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Radial Active Magnetic Bearing Control using Fuzzy Logic

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Abstract

presented in this paper is a fuzzy logic approach to improve performance of a radial active magnetic bearing control system .classical ,linear design technique are most often used to control the natural instability of these bearing, but magnetic nonlinearities limit control effectiveness and the region of stable performance. therefore ,the a idea here is to adjust the linear controller signal in such a way that nonlinear effects are better compensated .the relationships of attractive force to the electromagnet currents and air gap are describe d and compensated using fuzzy principles, rather than a precise model-based control approach. Computer simulations are used to confirm that a fuzzy description of nonlinear compensation does indeed improve system performance, without requiring an exact model of the bearing nonlinearities.

Keywords: Active Magnetic Bearing, Magnetic Levitation, Fuzzy logic.

1. Introduction

Active magnetic bearings are being increasingly used in industrial applications where minimum friction is desired or in harsh environments where traditional bearings and their associated lubrication systems are considered unacceptable (Choi 2006 and L.O'Conner 1992) .commercially available technology was pioneered by the French in the early 1970's and is licensed by several American and Japanese firms. Typical applications for active bearings include turbo molecular vacuum pumps, gas pipeline centrifugal compressors, sealed pumps, and electric utility power plant equipment .application of the magnetic bearing in aerospace and cryogenic environments is also being examined. Bearings that also employ permanent magnets have been recently developed, but the majority of systems use electromagnets. Since the alto magnetic bearing is an active device, it can also generate beneficial characteristics that are impossible to achieve with traditional rolling element and fluid film bearings (Y.Zhang, 1991 and

E.Maslen,P.Hermann 1989) .In theory, loads can be moved and force disturbances can be gracefully damped (Schweitzer, G, 2009 and H.M.Chen 1988),rather than bearing passed onto the remainder of the mechanical system. Despite the great potential, the highly nonlinear and naturally unstable dynamic characteristic make AMB systems difficult to control. initial studies were concentrated firstly on the classical linear control techniques which were based on proportional –integral – derivative (PID)or proportional derivative (PD) type controllers and then followed by the modern controllers such as LQG and $H\infty$ which were also based on linear control theory. These linear controllers are designed by linear zing the dynamic model of a magnetic bearing about a nominal equilibrium point (Ming-Mao Hsu, Seng-Chi Chen, 2015 and M.Fujita,F.Mastsumura 1990).The main controllers used for AMB in most practical installation are the traditional PID type .whilst the performance of the PID controller is generally satisfactory for most practical applications. This type of controller becomes ineffective when the rotor is subjected to extreme operating conditions .thus, several non- linear control techniques have been proposed to deal with the non-linear dynamics of the AMB (S. C. Chen, 2013).

Research work on non-linear control of AMB has been undertaken by several authors to overcome the shortcoming of the linear PID controllers. Yeh proposed a sliding control scheme to deal with the non-linear dynamics of AMB systems (T.J.Yeh, Y.J.Chung, 2001). Marcio S. used a back stepping approach as compensation for parametric uncertainly and eliminating state measurements (Seng-Chi Chen, 2014),.however, these controllers are more complicated compared with their linear counterparts .At this point, a fuzzy logic controller (FLC) is seen as a solution for both of these problems (Belhamdi, S, 2015).Hong S.K. used a robust fuzzy control scheme for magnetic bearing (MB) systems. Hung J.Y.

Combined an FLC with a PID controller for adjusting the output of the PID controller in such a way that nonlinear effects are better compensated (Belhamdi, S, 2013).Maki K.H. used an FLC to tune the gains of the linear PD controller to improve the performance of the AMB control system (T. Dimond, 2012).

2. Active magnetic bearing model

A typical AMB configuration consists of a stator and a rotor. The coils are wound around each pole of the stator Each rotor axis has a pair of amplifiers to provide current to the bearing coils and an attractive force to adjust the position of the rotor along the particular axis. The current carrying coil wrapped around the stator of an AMB system creates a magnetic field within the stator, the rotor and air gap between the rotor and the stator.

In the derivation of the forces that are generated in the magnetic field, the following assumptions hold.

- Leakage of magnetic flux is neglected.
- Fringing effect i.e. the spreading of magnetic flux in the air gap is neglected.
- The magnetic iron is operating below saturation level.
- The expression for the electromagnetic force that is generated in a single –acting actuator is given in (1), where μo is the permeability of air, N is the number of the coil turns on the magnetic actuator, S is the area of the one magnetic pole, I is the coil current, and Co is the length of one air gap

$$F = \frac{\mu_0 N^2 S.i^2}{4C_0} \qquad (1)$$

In the actual operation of the AMB, a pair of magnetic actuators counter- acting each other is used. This configuration is known as the difference driving mode Figure.1 shows the basic principle of an active magnetic bearing.

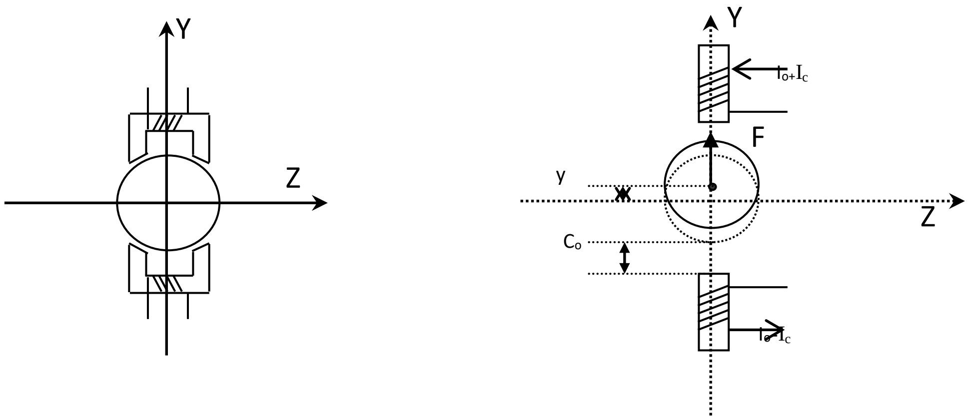


Figure1. Representation of a AMB with 1 DLL

The force produced in this system can be determined by assuming that the current in the decreasing air gap is (Io+Ic) and the current in the opposite side is (Io-Ic).the air gap is (Co-y)in the decreasing side ,and (Co+y) in the opposite side .Ic is the control current and Co is the nominal air gap i.e. the gap at equilibrium position in the Y- axis, and y is the displacement of the rotor from its equilibrium position in the Y-direction.F1 and F2 denote the forces of the two counter-acting actuators respectively, whilst F denotes the resultant force ,then the nonlinear force equation for the difference driving mode is (2).

$$F = F_1 - F_2 = \frac{\mu_o \; S \; N^2}{4} \cdot \left[\frac{(I_o + I_c)^2}{(C_o - y)^2} - \frac{(I_o - I_c)^2}{(C_o + y)^2} \right] \qquad (2)$$

Application of the Newton's second law to the AMB systems gives (3).

$$m\,\ddot{y} = K \cdot \left[\frac{(I_o + I_c)^2}{(C_o - y)^2} - \frac{(I_o - I_c)^2}{(C_o + y)^2} \right] \tag{3}$$

Where m is the mass of the rotor; $K = \frac{\mu_o\, S\, N^2}{4}$, which is the force constant. Equation (3) is the model used in the simulations, and plant parameters are shown in table 2.

3. Simulation model of AMB with linear controllers

The mathematical model that has been developed in section II is implemented using Matlab /simulink development AMB is the instability of the rotor .the most common PID controller is used to calculate the control current.

The regulator represented in the figure .2. The form of the regulator is given by equation 4.

$$G_c(s) = K_p.\left(1 + \frac{1}{T_i s} + T_d.s\right) \cdot \frac{1}{1 + \frac{T_d}{N}.s} \tag{4}$$

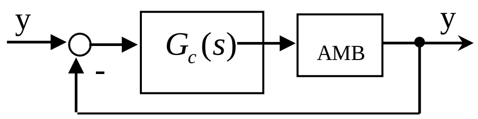
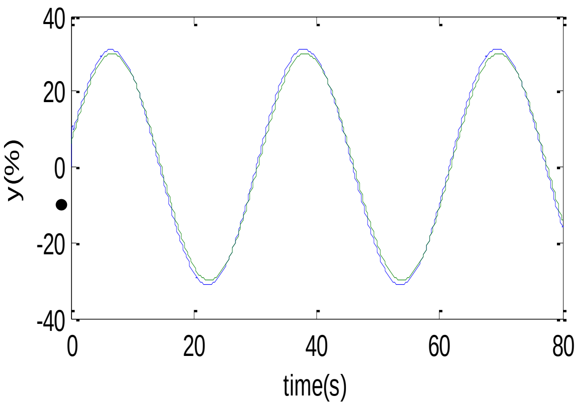
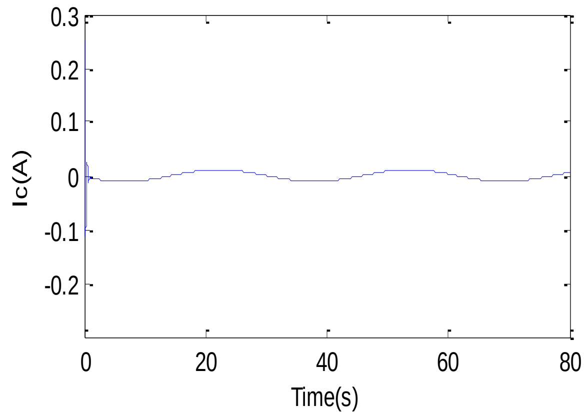


Figure.1. Diagram block of the AMB in closed

For calculated the gains of the regulator one uses a method of approach fast, consist in taking $T_i \approx T/10$ *et* $T_d \approx T_i/4$ *with* T :the dominant time-constant of the process and one generally chooses N about 10. Results of simulations of the AMB in loop closed with filtered regulator PID (KP=280, Ti=8, Td=2, N=10) and y ref =30% are consigned in the figure .3. We note that the active magnetic bearing is currently stable in closed loop.



a) : Displacement of the AMB



b) : Control of the AMB

Figure.3. application of PID to the AMB

4. Design of the FLC controller

Fuzzy logic theory was first established in Zadeh's seminal paper in 1965.Mamdani applied fuzzy logic to dynamics about 10 years later .the Mamdani architecture of a fuzzy logic controller is based on qualitative and empirical knowledge of human beings. Later Takagi and Sugeno established a fuzzy model, called the Takagi-Sugeno model, which can be more easily used for analytical purposes. Mamdani architecture is used here to build a non-linear rule-based fuzzy logic control system. Fuzzy logic controllers for active magnetic bearings are synthesized and designed for stabilizing the system during the command following process. The antecedent and consequent of each rule are defined in terms of input and output variables in predefined membership function. These membership functions possess qualitative description, which generalize the notion of assigning a single degree to a specific response severity or corrective action level.

The expert's experience is incorporated into a knowledge base with 25 rules (5 x 5). This experience is synthesized by the choice of the input-output (I/O) membership functions and the rule base. Then, in the second stage of the FLC, the inference engine, based on the input fuzzy variables e and Δe, uses appropriate IF-THEN rules in the knowledge base to imply the rules in the knowledge base to imply the final output fuzzy sets as shown in the Table1, where NB, N, Z, P, PB, correspond to Negative Big, Negative, Zero, Positive, Positive Big respectively (Belhamdi, 2013).

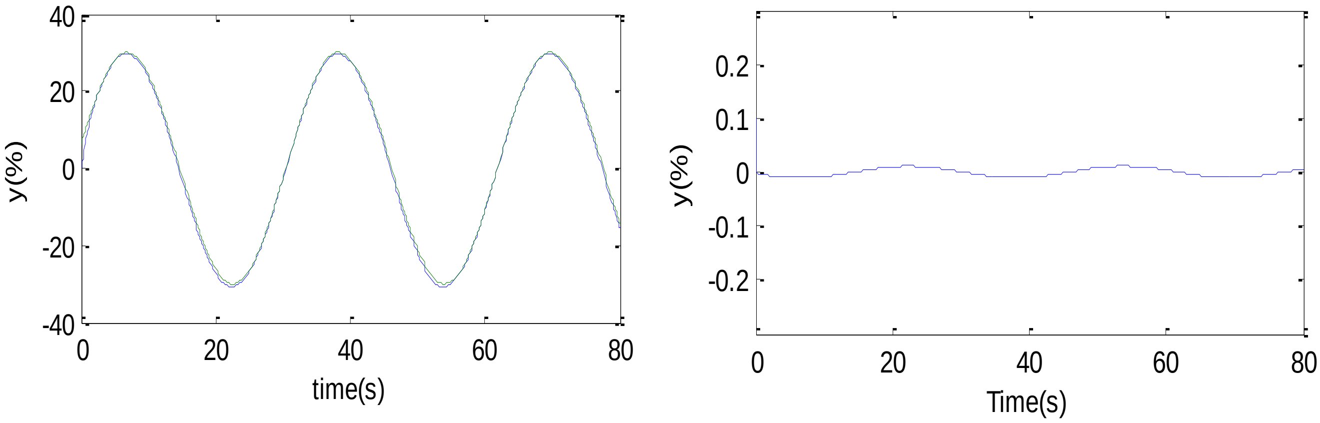
		e				
		NB	**N**	**Z**	**P**	**PB**
Δe	**NB**	NB	NB	N	N	Z
	N	NB	N	N	Z	PB
	Z	N	N	Z	P	PB
	P	N	Z	P	P	PB
	PB	Z	P	P	PB	PB

Table1. Fuzzy rule for type-1 FLCs

4. Simulation Results

The AMB whose parameters are shown in table I is simulated by using MATLAB. Equation (3) of the magnetic bearing system is built with S-function of MATLAB, and the basic fuzzy logic controller is built with the Fuzzy Inference System toolbox of MATLAB.

The figure (4) presents the evolution of the exit (displacement) and the manipulated variable. It is noticed well that displacement follows its reference well.



a) : Displacement of AMB

b) : Control of the AMB

Figure.4. Application of FLC to the AMB

Figure.7 shows the comparison between the responses of the traditional PID controller and the FL controller .it can be seen from fig (5) that when the FL control method is adopted, the overshoot of the rotor displacement is less than 4% and the rising time is less than 2.2 second. In contrast, the overshoot is bigger and the rising time is longer when the traditional PID method is adopted.

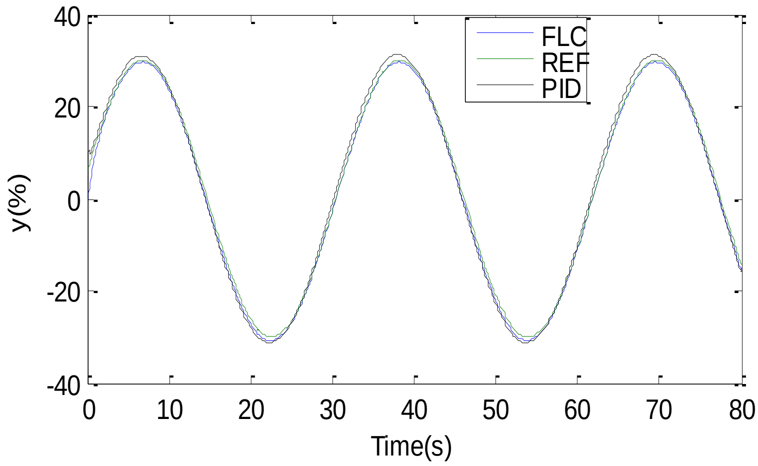


Figure 6. Comparison between the PID and FLC

4.1 In the presence of a disturbance in level

In this case we apply a disturbance of form square of period equal to 20s and of amplitude equalizes at 1.5%.the curves represented by figure. 7.

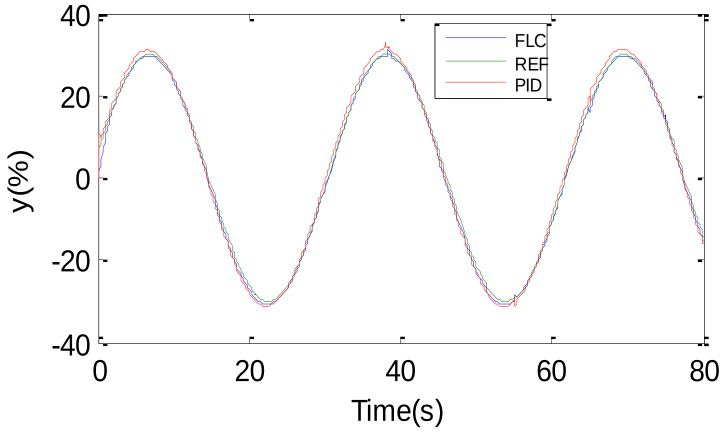


Figure.7. Application of PID and FLC to AMB

4.2 In the presence of a sinusoidal disturbance

Now; we apply a disturbance of sinusoidal form of frequency equal to 0.8 rad/s and of amplitude equalizes to 1.5%.the curves represented by figure.8.

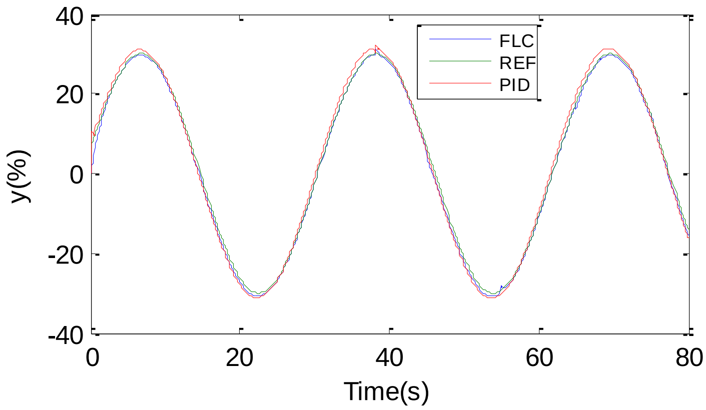


Figure 8. Application of PID and FLC to AMB

- It can be seen that the FL controller has stronger disturbance rejection ability compared with the traditional PID controller.

5. Conclusion

The fuzzy logic and PID type controllers for AMB have been studied. Initially, dynamic model of the AMB has been developed. First, a PID type controller has been applied to the system and the step response of the controller obtained. Owing to the small air gap, good results were achieved with linear controller with reasonable position errors. Since AMB have a nonlinear structure, the influence of the parameters on the performance of the system is clear. Thus, a nonlinear controller is formed in the simulation model by Fuzzy reasoning. Simulation results show that system performance is improved with FLC. It is observed that fuzzy control is giving better response than conventional controller.

Appendix

TABLE 2

PARAMETERS OF THE AMB SIMULATION MODEL

μ_o	4π x 1e-7
S (m²)	920.28e-6
N	100
m (kg)	8.5
I_o (A)	35e-3
C_o (m)	1e-3
i_o, y_o	(0,0)

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