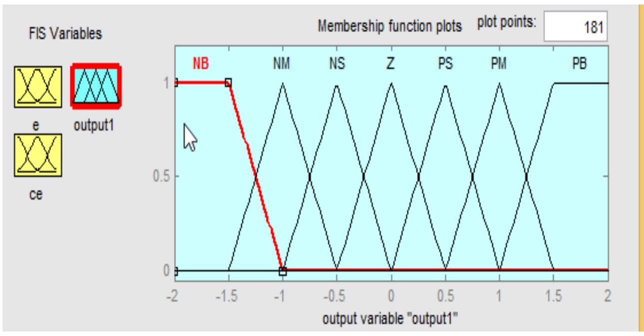
Fig. 7. Fuzzy inference system



(a)



(b)



(c)

Fig. 8. Input and output membership of fuzzy inference system

Table I: Fuzzy rule base

$u(t)$		$\Delta e(t)$						
		NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
$e(t)$	**NB**	NB	NM	NS	NB	PS	PM	PB
	NM	NM	NM	NM	NM	PS	Z	PB
	NS	NB	NM	NM	Z	PS	PM	PB
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	Z	Z	Z	PS	PS	PM	PB
	PM	Z	Z	Z	PM	PM	PM	PB
	PB	PB	PB	PB	PB	PB	PB	PB

The fuzzy controller has 2 inputs i.e. $e(t)$ and $\Delta e(t)$

$$\Delta e(t) = e(t) - e(t-1)$$

NB: Negative Big; NM: Negative Medium; NS; Negative small; Z: Zero; PS: Positive Small; PM: Positive Medium; PB: Positive Big

VI. SIMULATION RESULTS

This section provides simulation results for magnetic levitation system using different controllers. Fig. 9 shows the output response of maglev system using a PID controller and a pulse input.

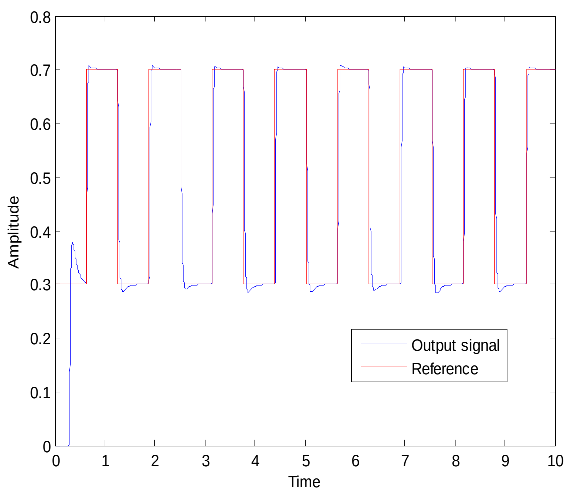


Fig. 9. Output of PID controller with pulse as input signal

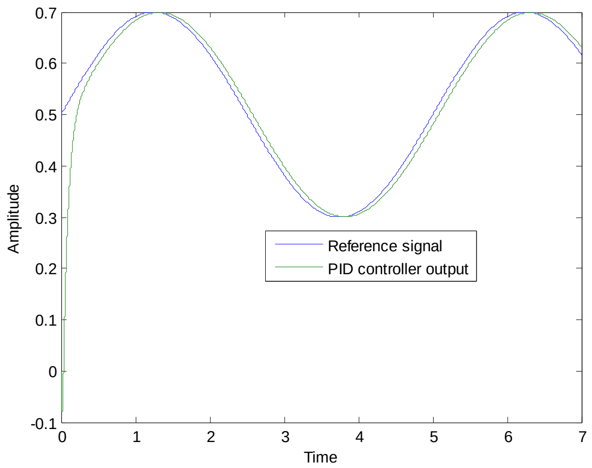


Fig. 10. Output of PID controller with sinusoidal input signal

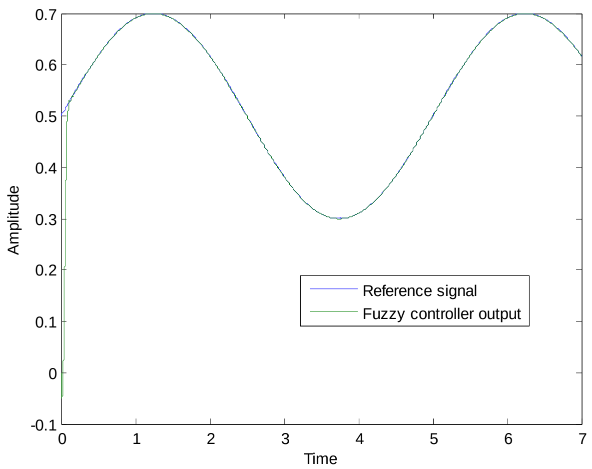


Fig. 11. Output of fuzzy controller with sinusoidal input signal

Fig. 10 shows the output response of maglev system using PID controller with a sinusoidal input. Fig. 11 shows the output response of fuzzy controller with a sinusoidal input.

VII. CONCLUSION

This paper provides a comprehensive analysis of different control strategy for magnetic levitation system. PID and fuzzy control of magnetic levitation system has been provided with necessary simulation and theoretical background. A comprehensive literature review of the area has been carried out. The controller response has been evaluated with different input and it is found out that fuzzy controller provides better output because the mean square error (MSE) is zero in fuzzy controller.

REFERENCES

1. Rafael Morales, Vicente Feliu, and Hebertt Sira-Ramírez, "Nonlinear control for magnetic levitation system based on fast online algebric identification of the input gain," IEEE Transactions on Control System Technology, vol. 19. No. 4, Jul 2011, pp. 757-771.
2. Panayiotis S. Shiakolas, Stephen R. Van Schenck, Damrongrit Piyabongkarn, and Ioannis Frangeskou, "Magnetic Levitation Hardware-in-the-Loop and MATLAB-Based Experiments for Reinforcement of Neural Network Control Concepts," IEEE Transactions on Education, vol. 47, no. 1, Feb 2004, pp. 33-1
3. F. Beltran-Carbajal, A. Valderrabano-Gonzalez, J.C. Rosas-Caro, A. Favela-Contreras, "Output feedback control of a mechanical system using magnetic levitation," ISA Transactions, 57, 2015, pp. 352-359
4. Jinquan Xu, He-Hwa Chen, Hong Guo, "Robust levitation control for maglev systems with guranteed bounded airgap," ISA Transactions, 59, 2015, pp. 205-214.
5. Yemei Qin, Hui Peng, Wenjie Ruan, Jun Wu, Jiacheng Gao, "A modeling and control approach to magnetic levitation system based on state-dependent ARX model," Journal of Process Control, 24, 2014, pp. 93-112.
6. Thomas Bachle, Sebastian Hentzelt, Knut Graichen, "Nonlinear model predictive control of a magnetic levitation system," Control Engineering Practice, 21, 2013, pp. 1250-1258.
7. Wen Yu, Xiaoou Li, "A magnetic levitation system for advanced control education," in Proc. International Federation of Automatic Control, 2014, pp. 9032-9037.
8. Vinodh Kumar E, Jovitha Jerome, "LQR based optimal tuning of PID for trajectory tracking of magnetic levitation system," Procedia Engineering, 64, 2013, pp. 254-264.
9. Santanu Kumar Pradhan, Bidyadhar Subudhi, "Nonlinear control of a magnetic levitation system using a new input-output feedback linearization," in Proc. International Federation of Automatic Control, 49-1, 2016, pp. 332-336
10. Shekhar Yadav, S K Verma, S K Nagar, "Optimized PID controller for magnetic levitation system," in Proc. International Federation of Automatic Control, 49-1, 2016, pp. 778-782
11. Jing-Chung Shen, "H-∞ control and sliding mode control of magnetic levitation system," Asian Journal of Control, vol. 4, no. 3, 2002, pp. 333-340
12. Hatem Elaydi and Mohammed Elamassie, "Multi-rate ripple free dead beat control for nonlinear system using diophantine equations," IACSIT International Journal of Engineering and Technology, vol. , no. 4, 2012, pp. 489-494
13. Zi-Jiang Yang, Michitaka Tateishi, "Adaptive robust nonlinear control of a magnetic levitation system," Automatica, 37, 2001, pp. 1125-1131
14. Walter Barie, John Chiasson, "Linear and nonlinear state space controllers for magnetic levitation," International Journal of Systems Science, vol. 27, no. 11, 1996, pp. 1153-1163
15. Zi-Jiang Yang, Kazuhiro Kunitoshi, Shunshoku Kanae and Kiyoshi Wada, "Adaptive robust output-feedback control of magnetic levitation system by K-filter approach," IEEE Transactions on Industrial Electronics, vol. 55, no. 1, Jan 2008, pp. 390-399
16. Rong-Jong Wai, Kun-Lun Chuang, and Jeng-Dao Lee, "On-line supervisory control design for Maglev transportation system via total sliding mode approach and particle swarm optimization, IEEE Transactions on Automatic Control, vol. 55, no. 7, July 2010, pp. 1544-1559
17. CHAO-LIN KUO, TZUU-HSENG S. LI and NAI REN GUO, "Design of a novel fuzzy sliding mode control for magnetic ball levitation system," Journal of Intelligent and Robotic Systems, 42, 2005, pp. 295-316
18. Zi-Jiang Yang, Kouichi Miyazaki, Shunshoku Kanae, and Kiyoshi Wada, "Robust position control of a magnetic levitation system via dynamic surface control technique," IEEE Transactions on Industrial Electronics, vol. 51, no. 1, Feb 2004, pp. 26-34
19. Faa-Jeng Lin, Li-Tao Teng, and Po-Huang Shieh, "Intelligent adaptive backstepping control system for magnetic levitation apparatus," IEEE Transactions on Magnetics, vol. 43, no. 5, May 2007, pp. 2009-2018
20. Kent H. Lundberg, Katie A. Lilienkamp, and Guy Marsden, "Low-cost magnetic levitation project kits," IEEE Control System Magazine, 2004, pp. 65-69
21. Rong-Jong Wai, Jeng-Dao Lee, and Kun-Lun Chuang, "Real-time PID control strategy for Maglev transportation system via particle swarm optimization," IEEE Transactions on Industrial Electronics, vol. 58, no. 2, Feb 2011, pp. 629-646

AUTHOR PROFILE

Dhanraj Suman pursuing his M.Tech in Control and Instrumentation specialization in Department of Electronics, University College of Engineering, Rajasthan Technical University, Kota, Rajasthan

Rajesh Bhatt is Associate Professor, Department of Electronics, University College of Engineering, Rajasthan Technical University, Kota, Rajasthan