Modeling and Analysis of Magnetic Levitation System Using Fuzzy Logic Control

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Abstract— **This paper presents the investigation on a system model for the stabilization of a Magnetic Levitation System (Maglev's). Furthermore, the investigation on Proportional Integrated Derivative Controller (PID) also reported here. In this paper shows to design both PID and Fuzzy Logic Control (FLC) based on the system model. Maglev's give the contribution in industry and this system has reduce the power consumption, has increase the power efficiency and reduce the cost maintenance. The common applications for Maglev's are Maglev's Power Generation, Maglev's trains and Maglev's ball bearing less system. In this study, it has also been observed that the basic design of Maglev's is an arrangement of electromagnets placed on top of the plant and makes the ball levitated in the air. The focus of this study is that to design the controller that can cope with Maglev's which highly nonlinear and inherently unstable. The modeling system is simulated using MATLAB simu link. This paper presents the comparison output for both PID Controller and Fuzzy controller to control the ball levitate on the air. The ISE performance index is shown to compare the performance both controller.**

Index Terms—Magnetic Levitation System (Maglev's), Fuzzy Logic Control, PID control.

I. INTRODUCTION

Now a days, Magnetic Levitation System or in short name Maglev's is very usable system that can be applied in many application area such as in magnetic bearings, high speed trains, vibration isolation, levitation of wind power generation, levitation of molten metal in induction furnaces, and levitation of metals labs during manufacturing. This Maglev's can be categorized as a repulsive systems and this system based on the source of levitate forces. These type of systems are normally is unstable and it is described as highly non linear where it is difficult to control the system. It is very challenging in order to construct the high performance feed back controllers to regulate the position of the levitation ball. In 1996, Walter Barietetal come out with idea linear and nonlinear state space controllers for magnetic levitation system. From the author said, the two state-space controllers are compared together in terms of their performance in controlling the hall's position. The first controller is based on transformation along with non linear state feed back is used to linearize the system. From this paper shows that the position tracking error of the system was oscillation about±0.45mm [1].

From the author Dan Cho Et al come out the idea of sliding mode control(SMC)to over come the parameter uncertain ties and reject disturbances to achieve robust performance. In this paper present the SMC was applied to a magnetic levitation system. It is found that the on on feed back linearization where a nonlinear state-space transformation along with nonlinear state feedback is used to linearize the system. From this paper shows that the position tracking error of the system was oscillation about ± 0.45 mm[1].From the author Dan Cho Et al come out the idea of sliding mode control (SMC) to overcome the parameter uncertainties and reject disturbances to achieve robust performance. In this paper present the SMC was applied to a magnetic levitation system. It is found that the performance of the SMC is better than that of the classical controllers[2]

The conventional controller such as PID controller is very reliable and simple controller to design. This controller used the method based on a linearization of the systems dynamics and compensates the effects of the non-modelled nonlinearity. Using this approach certain systems can be stabilized close to their nominal operating point. From the author, WenbaiChen et al said, PID controller can be a robustand reliable system if the PID parameter can be determine dortuned that make the system very stable. The author proposed the method chaos optimization that can give contribution in PID parameter setting. The author also said with chaos optimization applied to PID parameter,the performance of PID controller was increase[3].

The fuzzy set theory was introduced by Zadehetal[7]
Has become as a powerful modeling tool that can work with the unstable system and highly nonlinearities of modern control. It was intelligent control and the good thing about fuzzy logic control, the parameter of fuzzy logic is very easy to tune by non expert person if compare with PID controller that need experience person to tune the parameter. The author, Tzuu-Hseng 0SLietal said the Fuzzy Sliding Mode Controller(FMSC) can achieve the asymptoticst ability of the system. This FMSC controller very helpful because with this controller, we need not to know in detail [8]. From the author, Chao-linKuo proposed the Novel Fuzzy Sliding- Mode Control(NFSMC)and from his paper presents the comparison effect of uncertainty in the ballmass between Sliding-Mode controller, Fuzzy Sliding-Mode controller and NFSMC.NFSMC show the minimum IAE and ISV performance[9].
rom the study, Fuzzy Logic Controller has good potential to stabilize the ballevitation in this research.

II RESEARCH METHODOLOGY

A Dynamic Model Analysis

The magnetic levitation system experiment is a magnetic Ball suspension system which is used to levitate a steel ball on air by the electromagnetic force generated by an electromagnet.

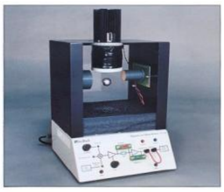

Figure 1 Maglev Plant Equipment

The magnetic ball suspension system consists of an electromagnet, a ball rest, a ball position sensor, and a steel ball. The magnetic ball suspension system can be categorized into two systems: a mechanical system and an electrical system. The ball position in the mechanical system can be controlled by adjusting 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.

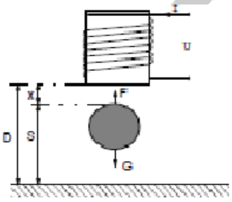

Figure 2 Schematic of Magnetic Levitation System

The voltage equation of the electromagnetic coil is given in equation 1

$$U = IR + L\frac{di}{dt} \qquad (1)$$

The magnetic force applied by the electromagnet is opposite direction compare to gravity force and it maintains the suspended steel ball levitated. The magnetic force F depends on the electromagnet current I, electromagnet characteristics and air gap x between the steel ball and the electromagnet. The motion of the steel ball in the magnetic field is expressed as

$$F - mg = -m\frac{d^2x}{dt^2} \qquad (2)$$

$$F = \frac{\beta\, i^2}{h} \qquad (3)$$

In the equation 3, shows that the current flows in the coil is nonlinear. The steady state of the operating point air gap between mass and the electromagnet is maintained by generating on magnetic force, which is adjusted so that the gravitational force of the steel ball is balanced. Using deviation variables, the small differences from the operating points are normalized over operating spaces and they are defined as follows:

$$F = F_0 + \left.\frac{\partial F}{\partial X}\right|_{I_0}.(X - X_0) + \left.\frac{\partial F}{\partial I}\right|_{X_0}.(I - I_0) \qquad (4)$$

Where f is the normalized resultant force, x is the normalized air gap, i is the normalized current and u is the normalized voltage.

$$f = \frac{F-G}{G} \quad x = \frac{X-X_0}{D} \quad i = \frac{I-I_0}{I_{\max}} \quad u = \frac{V-V_0}{V_{\max}} \qquad (5)$$

$$f = -m.D/G\cdot\frac{d^2x}{dt^2} = -m\frac{D}{m.g}\frac{d^2x}{dt^2} = -\frac{D}{g}\frac{d^2x}{dt^2} \qquad (6)$$

$$f = \frac{D}{G}\left.\frac{\partial F}{\partial X}\right|_{I_0}.x + \frac{I_{\max}}{G}.\left.\frac{\partial F}{\partial I}\right|_{X_0}.i \qquad (7)$$

$$u = i + \frac{L}{R}\frac{di}{dt} \qquad (8)$$

$$K_e = \frac{I_{\max}}{G}\left.\frac{\partial F}{\partial I}\right|_{X_0}, T_e = \frac{L}{R}, K_m = -\frac{D}{G}\left.\frac{\partial F}{\partial X}\right|_{I_0}, T_m = \sqrt{\frac{D}{g}} \qquad (9)$$

Then the equation (5), (6), and (7) can be rewritten as

$$f = -{T_m}^2.\frac{d^2x}{dt^2} \qquad (10)$$

$$f = -K_m.x + K_e.i \qquad (11)$$

$$u = i + T_e.\frac{di}{dt} \qquad (12)$$

Then the block diagram of the linearised model as shown in Figure 3.

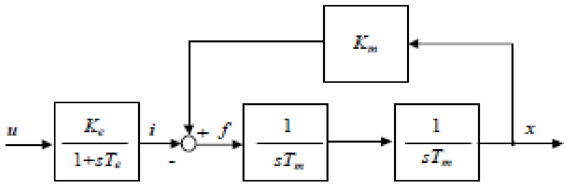

Figure 3 Block Diagram of Linearization System

B Fuzzy Logic Control:

Fuzzy logic controller design is based on the linguistic description of the control strategy. There are specific components characteristic of a fuzzy controller to support a design procedure. In the block diagram in Figure 4, the controller is between a preprocessing block and a post processing block. The following explains the diagram block by block. There are three sources of nonlinearity in a fuzzy controller.

- The Inference Engine-If the connectives *and* and *or* are implemented as for example Min and Max respectively,they are nonlinear.
- The Defuzzification - Several defuzzificati on methods are nonlinear.

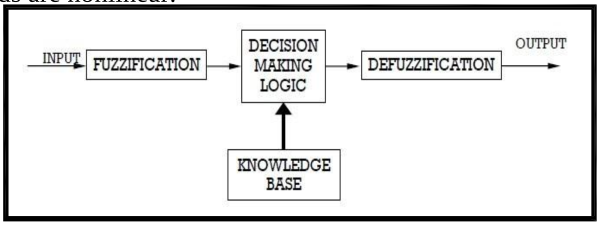

Figure4:Block Diagram of Fuzzy Logic Controller

The first block inside the controller is fuzzification, which converts each piece of input data to degrees of membership by a lookup in one or several membership functions.

There is a degree of membership for each linguistic term That applies to that input variable. The degree of membership is the fuzzified input and this proceeds to the rule base. A comparison to a pre-tuned membership function, such as that given in Figure5, Figure6, Figure7andFigure 8 must be carried out for this purpose.

A possible of the membership functions for the three mentioned variables of the magnetic levitation system represented by a fuzzy set is as follows:

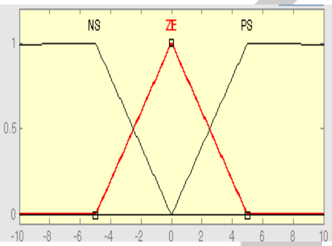

Figure5.Membership Function for Input,Error

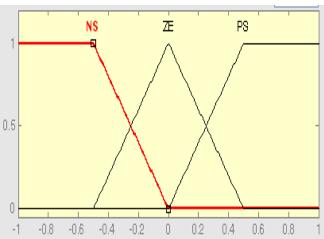

Figure6.Membership Function for Input,Rate of Error

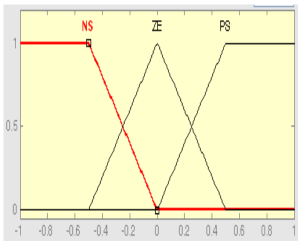

Figure7.Membership Function for Input, Rate of Error

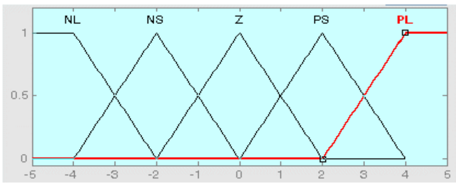

Figure8.Membership Function for Output

The rules may use several variables both in the condition and the conclusion of the rules. The controller scan therefore be applied to both multi-input-multi-output (MIMO) problems and single-input-single-output(SISO) problems. The typical SISO problem is to regulate a control signal based on an error signal. The rule base utilizes *if then* condition statements to alter the controlled variable. The 'inference engine' is part of the rule base. Simple syllogisms are used to*'infer'* a decision from one or several conditions. The rule base used in the magnetic levitation system can be represented by the following **Table 1**with fuzzy terms derived by modeling the designer's knowledge and experience.

Table 1 Rulebase

Output=Voltage		Deltae		
		NS	Z	PS
e	NS	NL	NS	ZE
	Z	NS	ZE	PS
	PS	ZE	PS	PL

The resulting fuzzy set must be converted to a number that can be sent to the process as a control signal. This operation is called defuzzification. Defuzzification is the inverse process by which the decision take non the input is transformed in to a crisp output.

C. Simulation using MATLAB

This software is able to send data (desired value of current) to fuzzy controller. Firstly plot a graph of detected current versus time to monitor the performance of the system. Sample of the MATLAB simulation diagram is showninFigure9,Figure10andFigure11.

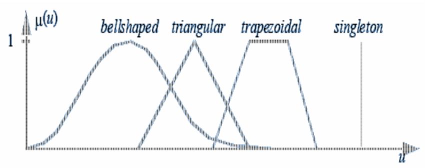

Figure9 Different shapes like bell-shaped, triangular, trapezoidal and singleton.

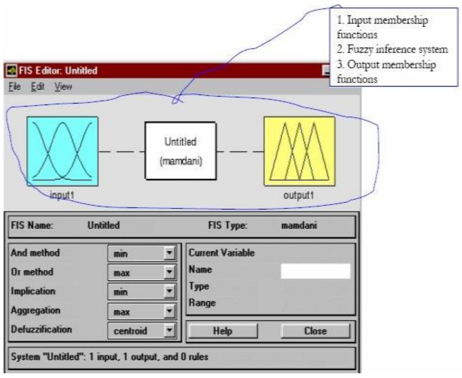

Figure10Fuzzytoolbox.

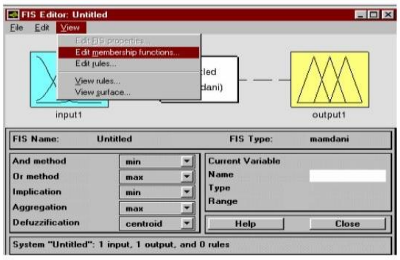

Figure11Membership functions

III. RESULT AND DISCUSSION

A. Simulation result with the MATLAB controller, PID Controller and Fuzzy Logic Controller

The input gains to PID controllers are; Kp=3000,Td =100andTi=50000.The step input is set as:step time= 0.3s,initial value=0.05,final value=0.05.
The output of PID controller, MATLAB design controller and fuzzy logic controller show in figure12.

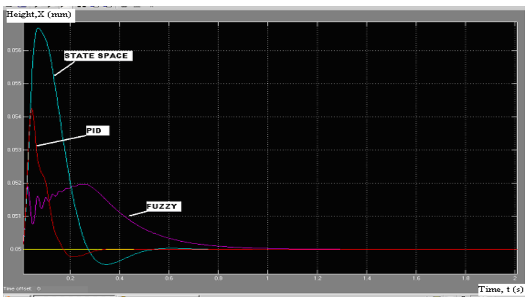

Figure12 The output response with PID controller,Kp=3000,Td=100 and Ti=50000,output response with Fuzzy Logic controller,Error gain= 5.8,Change of error gain=0.03 and Off set gain=3.3 and MATLAB Design controller.

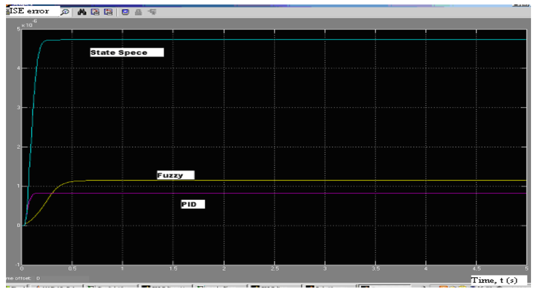

Figure13 Performance of all controllers using ISE method

From the Figure13 shows:

i) ISE performance index for fuzzy:$6.399e^{-7}$
ii) ISE performance index for PID:$8.26e^{-7}$
iii) ISE performance index for Mat lab Controller:$4.735e^{-6}$

The ITAE provides the best selectively of the performance indices; that is, the minimum value of the integralis readily discernible as the system parameters are varied.Here only shown the performance index for ISE because it almost gives at is faction because minimizationo f ISE is often of practical significance. Performance indices are useful for analysis and designof control systems.Below show the performance of controller using rise time, maximum over shoot and settling time. Performance of controller show as

<u>Fuzzy Logic Controller:</u> Max over shoot=0.0513
Ri-setime=0.0523s,at0.005117.
Settling time=0.9898s.
Percent over shoot=2.6%.

<u>PID Controller:</u>
Max over shoot=0.0542
Risetime=0.0335s,at0.005378.
Settling time=0.3021s.
Percent over shoot=8.4%.

<u>MAT LAB Controller</u>
Max over shoot=0.0567
Risetime=0.0523s,at0.005603.
Settling time=0.5024s.
Percent over shoot=13.4%.

From all data shows that least error is coming from Fuzzy controller. The biggest error scome from the controller designed by Mat lab.

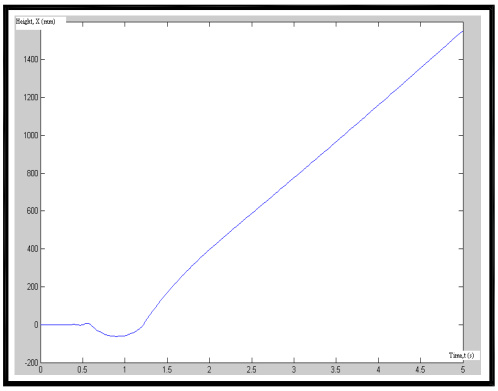

Figure14SimulinkofMagneticLevitationSystem

Figure14 show the simulink block in the MATLAB tool. From figure, ithas the design of PID controller, Fuzzy logic controller and MATLAB controller.

B Discussion for Simulation result with the Fuzzy Logic Controller.

In Figure15, shows the system is unstable system. When no controller applied to the system the ball will fall down or attract to magnetic.

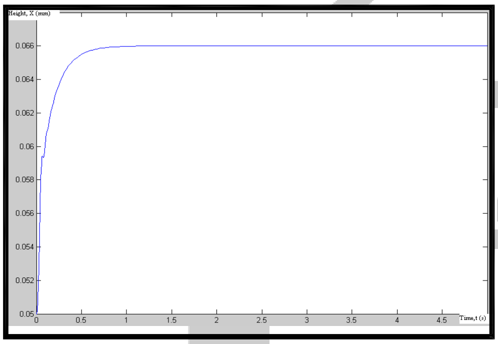

Figure15:No controller apply to the Magnetic Levitation System

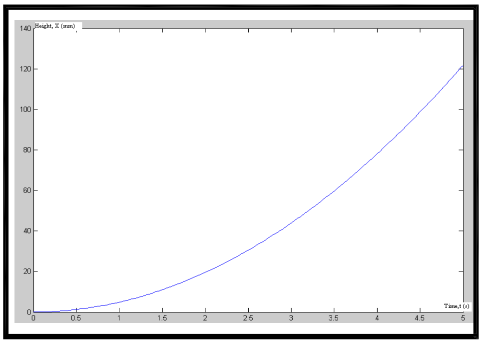

Figure16:Only Error applied in membership

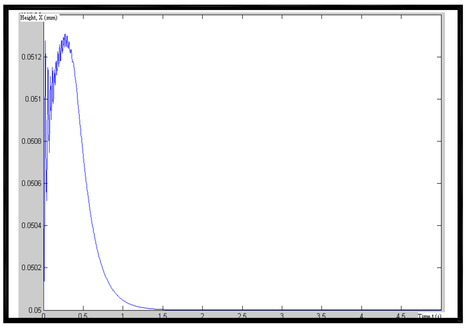

Figure17 Errorgain=2,diferror=0.02,outputgain=400, integralerrorgain=0.

In Figure 16, shows that only error applied in membership functionin Fuzzy Logic Controller,the output from the MAGLEV tends to unstable. Then when applied the change of error in the membership function show in Figure17, the output now to best eady state value.But still now good because haves teady state error.

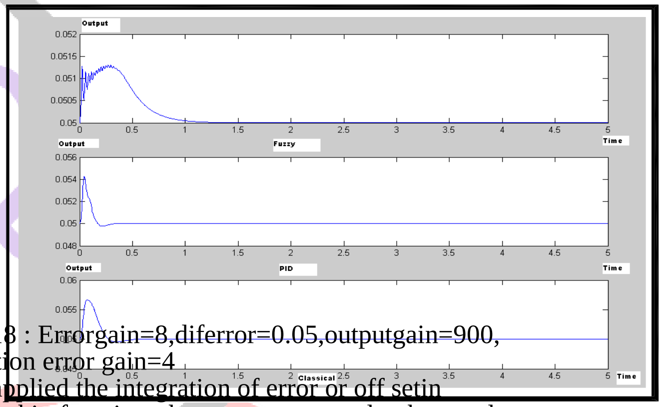

Figure18 : Errorgain=8,diferror=0.05,outputgain=900, integration error gain=4

When applied the integration of error or off setin membership function, the output now tend to best eady state value with zero steady state error. It shows in Figure18.

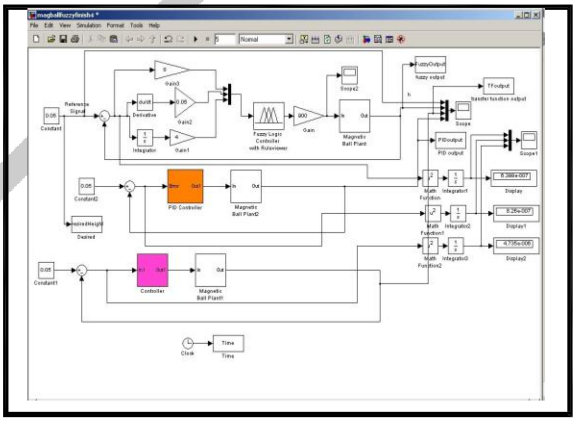

Figure19Comparison outputresultfromallcontroller

In Figure19 : shows the comparison output from all controllers. From observation, it shows that the fuzzy controller has best performance compared to other controller.It can seen from ISE figure that shown in Figure 13.

IV.CONCLUSION AND FUTUREWORK

The output of the magnetic levitation system is observed and analyzed. A part from that, comparison sare made to see which systems give better performances by considering the time settling, time peak, steady state error and how much oscillations occurs.

From the figures, we can conclude that the PID controller gain is proportional with time integral. This means when the K_p value is bigger, the output will have smaller value of off set but the more oscillatory the process becomes. Where else, if the Ti is bigger, the off set is bigger but the oscillation is less.

As for the fuzzy controller, the response is slower than the PID controller. However, fuzzy controller shows the best performance in terms of lowest over soo among three controller and no steady state error. It reaches the desired set point at t=0.98sec. The PID controller has steady state error and with the best adjustment, it reaches to the desired set point. Scaling factors are most important with respect to fuzzy controller performance and provide a guide line for tuning. It was shown that the scaling Factors play a role similar to that of the gain coefficients for

Conventional controllers.

In the future, it can be implemented the PID-Fuzzy controller or Neural Network controller to control the MAGLEV system.

Lastly, this simulation can be implemented to magnetic Levitation system,CE152model. Then it can be compared the result between simulation value and the actual plant value

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