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Comparisons of Fuzzy MRAS and PID Controllers for EMS Maglev Train

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Abstract: In this paper, a Magnetic Levitation (MAGLEV) train is designed with a single degree of freedom electromagnet-based system that allows the train to levitate vertically up and down. Fuzzy logic, PID and Mras controllers are used to improve the Magnetic Levitation train passenger comfort and road handling. A matlab Simulink model is used to compare the performance of the three controllers using step input signals. The stability of the Magnetic Levitation train is analyzed using root locus technique. Controller output response for different time period and change of air gap with different time period is analyzed for the three controllers. Finally the comparative simulation and experimental results demonstrate the effectiveness of the presented fuzzy logic controller.

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1. Introduction

Magnetic levitation is the process of levitating an object by exploiting magnetic fields. If the magnetic force of attraction is used, it is known as magnetic suspension. If magnetic repulsion is used, it is known as magnetic levitation.

Magnetically Levitated (Maglev) trains differ from conventional trains in that they are levitated, guided and propelled along a guide way by a changing magnetic field rather than by steam, diesel or electric engine.

The magnetic levitation system is a challenging nonlinear mechatronic system in which an electromagnetic force is required to suspend an object in the air and it requires a high-performance controller to control the current through the superconducting magnets.

This research is aimed at developing methods of improving efficiency in transportation. Additional applied technologies that may have uses in other applications, from inter-satellite communications, to magnetic field probes.

The two main types of maglev Technology are:

- Electromagnetic suspension (EMS): uses attractive force system to levitate. Which is a German technology.
- Electrodynamic suspension (EDS): uses repulsive force system to levitate. Which is a Japan technology.

2. Mathematical Models

2.1 Maglev train system mathematical model

The electromagnetic force f (i, z), acts on the train, which can be expressed as the following dynamic formula in upward direction according to Newton's law:

$$m\frac{d^2z(t)}{dt^2} = mg - f(i,z)$$

Where m is the weight of the vehicle and g is the gravitational constant.

The electromagnetic force

$$f(i,z) = -\frac{i^2(t)}{2}\frac{dL(z)}{dz}\Big|_{i=constant\ for\ linear\ system}$$

The voltage-current relationship for the coil is given
by

$$V(t) = Ri(t) + L(z)\frac{di(t)}{dt}$$

The displacement of the train is measured by the sensor photo-detector which is the output and can be formulated as:

$$Y = V_z(z) = \beta z$$

Where
β is the sensor gain

The overall transfer function between the coil input voltage V (s) and the sensor output
voltage Vz (s) is given by

$$G(s) = \frac{V_z(s)}{V(s)} = -\frac{K_I\beta}{(R + sL_1)(ms^2 - K_z)}$$

3 The Proposed Controller Design

There are two approaches of control system design.

3.1 Outward approach:

Is a control design approach that starts from inside to outward i.e. first the open loop transfer function is shaped by controlling it poles and zeros, adding proper control design to the system, so that stable overall transfer function will be achieved.

3.2 Inward approach:

Is the reverse of the outward approach i.e. first a desired closed loop transfer function is designed, and then solve for required controller.

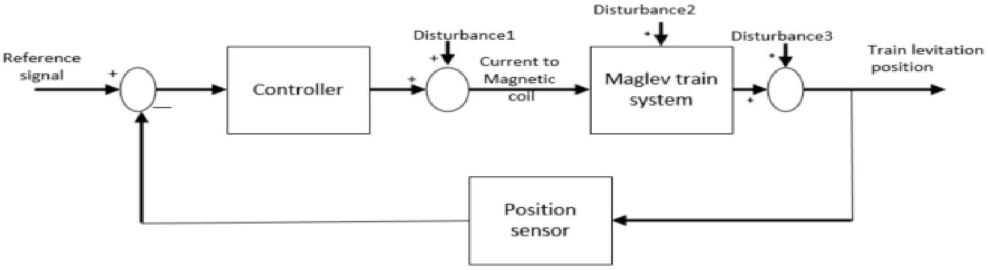

Fig 1. Block Diagram of Closed Loop Maglev Train Control System

3.3 Stability of maglev train system

The maglev train system model has been represented by a transfer function G (s).

$$G(s) = \frac{Y(s)}{U(s)} = \frac{-280}{(s + 10)(s + 44.3)(s - 44.3)}$$

The system has zeros at s = -10 and have poles at s = −44.3, and s = 44.3. From this, the system has a pole on the right hand side of the s-plane and this is not stable.

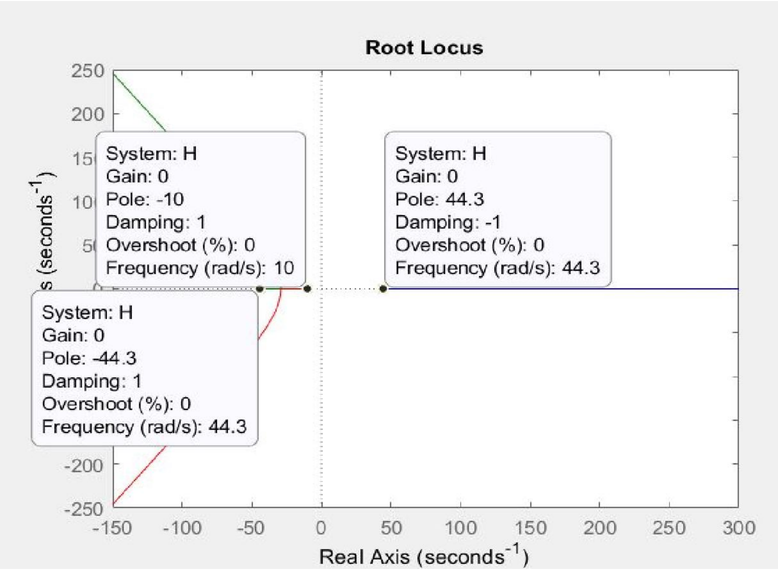

Fig 2. Root locus stability of maglev train system

3.4 Fuzzy Controller

The fuzzy logic control block diagram is shown in Figure 3 below.

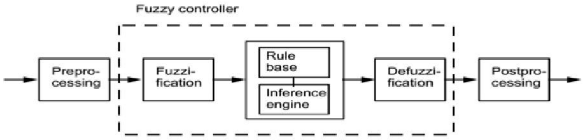

Fig 3. Block diagram of fuzzy logic Controller

The Simulink model of the fuzzy logic controller is shown in Figure 4 below.

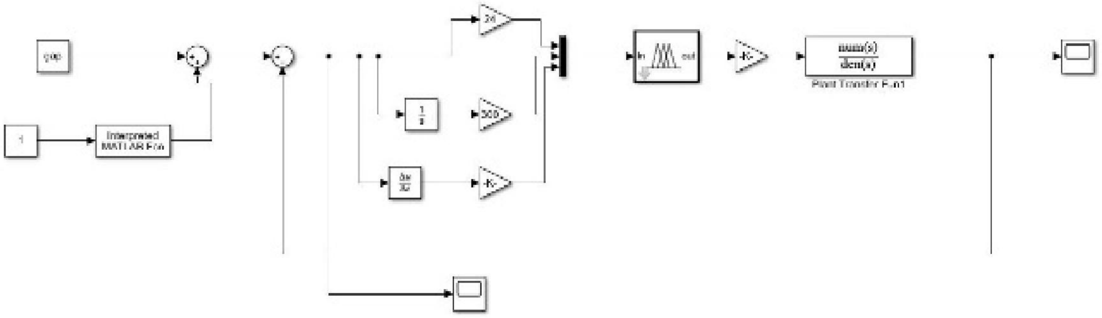

Fig 4. Simulink model of the fuzzy logic controller

3.4.1 Input and Output of fuzzy controller

The error and change of error input and the output of the fuzzy logic controller is shown in Figure 5, Figure 6 and Figure 7 respectively.

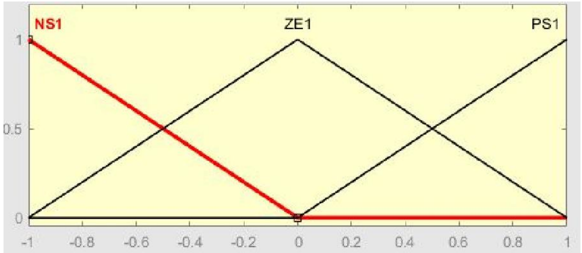

Fig 5. Error input

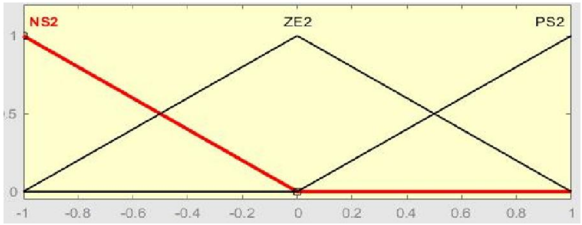

Fig 6. Change in error input

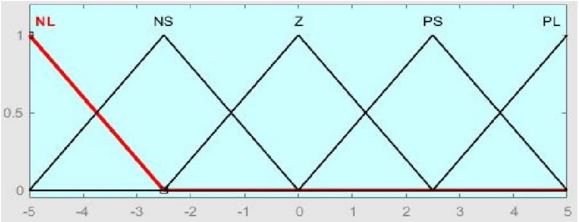

Fig 7. Output The rule base of the fuzzy controller is shown in Table 1 below.

Table 1. Rule base of the fuzzy logic controller

output		(de/dt) error		
		NS2	Z2	PS2
Error	NS1	NL	NS	Z
	Z1	NS	Z	PS
	PS1	Z	PS	PL

3.5 MRAS

Let the proposed system be described by

$$\frac{d^2y}{dt^2} = -a\left(\frac{dy}{dt}\right) - by + bu$$

Where y is the output of plant and u is the controller output or manipulated variable

Similarly the reference model is described by:

$$\frac{d^2y_m}{dt^2} = -a_m\left(\frac{dy_m}{dt}\right) - b_m y_m + b_m r$$

Where y_m the output of reference model and r is the reference input.

The controller be described by the law:

$$u(t) = \theta_1 r(t) - \theta_2 y(t)$$

The controller parameters are chosen as:

$$\theta_1 = b_m/b \qquad \theta_2 = (a_m - a)/b$$

And

The update rule for the controller parameters using MIT rule is described by:

$$\frac{d\theta_1}{dt} = -\alpha e\left[a_m \frac{r}{p+a_m}\right]$$

And

$$\frac{d\theta_2}{dt} = -\alpha e[a_m y \quad (p+a_m)]$$

Where $\alpha = \gamma\, b/a_m$ the adaptation gain and the error is

$$e = y - y_m.$$

The Simulink model of the Mras controller is shown in the Figure 8 bellow.

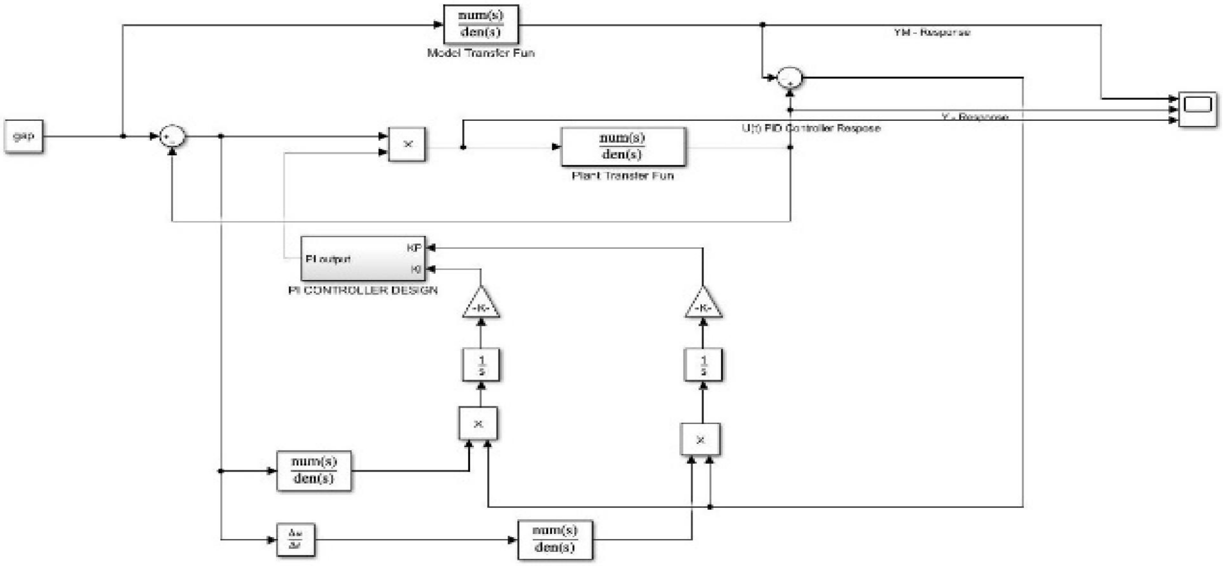

Fig 8 Simulink model of the Mras controller

3.6 PID

The PID (Proportional-Integral-Differential) regulator control depending on the proportional, integral and differential of the deviation

General equation of PID:

$$Output = K_p e(t) + K_I \int e(t)dt + K_D \frac{d}{dt} e(t)$$

Where: $e = Setpoint - Input$

3.6.1 PID Tuning

The ZNFD method may be difficult to perform because it is problematic to adjust the gain until the close-loop system oscillates. A little beyond that results causes instability.

The response of automatic tuning is relatively good when compared to the response of Ziegler Nichols. So, automatic tuning tools on mat lab is used to stabilize the system. Based on the parameters found from auto tuning, try and errors method is used until better result is achieved.

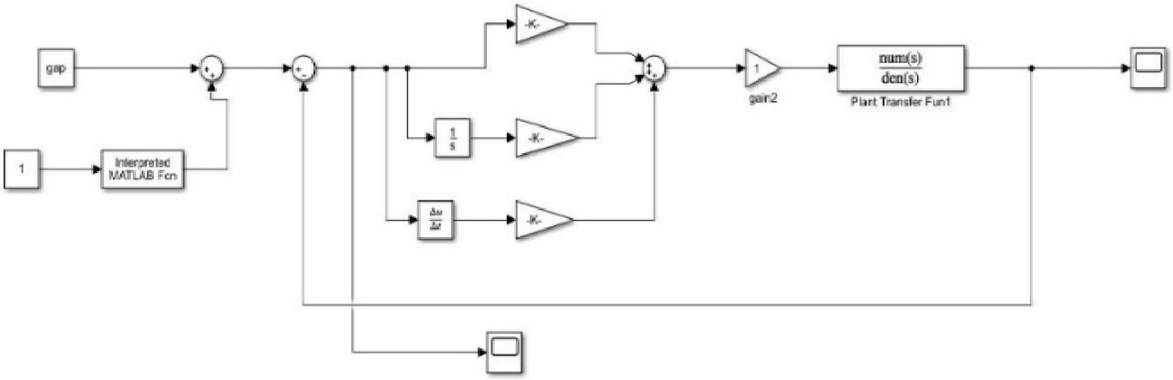

Fig 9 Simulink Diagram of Magnetic Levitation System using PID Controller

4 Result and Discussion

4.1 Magnetic force versus current graph

The magnetic force versus current graph of the Maglev train system is shown in Figure 10 below.

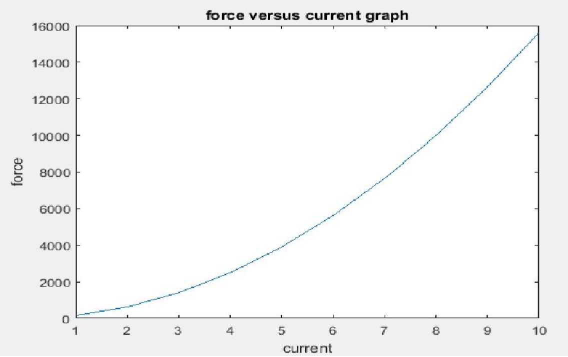

Fig 10. Magnetic force versus current graph plot

4.2 Maglev train system simulation response

The simulation output for Maglev train system without controller and Step Response of PID Auto-tuning for Maglev System is shown in Figure 11 and Figure 12 respectively.

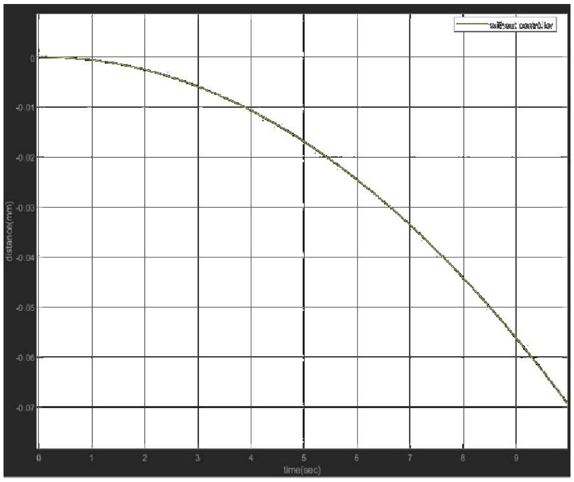

Fig 11 Maglev train system without controller

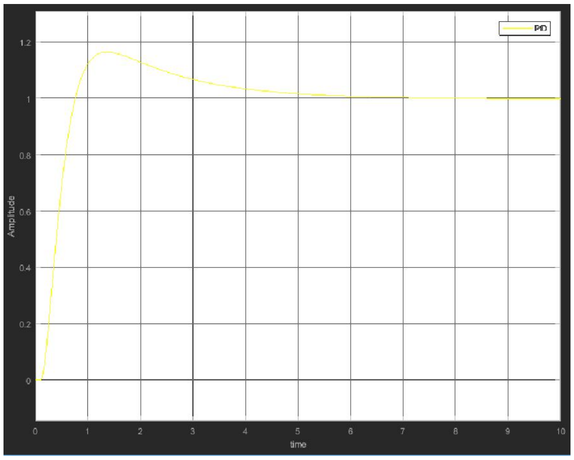

Fig 12 Step Response of PID Auto-tuning for Maglev System

4.3 Comparison of the Proposed Controllers

The output response of PID, FUZZY and MRAS Controllers for a step input is shown in Figure 14 below.

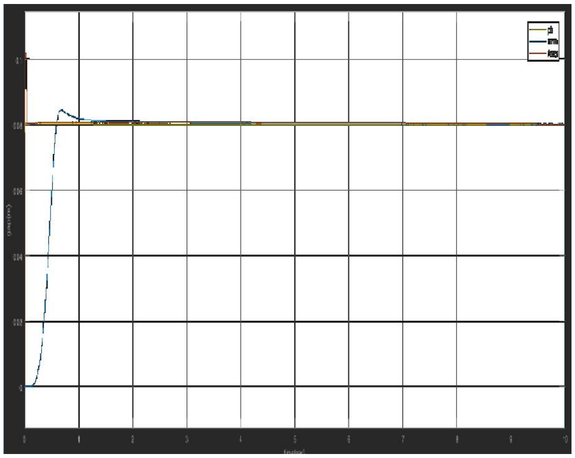

Fig 14. Output response of PID, FUZZY and MRAS Controllers for a step input.

The output response of maglev train system with different time period is shown in Figure 15 below.

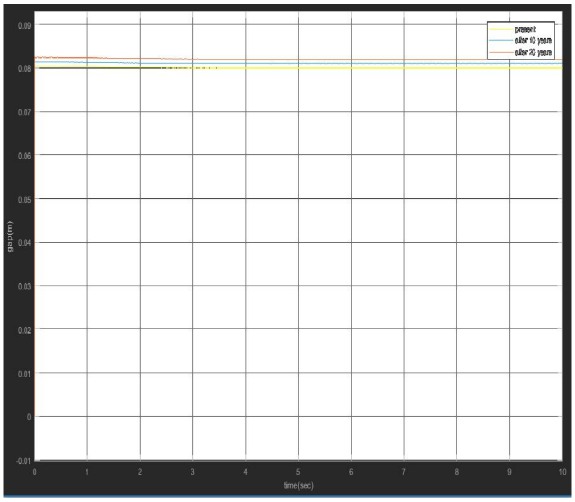

Fig 15. Output response of maglev train system with different time period

4.4 Numerical values of the Performance of PID, MRAS and Fuzzy Controllers

The numerical values of the proposed controllers is shown in Table 2 below.

Table 2. Numerical values of the proposed controllers

Controller	Max Overshoot	Rise time (sec)	Settling time (sec)	Percent Overshoot (%)
PID	0.0567	0.0523	0.5024	13.4
MRAS	0.0542	0.0335	1.3021	8.4
FUZZY	0.0513	0.0523	0.9898	2.6

The controller output response for different time period is shown in Table 3 below.

Table 3. Controller output response for different time period

	Controller output			
Time	Max Overshoot	Rise time (sec)	Settling time (sec)	Percent Overshoot (%)
present	0.0513	0.0523	0.9898	2.6
After 10 years	0.0518	0.0589	1.014	2.73
After 20 years	0.0525	0.0652	1.122	2.78

The Change of air gap with different time period is shown in Table 4 below.

Table 4. Change of air gap with different time period

period	Air gap (m)
Present	0.08
After 10 years	0.081
After 20 years	0.082

5. Conclusion

Magnetic levitation system is inherently unstable system, because of the system nonlinearity. The output of the magnetic levitation system is observed and analyzed.

The simulation result showed that the settling time of PID controller is smaller than the settling time of MRAS and Fuzzy Controller. The rising time of MRAS controller is smaller than the rising time of PID and Fuzzy Controller. But the maximum overshoot and percent overshoot of Fuzzy controller is very good when compared with PID controller and MRAS controller. And the controller can track the gap change and it could re-arrange itself with the gap change occur by change of time.

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