

## Steel Ball System Control Using T-S Type Fuzzy Logic

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**Abstract.** In this paper the Takagi-Sugeno type fuzzy logic was utilized for the purpose of control of electromagnetically levitated steel ball system. The system is the basis for important systems such as, the modern train which floats along the rails, aerospace shuttles, magnetic bearings and high precision systems. Such systems apart from being nonlinear they are also not stable. Results were obtained using the SIMULINK/MATLAB software and the control system developed for the electromagnetically levitated steel ball system was able to stabilize it with good response.

### Introduction

Levitation was seen as a magical sort of phenomenon that has long fascinated people. In our age of advanced materials and cheap high-speed computing, we have the ability to make levitation a common place and integral part of modern life. This phenomenon is typically accomplished using actively controlled electromagnets. Magnetic actuation has the potential for numerous other applications. In addition to supporting loads (levitation), it can dampen vibration, apply precision force, and move objects to precise distances, all with no contact between surfaces and essentially no friction. This type of actuation can be used in harsh environments (corrosive, vacuum, etc.) where traditional mechanical or hydraulic actuators might not survive [1]. A magnetic actuator can operate in ultra clean environments without the hazard of producing contaminants from its use. The main hindrance to the widespread application of magnetic levitation and other magnetically actuated systems is the complexity of the involved physics and the need for cheap and effective control systems to operate the system and maintain stability. The control objective is to keep a ferromagnetic object (steel ball) suspended in midair by controlling the current through an electromagnet. The basic principle is to use the current to manipulate the electromagnetic force which can counteract the weight of the steel ball and keep it suspended in the air. By measuring the location of the object using a non-contact sensor, and adjusting the current, the levitated object can be positioned very accurately. The magnetic levitation system serves to hold a small steel ball in stable levitation at some steady-state operating position. It does this by using an electromagnet to produce forces to support the ball's weight. The electromagnetic forces are related to the electrical current passing through the electromagnet coil [2].

[1,3,4] have utilized the system linearization and phase lead compensation technique for the control of the magnetic levitation system, [1,5] the PID and [6] the pole placement control techniques. These methods work quite well within the linear operating regions and as mentioned earlier in reality the system is highly nonlinear in nature. In [7] control scheme was developed based on the flatness-based feedback linearization method using computational techniques proposed by Levine and the controller gains were obtained and optimized using the particle swarm optimization

algorithm. The method was superior to the earlier mentioned methods because of its effort to solve for the nonlinearity issue but it is more complex approach. [2] Contributed by solving the problem of complexity using the mandami type fuzzy logic. Fuzzy logic for control purposes has desirable attributes such as: good abilities in nonlinearities handling, flexibility and reasoning (intelligence incorporation), simple and relative fast design [8]. Higher computation efficiency, more suitability to nonlinear systems, better compatibility for mathematical analysis, optimization, adaptive systems and reliable continuity in output surfaces are characteristics of the Takagi-Sugeno (T-S) type fuzzy logic even though the mandami counterpart was more popular, completely intuitive and more suitable to humanoid signals [9]. Therefore, in this the paper it was applied to an electromagnetically levitated steel ball system.

### The System Model

The electromagnetically levitated steel ball was as shown in Fig. 1. The steel ball remains floating in air due to the presence of resultant force produced as a result of current flowing through the coils of the electromagnet which acts against the weight of the ball.

$$E_f(i, n) = mg - k \left( \frac{i}{n} \right)^2 \quad (1)$$

Eq. 1 gives the resultant electromagnetic force pulling the ball. Where:  $n$  is the distance between the steel ball and the electromagnet,  $i$ ; the current flowing in the electromagnet coil,  $g$ ; acceleration due to gravity,  $k$ ; the magnetic plant constant and  $m$ ; the mass of the steel ball [3,10].

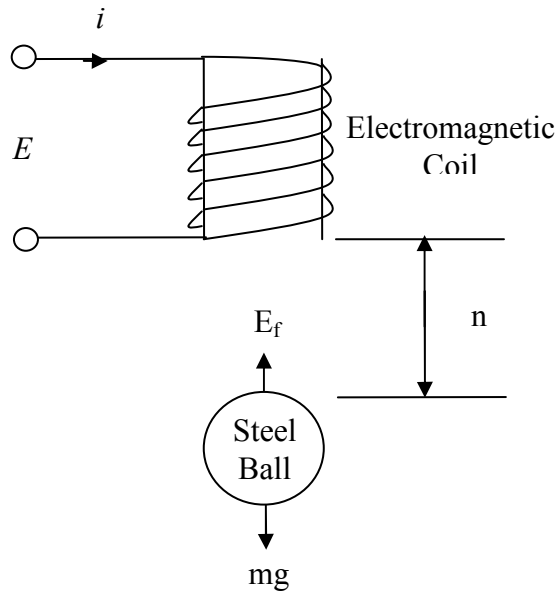


Fig. 1: The Electromagnetically Levitated Steel Ball System.

Applying KVL across the circuit yields Eq. 2 below:

$$E = ir + l \frac{di}{dt} - l_0 n_0 \frac{i}{n^2} \frac{dn}{dt} \quad (2)$$

Where:  $r$ ; is the resistance of the circuit,  $l$ ; is the circuit inductance,  $l_0$ ; is the inductance at the desired position and  $n_0$ ; is the the desired position [10].

Eqs. 1 and 2 govern the behavior of an electromagnetically levitated system. The plant transfer function used for this paper was obtained experimentally using system identification as shown in Eq. 3 using maglev model 33-210 which is a product of Feedback Inc. Limited [10]. Table 1 shows some of the system parameters.

$$G(s) = \frac{1488.4}{(s + 30.5)(s - 30.5)} \quad (3)$$

Table 1: Some Parameters of the Electromagnetic Levitation System

Parameter	Value
Equilibrium distance, $n_0$ (mm)	22.5
Mass of steel ball, $m$ (Kg)	0.021
Magnetic plant constant, $k$ (Nm <sup>2</sup> A <sup>-2</sup> )	1.477x10 <sup>-4</sup>
Electromagnetic coil resistance inductance, $l$ (mH)	296.74
Gain of sensor, $M$ (V/m)	450.3

(Source: [10])

### The Controller Implementation

The T-S type fuzzy logic was used for the stabilization control of the steel ball system which is not stable in absence of controller and it is also nonlinear in nature and the results were simulated using MATLAB/SIMULINK. The inputs of the controller are the error (E) and derivative of the error (dE) signals. They are both implemented with three trapezoidal membership functions which are given names as; negative (Ne), zero (Ze) and positive (Po) and their definitions are as shown by Eqs. 4 - 11. The controller has a single output which provides the control/actuating signal (C), it was made of five linear membership functions; negative big (Nb), negative small (Ns), zero (Ze), positive small (Ps) and positive big (Pb) and their definitions are shown by Eqs. 12 - 17.

$$E = \{Ne, Ze, Po\} \quad (4)$$

$$Ne = \{(e(a_{ne}, b_{ne}, c_{ne}, d_{ne}), \mu_{Ne}(e)) | e \in E\} \quad (5)$$

$$Ze = \{(e(a_{ze}, b_{ze}, c_{ze}, d_{ze}), \mu_{Ze}(e)) | e \in E\} \quad (6)$$

$$Po = \{(e(a_{po}, b_{po}, c_{po}, d_{po}), \mu_{Po}(e)) | e \in E\} \quad (7)$$

$$dE = \{Ne, Ze, Po\} \quad (8)$$

$$Ne = \{(de(a_{ne}, b_{ne}, c_{ne}, d_{ne}), \mu_{Ne}(de)) | de \in dE\} \quad (9)$$

$$Ze = \{(de(a_{ze}, b_{ze}, c_{ze}, d_{ze}), \mu_{Ze}(de)) | de \in dE\} \quad (10)$$

$$Po = \{(de(a_{po}, b_{po}, c_{po}, d_{po}), \mu_{Po}(de)) | de \in dE\} \quad (11)$$

$$C = \{Nb, Ns, Ze, Ps, Pb\} \quad (12)$$

$$Nb = \{(c(a_{nb}, b_{nb}, c_{nb}), \mu_{Nb}(c)) | c \in C\} \quad (13)$$

$$Ns = \{(c(a_{ns}, b_{ns}, c_{ns}), \mu_{Ns}(c)) | c \in C\} \quad (14)$$

$$Ze = \{(c(a_{ze}, b_{ze}, c_{ze}), \mu_{Ze}(c)) | c \in C\} \quad (15)$$

$$Ps = \{(c(a_{ps}, b_{ps}, c_{ps}), \mu_{Ps}(c)) | c \in C\} \quad (16)$$

$$Pb = \{(c(a_{pb}, b_{pb}, c_{pb}), \mu_{Pb}(c)) | c \in C\} \quad (17)$$

## Results and Discussion

Figure 2 is the unit step response of the system. The graph shows the response of the system and the desired steel ball position which is the reference position or signal. Hence, in 0.025 seconds the steel ball will reach and remain at the desired or reference position. It can also be deduced that the system has an overshoot of 0%, no or negligible overshoot which is very good as entails good accuracy and high degree of stability tendency. Figure 3 shows how the error signals change as the system reaches steady state. The proportional error shows how the position and derivative the velocity of the steel ball changes with time. Figure 4 shows the dynamics of control signal with time as the system attain steady state. Figure 5 is the tracking performance test of the system. A continuous sine wave signal was applied to the system with the aim of determining how well the system responds to changes in the desired position of the ball. Therefore, it can be seen from the graph that the response is very close to the reference signal which signifies a good tracking performance.

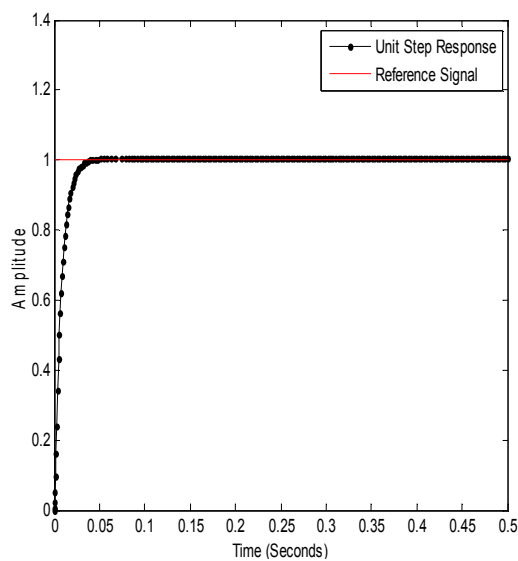


Fig. 2: Unit Step Response of the System.

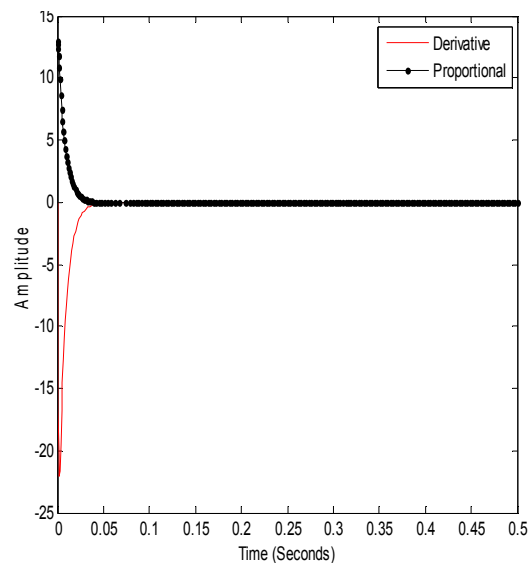


Fig. 3: Error Signals Response of the System.

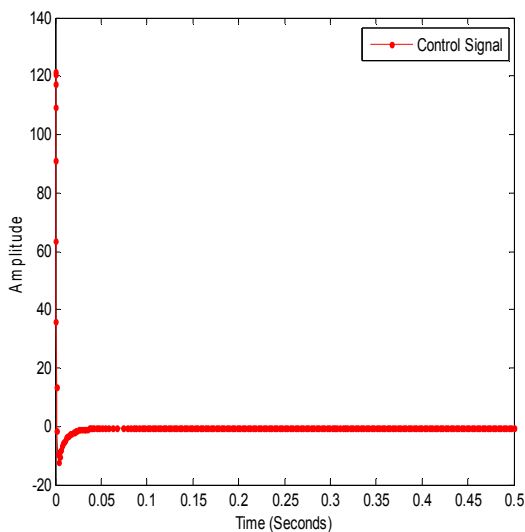


Fig. 4: Control Signal Response of the System.

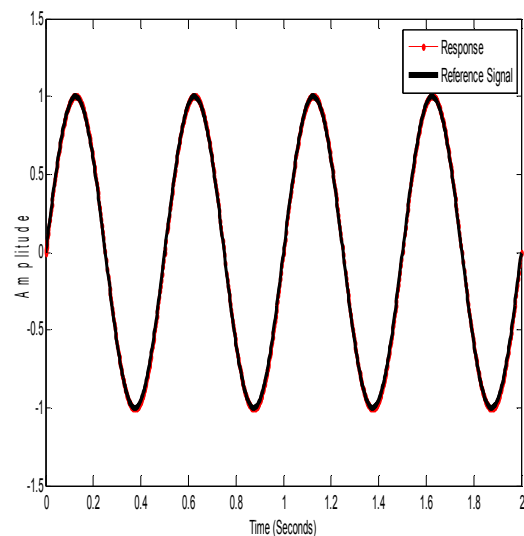


Fig.5: Tracking Performance Response of the System.

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## Conclusion

The magnetic levitation system has important applications and hence there is need to develop control strategies which are simple, good performance and flexible. The T-S type fuzzy logic controller was successfully applied for stabilization control of an electromagnetically levitated steel ball system. The system also showed a good tracking performance.

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