ARTICLE IN PRESS

Alexandria Engineering Journal (2016) xxx, xxx–xxx

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Alexandria Engineering Journal

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ORIGINAL ARTICLE

Characterization and adaptive fuzzy model reference control for a magnetic levitation system

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Received 9 February 2016; revised 9 April 2016; accepted 23 April 2016

KEYWORDS

Magnetic levitation;
Fuzzy control;
Adaptive control

Abstract This paper shows the implementation of a fuzzy controller applied for magnetic levitation, to make this, the characterization of the magnetic actuator was computed by using ANSYS® analysis. The control law was a Mamdani PD implemented with two microcontrollers, to get a smooth control signal, it was used a model reference. A learning scheme was used to update the consequents of the fuzzy rules. Different reference signals and disturbances were applied to the system to show the robustness of the controller. Finally, LabVIEW® was used to plot the results.

1. Introduction

The commercialization and the industries are incremented the fuzzy logic implementations in common processes and machines [1], they are saying that these machines are intelligent systems [2]; however, a fuzzy control is only a nonlinear control [3]; nevertheless, the knowledge of an expert can be used to build the fuzzy control.

This paper shows a magnetic levitation system, this kind of system has lower friction than the mechanical ones, so less energy must be used, some applications are the high speed train and magnetic breaks, and it is possible to appreciate that magnetic force is very important for the technological development.

In [4] it is possible to see the design and implementation of a magnetic levitation system, the control was with a feedback linearization; however, the authors explain that the control is sensible to model errors. By using this idea in [5] an external loop with an integral part was used to reduce the steady-state error, it was developed using the frequency response.

In the work of Challa [6] other control was developed to control the magnetic levitation of an object in a determined operation point, they were applied compensators in an analogous way; here, the electronic development uses the optical characteristics of sensors.

In the chapter 11 of [7] it is shown the design of an analogical PID by using operational amplifiers, where it was not needed an important economic investment.

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.04.032
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A fuzzy PID is shown by Kim et al. [8], where the fuzzy system is tuned in order to improve the response in a levitation system, in [9] the control used is also a fuzzy PID, a steady-state error can be regarded in the results, the authors mention that the problem was to tune the integral gain. In [10], where there were used two control strategies, a classical PID [11] with its fuzzy counterpart in two versions: a fuzzy P + I + D and a fuzzy PD + PI, the experimental results were possible with a OMRON® FB-30AT (with a special processor for algorithms FP 3000), here the authors had explained that the best performance was by using the fuzzy P + I + D, due a simplification in the multivariable structure as the decomposed fuzzy controllers presented in [12,13].

In [14] it was presented a comparison between the application of a fuzzy control and a linear quadratic regulator for magnetic levitation, in this paper the magnetic model is presented and it was used the Hilink platform board in the application, the results show a better response for the fuzzy controller due its robustness when a disturbance was presented, these results were to regulate the position not for tracking. In order to have tracking, the tuning of a PID by using a linear quadratic regulator was presented in [15]. However, a fuzzy control can be developed without having the mathematical model as Ishaque et al. [16] mentioned.

In order to improve the transient performance in magnetic levitation, a two degree of freedom PID was presented by Ghosh et al. [17] where two compensators were used to modify the control robustness.

An application with radial basis function neural networks was presented in [18] where an ARX model was tuned with neural networks, and based in the model, a predictive control was applied with a good accuracy, also it is possible to appreciate its continuation in [19].

The aim of this paper is to implement an adaptive fuzzy control for a magnetic levitation by using an electromagnet, with a controller capable to track some trajectories, this controller is an adaptive Mamdani PD, a similar control design can be seen in chapter 6 of [3].

The actuator design was possible with a magnetostatics analysis in ANSYS®, this is a software that can predict the physical characteristics and the response of real systems, so this software is used in the development of physical products in industry, this software can emulates mechanical systems, electronic components, fluid, and electromagnets [22].

To simulate the electromagnet it was used the magnetic core configuration, the coil current, and the number of turns. The magnetic force is important for this kind of systems, in [20] a similar analysis was shown and the control is a predictive one that uses the nonlinear model.

The fuzzy control was implemented in a microcontroller DsPIC that computes the error tracking to supply the required voltage, by using other microcontroller and LabVIEW® the reference signal is selected and the movements measured are plotted in a computer.

2. Materials and methods

To have an idea about the levitation system, its modeling is now described, it helps to determine the discourses universes used by the fuzzy controller; the levitation system is composed by two parts, the actuator is a coil that supplied the magnetic force, and the entire model has the sphere and its reaction with the magnetic field.

2.1. Actuator design

The electromagnet has a core with a "T" shape, it is laminated and built with silicon steel, the kind used in transformers due its major magnetic permeability that produces a better response for the hysteresis cycle; the laminated core reduces the eddy current losses. The core shape selected was due its capability of concenter the magnetic flow before its dissipation to the opposite magnetic pole, and the reduced dimension needed for the coil.

In Table 1 they are shown the values used to build the coil, the wire characteristics were obtained from the specification sheet given by the distributor, the reel dimensions can be seen in Fig. 1. These values were used to get the model of the electromagnet in order to tune the fuzzy control used in the experimental platform.

To have the theoretical coil parameters, the equations set (1) was used

$$\begin{aligned} n_c &= b/\phi, \\ n_{vpc} &= a/\phi, \\ n_{vt} &= n_c n_{vpc}, \\ L_{vpc}(c) &= 4((e+2f)+j\phi), \\ L_t &= L_{vpc} n_{vpc}, \\ R &= L_t R_{CU}/S_\phi, \end{aligned} \tag{1}$$

where n_c is the number of layers, n_{vpc} is the number of turns by layer, n_{vt} is the total of turns in the coil, L_{vpc} is the length of a turn by layer, c is the layer number, $j = 0, 2, 4, \ldots$ is an even number that corresponds to the layer number, L_t it the total length of the coil, R is the coil resistance, R_{CU} is the copper resistance and S_ϕ is the transversal area section of the wire. In Table 2 they are shown the theoretical parameters found and the real values obtained in the electromagnet construction.

To analyze the magnetic force it was used ANSYS®, the specifications were: an empty sphere with 3 mm of thickness, with a diameter of 60 mm, N = 1100 (number of turns in the coil), $I = 2A$ (current applied). It is necessary to approach the real system, therefore, it was used a structural steel for the sphere and the magnet core in the model, this was in order to have the more realistic results due the magnetostatic analysis done. The simulation was for each millimeter in the operation region to have a magnetostatic force curve and an inductance-distance curve; these curves were used to build a mathematic model, Fig. 2 shows a simulation for the model obtained.

2.2. Magnetic force model

There are some approximations to compute the magnetic force, they are shown four of them to approach the results obtained by using ANSYS®, due the CAD model is based in the real actuator. The approximations used are the following: