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Magnetic Train System by Interval Type-2 Fuzzy Logic Control Based on Social Spider Optimization

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Abstract - **Those attractive suspension frameworks of a low speed magnetic levitation train will be taken similarly as this article about study. The design and analysis of the suspended intelligent console on the magnetic train, and the redesign of the non-linear mathematical equations of the magnetic train suspension model were discussed. The structuring and implementation of an Interval Type-2 fuzzy controller and Type-1 Fuzzy controller like PID Controller to control the Magnetic Train in non-linear attractive levitation demonstrate to pursue the ideal position. Enough results are included to demonstrate that the power controller significantly reduces the parameter blurring effect (uncertainty) by performing a seamless control action. The parameters of IT2FLC-PID tuning by social spider Optimization Method (SSO) to achieve least error .Structuring and implementation of the Interval Type-2 fuzzy controller and Type-1 Fuzzy controller like PID Controllers to control the train in a nonlinear attractive levitation demonstrate to pursue the ideal position. The parameters of PID tuning by social spider Optimization Method (SSO) to achieve least error in the two controllers (IT2FLC and T1FLC). Metal train mass and coil resistance value changes as blurring (uncertainty) working to the magnetic train levitation system. The results with a non-linear magnetic train and blurring (uncertainty) parameters under the MATLAB condition are compared in several tests such as standard, blurring (uncertainty), and robustness.**

Keywords: Magnetic Train System, An interval, Type-2 Fuzzy logic (IT2FLC), Type-1 Fuzzy logic (T1FLC), Social Spider Optimization Method, SSO.

I. INTRODUCTION

Because of its technological, agreeable Furthermore Ecological attractions, a low speed magnetic levitation train may be viewed as on make a standout amongst those the greater part guaranteeing urban rail movement frameworks for the qualities about low noise, An solid climbing ability, a little turning radius, and low capital venture and support expenses [1]-[4]. HSST is an ordinary representational of a soft-velocity magnetic train line with maximum-velocity about one hundred km/h. The Changsha magnetic train may be those to start with low-velocity magnetic levitation business rode previously, peking [5]. Magnetic trains may operate on the electromagnetic suspension (EMS) model, which requires live controls for stable suspension. This attractive suspension frame is the pivotal innovation organization for the majority in a low-speed magnetic lift train, which needs to be pulled into consideration about a large number of analysts later. The attractive suspension framework experiences Different control complexities for example, such that 1) open-loop less stability; 2) crucial solid non-linearity; Furthermore 3) exogenous aggravation [6]-[7]. Those accepted suspension control system for those maglev train may be those straight extension at those harmony purpose of the system, which uses those straight control principle should plan the control law [8-11]. However, those attractive suspension framework may be determinedly nonlinear Furthermore might lose solidness under bigger disturbances with straight controllers. This sort of unsteadiness will prone prompt extreme security mishaps under secondary train velocity since the hanging air gap of the train may be more or less 7mm. Moreover, concerning illustration a rider-carrying magnetic levitation system, the evolving load and different framework parameter uncertainties essentially influence the movement and Progress.

Therefore, compared with the traditional suspension control methods, which main Think as of the stability, the propelled suspension controller need additionally gained All the more thoughtfulness regarding move forward the generally execution of the control system, for example, such that the progressive reaction personal satisfaction and robustness. Scientists bring used Different shrewdly control schemes on configuration the control of maglev framework. Wang, et al. [12] used An increase table control technique done understanding for those framework nature programmed changing sentiment addition parameter, will enhance those heartiness for vehicles Previously, a adaptable rail. However, the controller might have been intended In view of a straight close estimation model, and the control execution will weaken The point when those framework moves out starting with those harmony side of the point. The interval type-2 fuzzy controller like PID is proper for the magnetic levitation. Tran et al. [14] suggested a discretionary finite time following controller

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(AFTC) to the EMS-type magnetic levitation framework with obscure flow. He, et al. [15] used the linear quadratic hypothesis Also an Unsettling influence nonlinear eyewitness with accomplish An enduring hanging. Wang et al. [16] utilized the state space estimator for a Kalman channel utilizing the state sentiment control law on unravel the hanging system's reliance on the firmness of the rail, yet the control item utilized An straight close estimation model. S. u et al [17] recommended a fluffy control strategy In view of those nonlinear maglev framework for the TSK fluffy system, and simulations showed those method's adequacy in managing limited external noise. Sun et al. [18] introduced a proposed controller taking the vibration data of the train beam without oscillations and high time behavior of the magnetic train model in theoretical side.

The uncertainties parameters are consist of the passenger weight uncertainty, actual and desired inductance. The magnetic levitation position controller is introduced to process the nonlinearity and uncertainty parameters. In this work, we first re-derived a non-linear mathematical model for the maglev system. Then, it is derived to the simple non-linear mathematical equations of the maglev model. A new Type-2 Fuzzy –PID based SSO is programmed by the matlab code, which can guarantee stability of the time response. The system stability has been prove by using time response strategies. To define the problems of oscillation, an type-2 fuzzy-PID controller (T2FLPIDC) is proposed. The principles of the SSO and the fuzzy logic sets are used to treat for total errors, and its ensure the stability and tracking error approach to zero as proven using the integral absolute error method. The paper contribution presents in two points. First, a new highly position control law is illustrated, which satisfied the control behavior, even beneath hard constraints. Second, those tests come about exhibit that that IT2FLC-PID for smooth hound control inputs might accomplish superior control execution over existing methodologies.

This paper is organized as follows. In Section II, the dynamic modeling of the magnetic train model is rederived. Section III general description of social spider optimization. Section IV introduces controllers' design of position control method. Section V illustrates the results of the simulation to test the behavior of the controller maglev train, and Section VI represents conclusions of the paper.

II. MAGNETIC TRAIN MODEL AND FUZZY LOGIC CONCEPTS

Maglev vehicles would by underpinned via numerous suspension focuses. However, out of structure decoupling from claiming levitation structure, the hanging framework could be deteriorated under An solitary attractive suspension framework [19]. Those single magnet suspension framework will be the fundamental of the magnetic train, What's more it may be All the more versant on examine the changing aspects of a single magnet framework [20-22]. Thus, those attractive suspension frameworks may be rearranged under a solitary attractive suspension model likewise indicated clinched alongside figure 1.

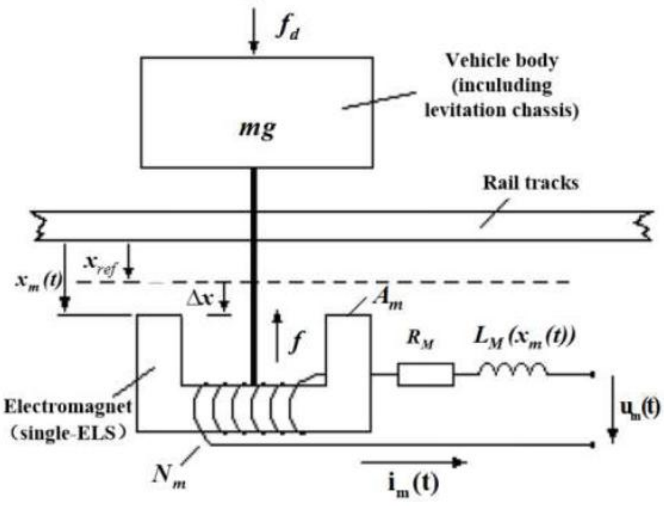

Figure 1: Setup of maglev train

According to ref.'s [16-19], the mathematical equations of the open- loop maglev can be derived in bellow:

$$\dot{x_1}(t) = x_2(t) \quad (1)$$

$$\dot{x_2}(t) = -\frac{\mu_0 A_m N_m^2}{4m}\left[\frac{x_3(t)}{x_1(t)}\right]^2 + g + \frac{1}{m} f_d$$

$$\dot{x_3}(t) = \frac{x_2(t)\, x_3(t)}{x_1(t)} + \frac{2x_1(t)}{\mu_0 A_m N_m^2}\left(u_m(t) - x_3(t) R_m\right)$$

$$y(t) = x_1(t)$$

where $x_1(t) = x_m(t)$, $x_2(t) = \dot{x_m}(t)$, $x_3(t) = i_m(t)$.

mg denotes the levitation electromagnets load gravity & self gravity, $x_m(t)$ air-gap between the track, x_{ref} and the electromagnet.

TABLE 1
Parameter qualities of the magnetic train model

Name of parameters	Value
Mass	700 m/kg
Turns number of coil N_m	450
Cross sectional area of magnet A_m/m^2	0.024 A_m/m^2
Permeance of Leakage η	zero
Air Permeability μ_0 $(H.m^{-1})$	$4\pi * 10^{-7}$
current(nominal) i_{ref}/ A	$191* 10^{-2}$
Air gap (nominal) i_{ref}/ m	$9* 10^{-2}$

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And Δx are target airgap and airgap error, respectively, N_m denotes the turn of electromagnetic coil, A_m denotes the area of pole, the coil current $(i_m(t))$ and coil voltage $(u_m(t))$, coil resistance (R_m), and the inductance coil $(L_m(x_m(t)))$).

It is clear that the state space equation (1) of the magnetic train model is highly non-linear. The parameters of maglev train model are recorded in Table 1. It will be inescapable that those magnetic levitation train will be exasperates by those. The wind force is the big reason for the changing on the grid. Also, those examine of the element execution of the framework under. Disturbances will be exceptionally imperative. With acquire the relative nonlinear scientific model of the coordinate is chosen as stated by those guideline for nonlinear. Coordinate change Likewise takes after.

$$\eta = [\eta_1\ \eta_2\ \eta_3]^T\ \epsilon\ \Omega_\eta\ ,\ \text{and}\ \Omega_\eta\ \epsilon\ R^3$$

Where

$$\eta_1 = x_1 \qquad (2)$$

$$\eta_2 = x_2$$

$$\eta_3 = g - \frac{\mu_0\ A_m\ N_m^2}{4m}\ [\frac{x_3}{x_1}]^2$$

Further, it is not difficult to obtain:

$$\dot{\eta_1} = \eta_2 \qquad (3)$$

$$\eta_2 = \eta_3$$

$$\dot{\eta_3} = \frac{\mu_0\ A_m\ N_m^2}{2m}\left[\frac{x_3\ \dot{x_3}}{x_1^2}\right] + \frac{\mu_0\ A_m\ N_m^2}{2m}\ [\frac{x_3^2\ \dot{x_3}}{x_1^2}] \qquad (4)$$

To smooth the following design, we state K and L as:

Thus, the mathematical equations of the nonlinear model for the updated coordinate axis are progressing as follows:

$$\dot{\eta_1} = \eta_2 \qquad (5)$$

$$\dot{\eta_2} = \eta_3$$

$$\dot{\eta_3} = f(\eta) + g(\eta)\ u_m$$

$$y = \eta_1$$

Where

$$f(\eta) = \frac{2k}{m}\left(1 - \frac{2k}{Lx_1}\right)\frac{x_2\ x_3^2}{x_1^3} + \frac{R\ x_3^2}{L\ x_1^2})$$

$$g(\eta) = -\frac{2kx_3}{Lm\ x_1^2}$$

The concept of fuzzy sets was born in July 1964. Zadeh [23] discovered that classical methods were correct for many non-linear systems, but solving the system needed a lot of risk & time. Hardware component in 1965, without performing highly computations to solve a model, Zadeh introduced a several kind of mathematical model. Diffuse logic techniques were born in 1965. From 1965 to 1979 there was no use of fuzzy logic, it only stayed on paper; the first implementation of fuzzy logic in 1979 in the Mamdani cement kiln [23]. In 1987 the Japanese started using this technique in an automatic meter control, and in i1985 they transformed the fuzzy logic of model mathematics into a practical model, developed the water processing system, and made it diffuse for general use.

The logic controller deals with the non-linearity and the uncertainties of the system. According to the theory of fuzzy logic, the controller can be created under the name of a diffuse PID controller, which ideals with the linear or non-linear controller and offers better performance than that. With classic PID [24-25], the uncertainty in T1FL Systems are limited, as are experts who have opinions on many experiences and parameters, which are determined by knowledge of the membership functions whose definition contained linguistic uncertainty [26].

The MF's of T-1FL Controller systems are clear, the quantities and experts have Clear set data expressed in several types of uncertainty, not without sufficient support [23] to belong to fuzzy type 2 sets characterized by a diffuse subject. This means that the parameters in [0,1] are diffusely defined in three dimensions, while the degree of belonging to the fuzzy set of type 1 in [0,1] is clear, they are 2-dimensional, to manages uncertainties and increases the DOF [27-28]. The two diffuser kinds are very brilliant controls for managing the applications of the non-linear control.

However, certain implementation are not helpful because they require a big rule- base and that much rules require extended computing time [29] suggested that IT-2FL Controller could decrease the rule-base, which means the FLC block entries (errors (e) and Error change (Δ) to reduce e)), the two inputs that were developed for IT2FLC.The number of rules is [7 ^ 2], and Strong technology for IT-2FL Controller will benefit from the application of the magnetic train model.

III. GENERAL DESCRIPTION OF ASOCIAL SPIDER OPTIMIZATION ALGOTITHEM

Social Spider Optimization is a populace based methods have been proposed for comprehending advancement procedures dependent on co-usable conduct of social creepy crawly which was created by E. Cuevas [30].

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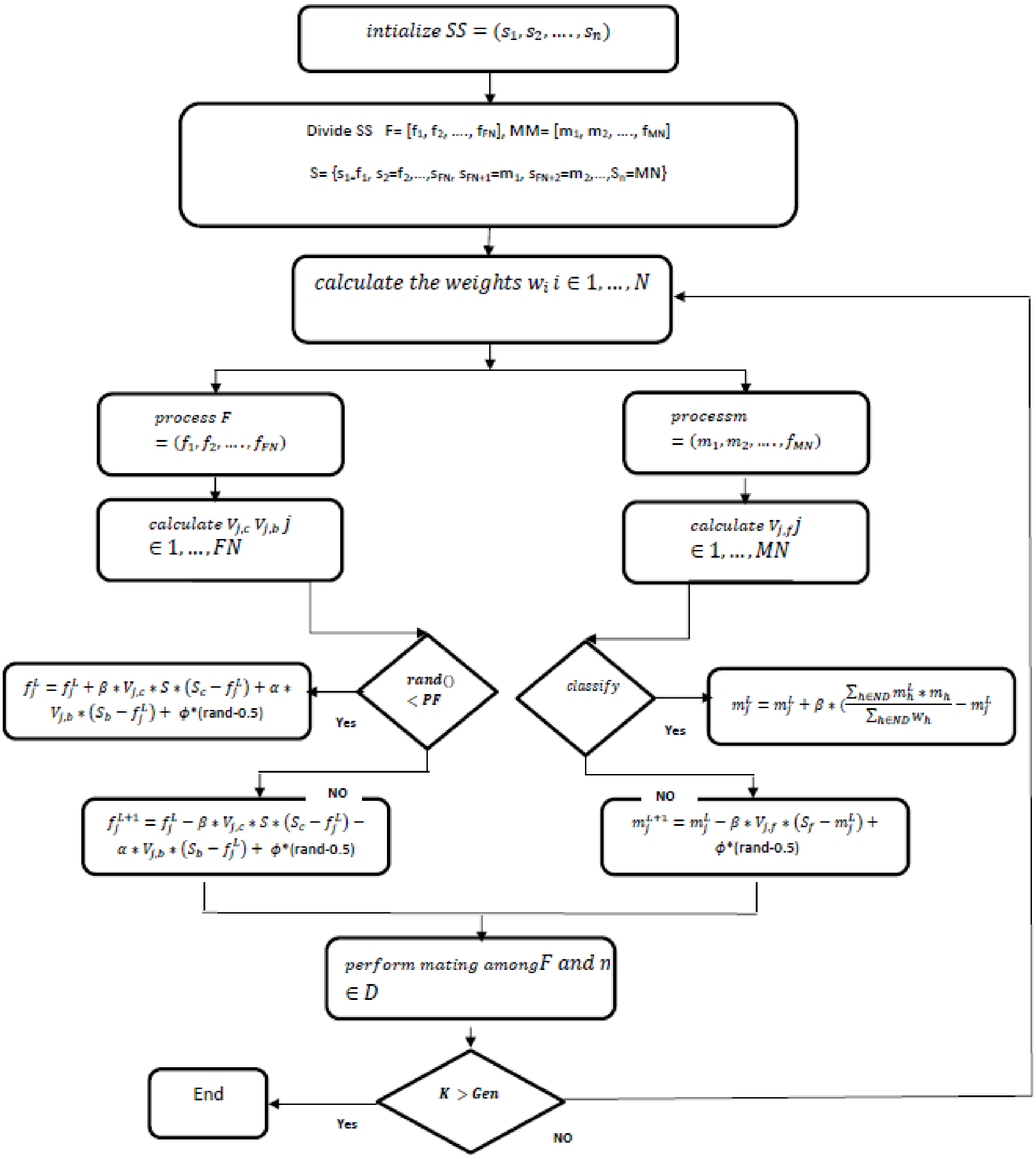

Figure 2: The SSO algorithm flowchart [30]

The Social Spider Optimization calculation surmises that the total hunt space is called shared web, though the social arachnids are collaborating to every others. Each social bug gets a weight as indicated by the wellness estimation of the given arrangements that is signified by the social bugs. In the Social Spider Optimization calculations, there are two hunt operators, for example, male bugs and female bugs. Both individual is to do by a lot of various developmental administrators that mimic different helpful practices that usually accepted inside the province depending up on the sexual orientation. The alluring element of the social-creepy crawly is the exceptionally female one-sided populace. The Social Spider Optimization calculations begin by characterizing the quantity of male and female creepy crawly will be separated as individual on pursuit space. A Social spider optimization (SSO) [26] algorithm was used for tuning the FLCr (type-1 and interval type-2) gains for Maglev train model.

The procedure to calculate the best input and output gains by using SSO, are presented in flowchart in fig.2. The advantages of SSO are that it is rapidly converging towards an optimum values, simple to compute, easy to implement and free from the complex computation than other algorithms.

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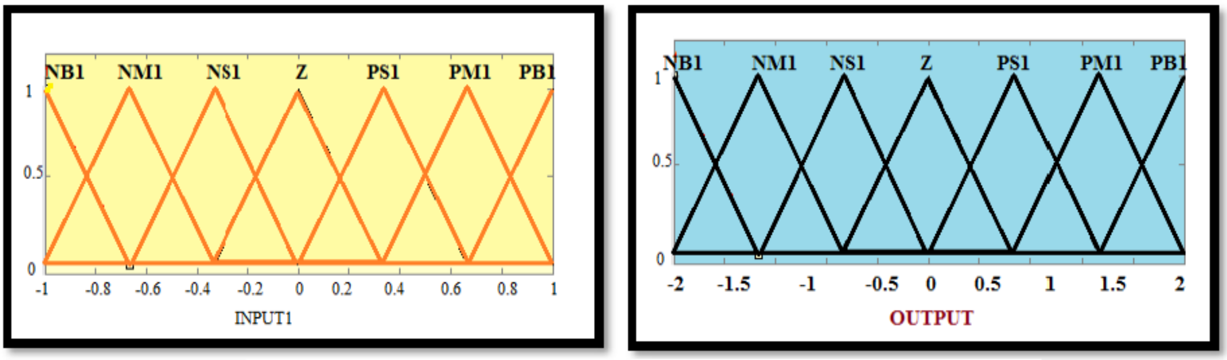
IV. THE DESIGN OF FUZZY TYPE-2 CONTROLLER

An interval type-2 and type-1 fuzzy logic controllers design for magnetic train system, Mamdani technique will be use, which has 2 I/Ps are: errors *(e)* and change of error (Δe) and 1 O/P is the voltage. By using Matlab software (2018a). for both controllers, it have been choose 7 Mf's as and I/P and O/P. For T1FLC the range [-1,1] for I/P and [-2, 2] for O/p in figure-3.



(a) (b)

Figure 3: (a) M f's for I/P 's, (b) M f's for O/Pt

The range of I/P & O/P are (-1, 1) in IT2FLC controller as showed in figure-4.

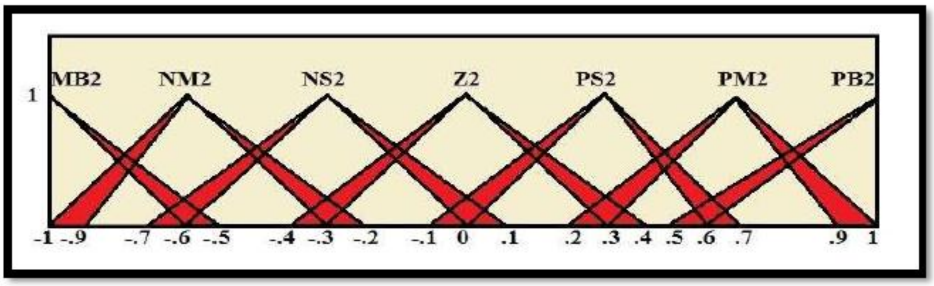


Figure 4: Mf's for I//P & O/P in IT2FLC

The rules have been written for both controllers after choose MFs based on experts according to table-II for T1FLC and IT2FLC as a matrix.

TABLE 2
Rule- Base of magnetic train system with 7 memberships for I/Ps and O/Ps for
A) T1FLC B) IT2FLC

Δe \ e	NB1	NM1	NS1	Z	PS1	PM1	PB1
NB1	NB1	NB1	NB1	NB1	NM1	NS1	Z
NM1	NB1	NB1	NB1	NM1	NS1	Z	PS1
NS1	NB1	NB1	NM1	NS1	Z	PS1	PM1
Z	NB1	NM1	NS1	Z	PS1	PM1	PB1
PS1	NM1	NS1	Z	PS1	PM1	PB1	PB1
PM1	NS1	Z	PS1	PM1	PB1	PB1	PB1
PB1	Z	PS1	PM1	PB1	PB1	PB1	PB1

Δe \ e	NB2	NM2	NS2	Z2	PS2	PM2	PB2
NB2	NB2	NB2	NB2	NB2	NM2	NS2	Z2
NM2	NB2	NB2	NB2	NM2	NS2	Z2	PS2
NS2	NB2	NB2	NM2	NS2	Z2	PS2	PM2
Z2	NB2	NM2	NS2	Z2	PS2	PM2	PB2
PS2	NM2	NS2	Z2	PS2	PM2	PB2	PB2
PM2	NS2	Z2	PS2	PM2	PB2	PB2	PB2
PB2	Z2	PS2	PM2	PB2	PB2	PB2	PB2

And then connect to the Magnetic train Simulink/Matlab nonlinear model. Figure-5 present's the model of IT2FLC and T1FLCand figure (6) showed the controller with nonlinear systems. Table 3 showed the optimum parameters gains by PSO.

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TABLE 3
T-1FL Controller gains

gain	Without unit
kp	1.5087
kd	0.0110
kpp	1.4999
ki	10^{-8}

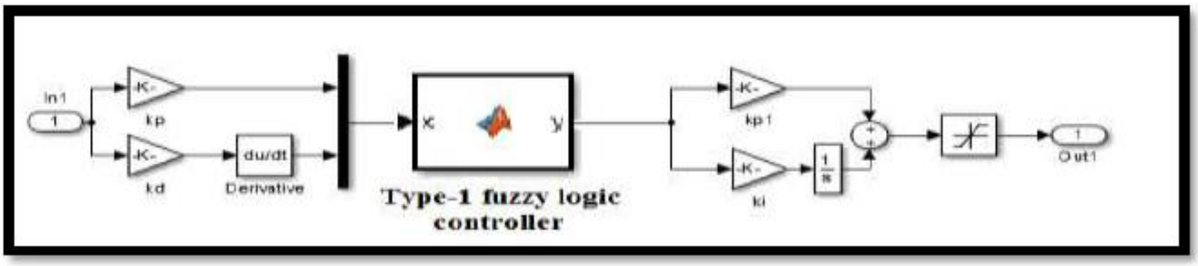

Figure 5A: Type-1 FLC (A)

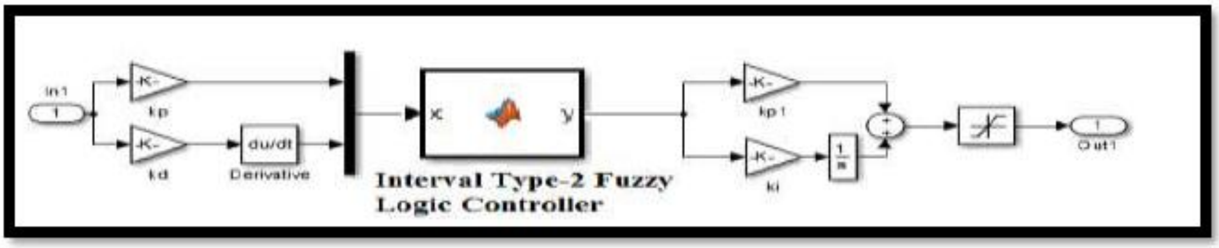

Figure 5B: The Structure of IT2FLC

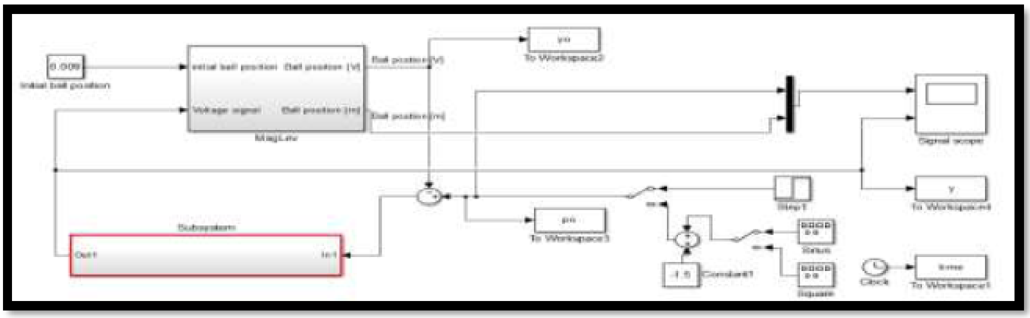

Figure 6A: Magnetic train with controller T1FLC

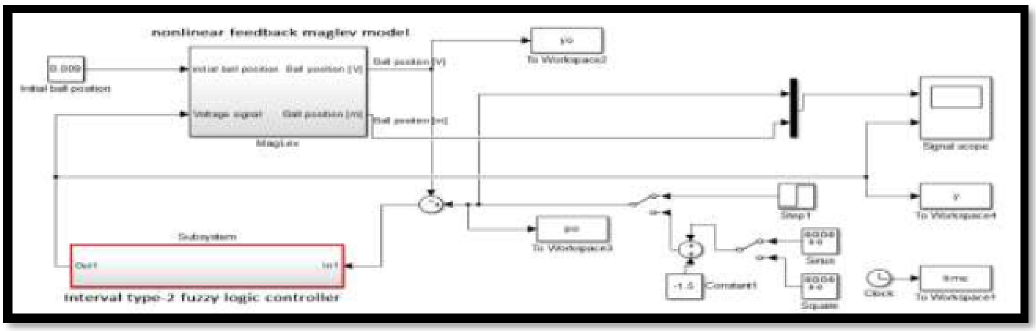

Figure 6B: Magnetic train with controller IT2FLC

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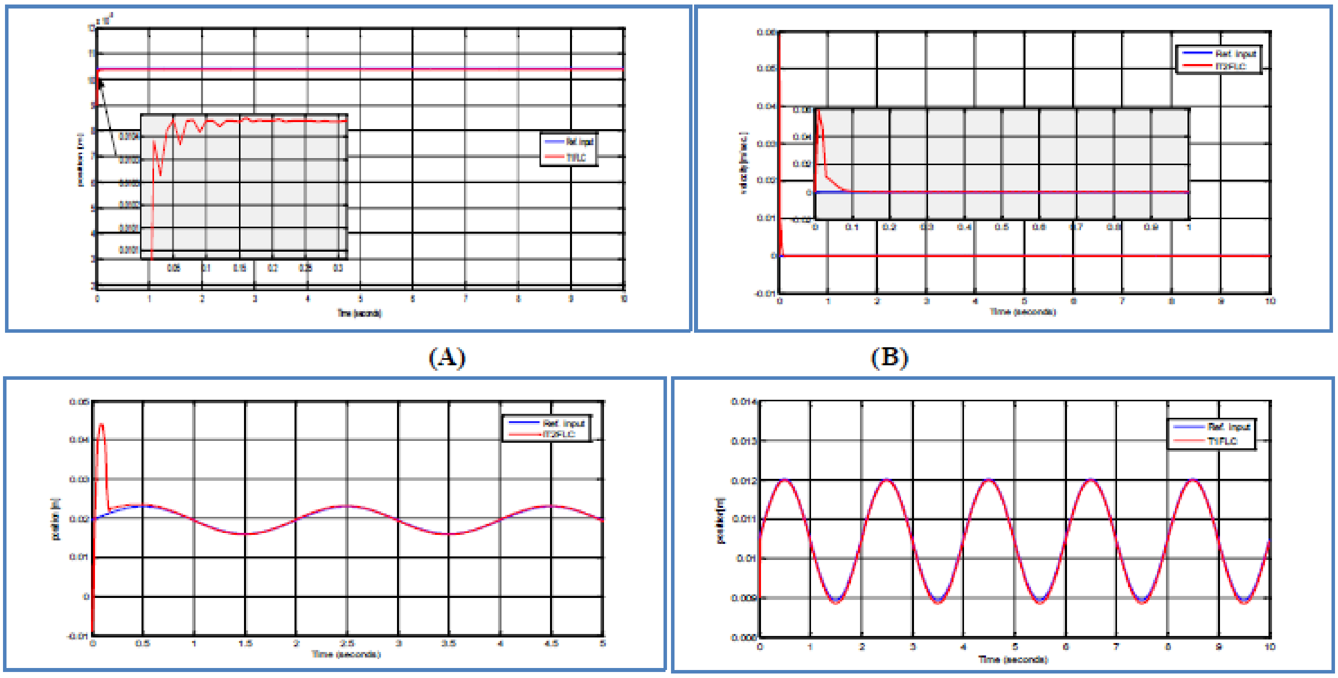
V. THE RESULTS OF SIMULATION

Now, for the results of both controllers for nonlinear magnetic train system with two methods standard and blurring.

Case 1: Standard

The controllers are connected to nonlinear magnetic train system without blurring with 2 types of I/Ps step and sine waves. Figure (7) represents the step input reference (TIFLC & IT2FLC), and sin waves input reference (TIFLC& IT2FLC) of magnetic train system.



(C) (D)

Figure 7: Step input ref. and A) TIFLC B) IT2FLC of magnetic train system, Sin waves input ref. and C) TIFLC D) IT2FLC of magnetic train system

As compared to the results from T1&IT2 FLC 's for non-linear magnetic train system in standard method in table IV.

TABLE 4
Numerical results from, T1&IT2 FLC's in standard method

Controller Types	Mp%	Ts (sec.)	Figures
T1FLC	0	35*10^-2	7A
	86*10^-3	3*10^-1	7C
IT2FLC	0	7*10^-2	7B
	58*10^-3	15*10^-2	7D

Table 4 represents the comparison between IT2FLC and T1FLC from two inputs step and sine wave for train position, and the best results with IT2FLC.

Case 2: Blurring (Mass train & Resistance coil)

It used both controllers to control non-linear magnetic train system with blurring (uncertainty) of train mass and coil resistance.

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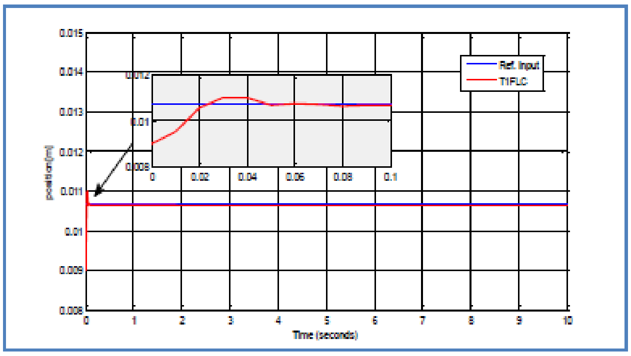
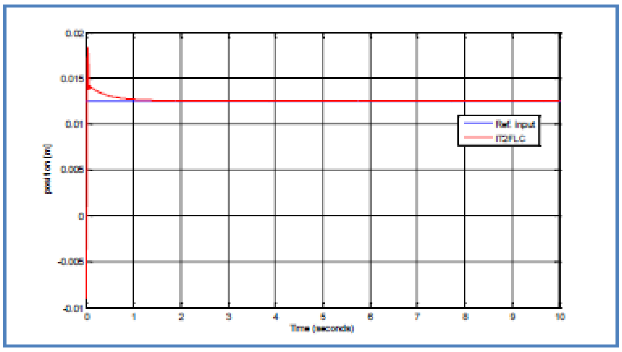
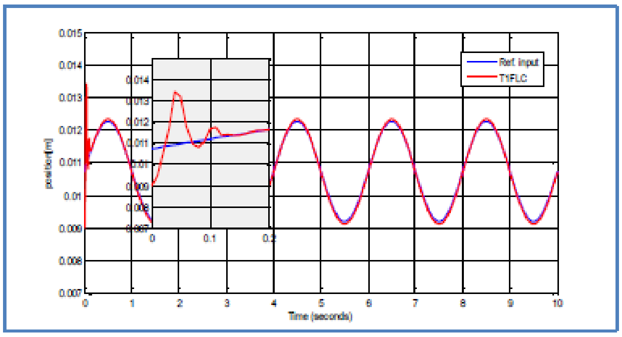
1. Mass blurring

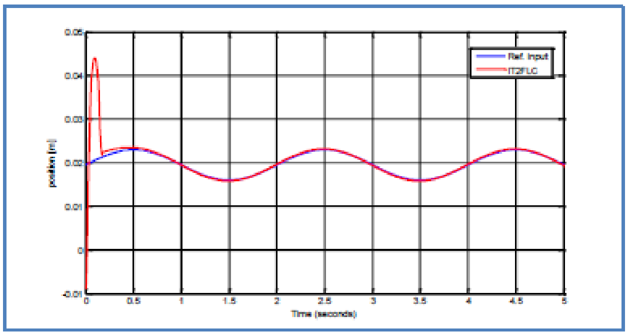
Figure (8) illustrates the response of step input reference with (50% mass blurring added to controllers (TIFLC & IT2FLC), and response of sine waves input reference with 50% mass blurring added to controllers (TIFLC & IT2FLC).





(A) (B)





(C) (D)

Figure 8: Response of Step input ref. with (50)% mass blurring added to controllers A) TIFLC B) IT2FLC Response of Sine waves input ref. with (50)% mass blurring added to controllers C) TIFLC D) IT2FLC

As compared to the results from T1FLC & IT2FLC to non-linear magnetic train model with 50% mass blurring case in table 5.

TABLE 5
Numerical compared from T1FLC & IT2FLC controllers with (50)%mass blurring

Controller Types	Mp%	Ts (sec.)	Figures
T1FLC	11*10^-3	8*10^-2	8A
	102*10^-3	20*10^-2	8C
IT2FLC	108*10^-4	601*10^-4	8B
	86*10^-3	75*10^-3	8D

2. Coil Resistance blurring

Figure (9) represents the response of step input reference with (10)% coil resistance blurring added to controllers (TIFLC & IT2FLC) and the response of sine waves input reference s with (10)% coil resistance blurring added to controllers (TIFLC& IT2FLC).

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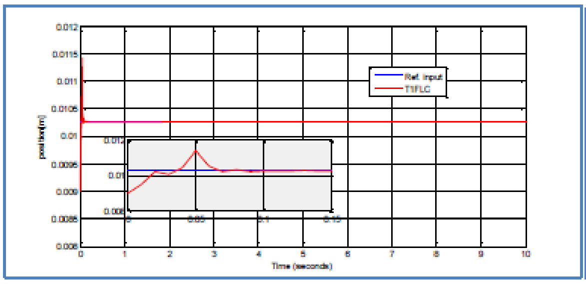
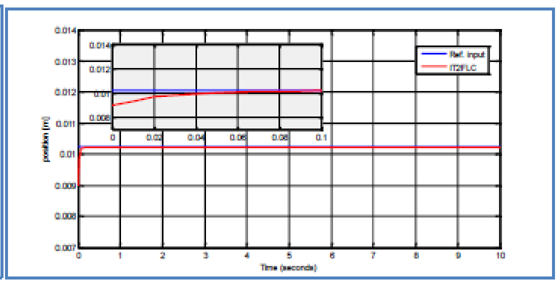
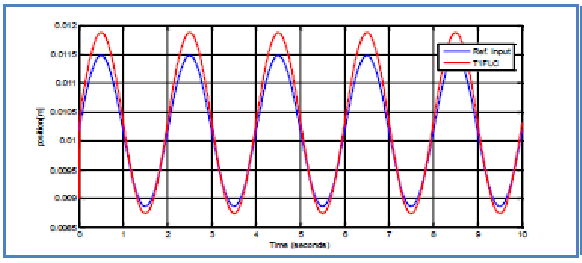
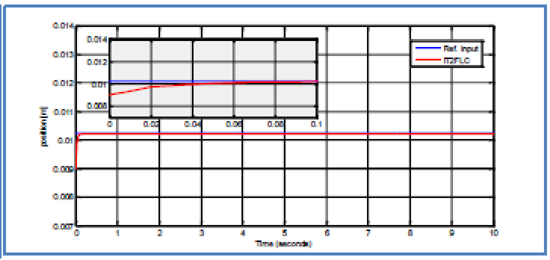




(A) (B)





(C) (D)

Figure 9: The response of Step input ref. with (10)% coil resistance blurring added to controllers A) TIFLC B)IT2FLC Response of Sine waves input ref. with (10)% coil resistance blurring added to controllers C) TIFLC D) IT2FLC

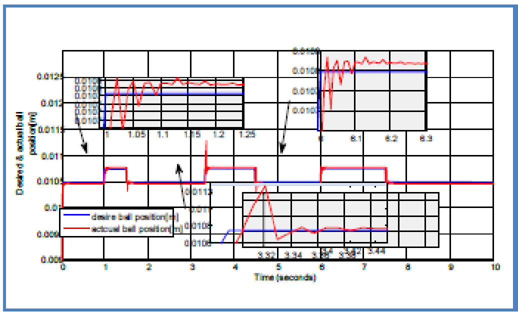
As compared to the results from T1FLC and IT2FLC to non-linear magnetic train system with (10)% coil resistance blurring case in table 6.

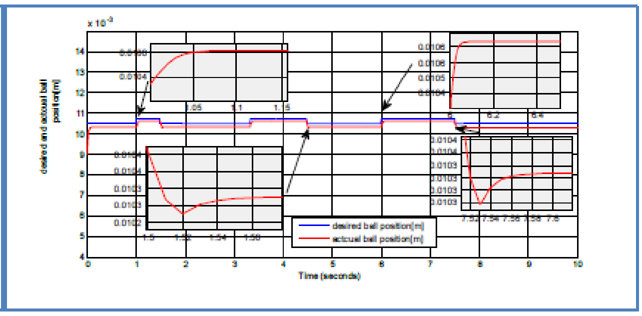
TABLE 6
Numerical compared from T1FLC & IT2FLC controllers with (10)% coil resistance

Controller Types	Mp%	Ts (sec.)	Figures
T1FLC	114*10^-4	10*10^-2	9A
	10*10^-2	18*10^-2	9C
IT2FLC	0	8*10^-2	9B
	50 *10^-3	10*10^-2	9D

Case 3: Robustness Test

The robustness of both controllers IT2FLC & T1FLC on non-linear magnetic train model.





(A) (B)

Figure 10: The desired and actual train position with A) T1 B) IT2 Fuzzy logic controller of magnetic train model for robustness

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Figure (10) shown the robustness for an IT2FLC as compare them from the maximum overshoot of T-1 FLC equal to (112*10^-3) and there in no maximum over-shoot of an interval type-2 fuzzy logic controller.

VI. CONCLUSION

The simulation analysis and design of both fuzzy controllers (Interval type-2 & Type-1), have been employed to control the non-linear model of magnetic train. SSO is the used to tune the optimum gains. From the simulated results can be observed the following conclusions points: In standard case, it is clear from the results of simulation that the response of position for magnetic train based on Interval type-2 fuzzy logic controller is faster than Type-1 fuzzy logic controller as shown in table 4.

A) In blurring case

- Mass blurring with (50)% over real value

Magnetic train results according to interval type-2 Fuzzy logic controller compared with Type-1fuzzy logic controller as shown in table IV as overshoot and settling time are less.

- Coil blurring with (10)% over real value

The results of the train based on interval type-2 FLC compared with T1 fuzzy logic controller as shown in table VI as overshoot and settling time are less.

B) The robustness test of Interval Type-2 fuzzy logic controller is the best than Type-1 fuzzy logic controller when the model's parameters are blurred.

C) In case when the sine wave used as an input to the system, it has been reported that an IT2FLC has better response than a T1FLC and that can showed from tables from IV to VI.

D) The proposed controllers Interval type-2 and tppe-1 fuzzy logic controllers can used with structures PID like fuzzy. It can implement with a multi number of membership functions.

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