DESIGN A FUZZY CONTROLLER FOR A MAGNETIC LEVITATION SYSEM IN THE LABORATORY

Nguyen Hoai Nam[1*], Cong Thi PhuongThao[2]
[1]College of Techonology – TNU, [2]Vietnam College of Coal and Minerals

SUMMARY

Nowadays, a variety of real systems operate based on the magnetic levitation systems. They include magnetic bearings, high-speed maglev train and magnetic melting systems. There are many methods to control these systems, such as PID controllers as well as nonlinear controller. In this work, we use a fuzzy controller. It is designed and simulated by using Matlab/Simulink. Then, it is applied to control a real magnetic levitation system in the laboratory. The fuzzy controller makes the system stable with high performances in comparison to that of PI controller. Its fuzzy rules are based on the experience obtained from the simulation and there is no usage of mathematical model of the real magnetic levitation system.

Key works: *Fuzzy controller, magnetic levitation system, PID control, microcontroller*

INTRODUCTION

Magnetic levitation (maglev) systems [1] are widely used in many areas including frictionless bearings, high-speed trains, vibration isolation of sensitive machinery, levitation of molten metal in induction furnaces, and levitation of metal slabs. These are obviously open-loop unstable and they are described by highly nonlinear differential equations. There are many methods used to control these systems but designed controllers are almost dependent on their mathematic models.

GA-Based Fuzzy Reinforcement Learning [2] was proposed to find a neural controller or a fuzzy controller for a magnetic levitation system. An adaptive robust nonlinear controller [3] via backstepping design approach was proposed for position tracking problem of a steel ball levitated by a magnetic system. They used a radial basis function network to approximate the uncertainty of the mathematic model. The other authors [4] used a polynomial function to approximate the nonlinear component of the system. Then, a feedback linearization controller is designed to solve the tracking problem of the levitated object. A VSC [5] for robust stabilization and disturbance rejection of a single degree of freedom magneticlevitation system was designed. A robust nonlinear controller [6] was designed and the dynamic surface control was modified and applied to the system. Input-to-state stability of the control system was analyzed. The design steps of novel fuzzy sliding mode control [7] was provided and then the Lyapunov stability analysis is given. Simulation of a ball magnetic levitation system was used to illustrate the effectiveness of the proposed controller. In [8], Adaptive robust output-feedback controller of a Magnetic levitation system was proposed by using K-Filter Approach. An FPGA based fuzzy controller [9] was designed for a magnetic levitation system. A fuzzy logic controller [10] was designed for the stabilization of magnetic levitation system. Then it was comapared with linear quadratic regulator controller. An exact feedforward linearization controller [11] combined with fuzzy-based gain scheduling for single DOF magnetic ball levitation system was designed. The comparative analysis of MIT rule based control with differential evolution (DE) algorithm based control [12] was carried out by applying them to magnetic levitation system in real time.

In this paper, we only review the most recent works which is highly related to ours during

[*] *Tel: 0917 987683, Email: hoainam@tnut.edu.vn*

the last decades. For our study, we design and fabricate a real model of magnetic levitation systems, which consists of coils, suspended object, position measurement sysem, h-bridge, Arduino UNO and computer. Then, a computer based fuzzy controller is designed and implemented to keep the position of the levitated object at expected point. The designed controller is compared with the classical PI controller either.

The next section is about design and fabrication of a real magnetic suspension system. A fuzzy and PI controllers were designed in the section 3. The section 4 will present some results after doing real time control. Conclusions and future work are given in the final section.

MAGNETIC LEVITATION SYSTEM

Our target is to build a real model of magnetic suspension systems with low cost and accepted exactness for experimental purposes. The levitated object is made of a cylindrical iron bar and 9 pieces of cylindrical thin magnet, but for other papers it is usually a steel ball. To reduce the cost of the system, we design and make our own location sensor based on encoder as in Fig. 1. When a positive voltage is applied to the coils the levitated object moves up nonlinearly proportional to the voltage. This makes the link 1 move up and then the link 2 rotates clockwise. By using an encoder, the angle position is measured. Thus, the position of the levitated object can be implied by multiplying the value of the angle with a sensor gain. The gain will be obtained by doing experiments. The encoder, in this case, has two channels and each channel has 448 pulses.

Fig. 1 shows the picture of the maglev control system where (1) – suspended object, (2) – coils, (3) – encoder, (4) – rotating shaft, (5) – link 1, (6) – link 2, (7) – location limiter, (8) – Arduino UNO, connected to PC/laptop, (9) – H bridge circuit.

For this system, the suspended part can move from zero to 2.5 cm (the highest position with respect to 5 DCV). A computer based control algorithm will determine the value of control signal and then this value will be converted into PWM signal through one of Arduino PWM pins. The PWM pin is connected to the H-bridge to provide a voltage to the coils. For convenience, we use Matlab/Simulink Toolbox and Arduino IO library to implement control algorithms. The Arduino UNO board is setup as follows:

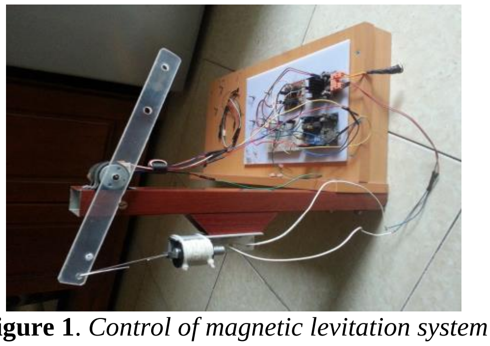

Figure 1. *Control of magnetic levitation system*

Pin 2: Channel A from encoder; Pin 3: Channel B from encoder; Pin 5: PWM; Pin 6: Direction; Serial port: COM3 (connection between Arduino and computer); Real time pacer: Speedup = 1; Voltage source: 12VDC.

In the next section, control algorithms will be designed and implemented.

CONTROL ALGORITHMS

In this part, we design two regulators: PI and fuzzy controllers. These controllers are programmed by connecting blocks in Simulink and then run in real time mode through the Arduino UNO card. Normally, the magnetic levitation system is designed to keep the levitated object at certain location during operation. This position is called a working point. In our project, the working point is set to be 1 cm. Thus, theoretically a PI controller can be designed to stabilize the system around the working point. Also, based on this known point, the ranges for input and output of the fuzzy logic system can be obtained.

PI regulator

For the PI controllers, a kind of trials and errors method is used to find the values of PI parameters consisting of proportion gain K_p and integral factor K_I. In the beginning, we set K_p to be a very small positive number and $K_I = 0$. Then, we run the control system in real time mode. (Case 1) If the setting time is long and the static error is big then we will increase K_p. The system will be run again with the changed gain. (Case 2) If there is an oscillation then the gain K_p will be decreased. After some experimental real time runs, we choose the best value of the tested gains of K_p. Next, we keep K_p unchanged and adjust the integral part K_I. The initial value of K_I is chosen as a small positive number. Again, we run the system in real time mode. If the static error is big then we increase or decrease K_I until the expected static error is reached. Thus the obtained PI controller is not the best one but acceptable one. This controller is later compared to fuzzy controller in term of close loop performances.

Fuzzy regulator

Basically, a fuzzy logic system consists of three components: fuzzification, If – Then rules and defuzzification. Behind the if–then rules are fuzzy operations such as fuzzy complement, fuzzy union and fuzzy intersection. Any function that satisfies certain conditions can be used as fuzzy operation, for example, MIN, MAX and PRODUCT. These functions are widely used in fuzzy logic system. There are two types of fuzzy models: Mamdani and Sugeno. In this work, we use Mamdani model because of its flexible in fuzzification and defuzzification method.

The expert knowledge is gained from the simulation in Simulink. A mathematical model of the magnetic levitation system [13] is used to test fuzzy controllers in Simulink. For simplicity, P based fuzzy controllers will be designed with three cases: 3, 5 and 7 fuzzy sets for each input and output. From the simulation, the fuzzy controller with 7 fuzzy sets offers the better performances against the others. Seven triangular membership functions are used for the input as shown in Fig. 2. The range for the input is from -0.2 to 1.3.

For the output, 7 triangular membership functions are also used as shown in Fig. 3. The output range is from 0 to 0.3. The fuzzy rules are as follows,

$If\ (input1\ is\ mf_i)\ Then (output1\ is\ mf_i)\ for\ i\ from\ 1\ to\ 7.$

The diagram of fuzzy control system in real time mode is shown in Fig. 4.

For the real time PI control system, the block of fuzzy logic controller is replaced with a block of PI controller. In the next section, some real time control results are shown.

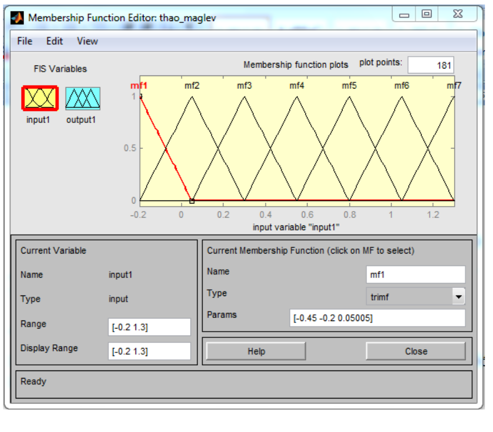

Figure 2. *Input fuzzy sets*

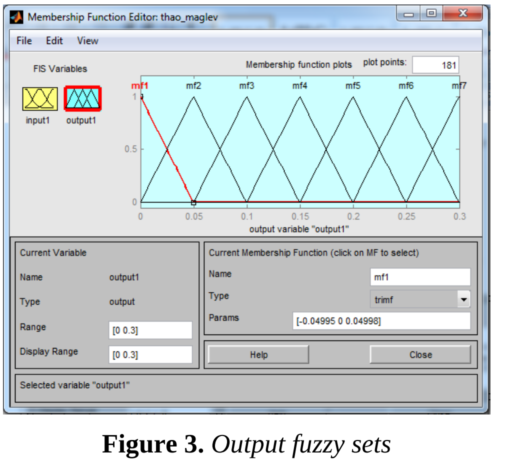

Figure 3. *Output fuzzy sets*

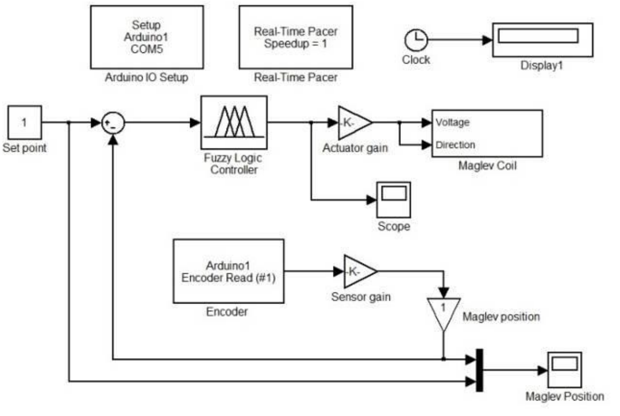

Figure 4. *The diagram of real time fuzzy control system*

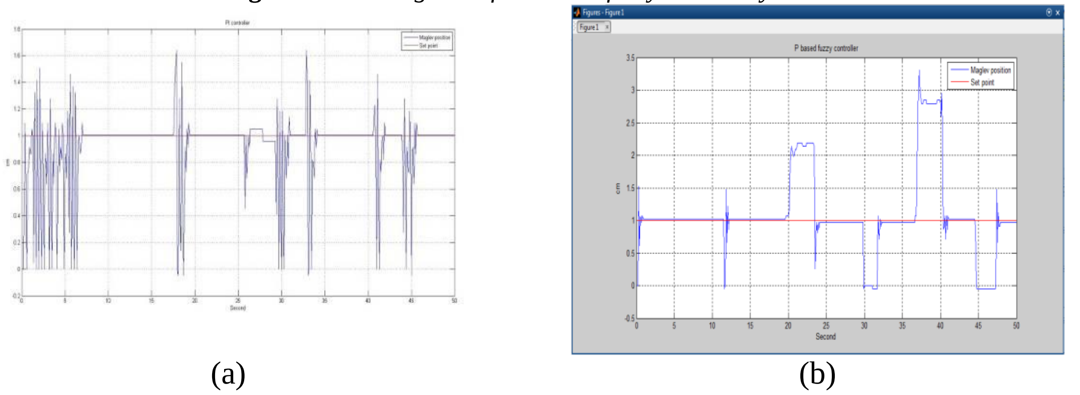

Figure 5. *The position of the levitated object, (a) - PI controller, (b) - fuzzy controller*

RESULTS

Running the control system in real time mode using PI and fuzzy controllers, the position of the suspended object is recorded and shown in Fig. 5 (a) and Fig. 5 (b) associated with their setpoint. In these figures, the red line is the setpoint and the blue curve is the position of the magnetic levitated object.

Disturbances are added to the system at certain time. At the time, the suspended object is moved out of the setpoint. Then it is forced to move back the setpoint by controllers after few seconds. In comparison, the fuzzy controller provided better performances against the PI controller: faster setting time, less oscillation and small static error.

CONCLUSIONS AND FUTURE WORK

In this work, we designed and made a magnetic levitation system in the labratory which can be used for experimental and educational purposes. Two controllers, PI and fuzzy, were designed and implemented on computer with the usage of Arduino Uno. Some comparisions have been made for the these controllers by running the system in real time mode. The fuzzy controller provided better characteristics at the working point. To improve the performances of the system, system identification is neccessary and other advanced controllers can be used. In addition, the position sensor system must be improved to provide better precision.

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TÓM TẮT

THIẾT KẾ BỘ ĐIỀU KHIỂN MỜ CHO HỆ THỐNG NÂNG TỪ TRONG PHÒNG THÍ NGHIỆM

Nguyễn Hoài Nam[1*], Công Thị Phương Thảo[2]
[1]Trường Đại học Kỹ thuật Công nghiệp – ĐH Thái Nguyên,
[2]Trường Cao đẳng Than và Khoáng sản Việt Nam

Ngày nay rất nhiều hệ thống thực khác nhau hoạt động dựa trên các hệ thống nâng từ. Các hệ thống này bao gồm các ổ đỡ từ, các tàu đệm từ cao tốc và các hệ thống nấu chảy từ. Có rất nhiều phương pháp để điều khiển các hệ thống này, như các bộ điều khiển PID và các bộ điều khiển phi tuyến. Trong bài này, chúng tôi sử dụng một bộ điều khiển mờ. Bộ điều khiển này được thiết kế và mô phỏng sử dụng Matlab/Simulink. Sau đó, bộ điều khiển mờ được áp dụng để điều khiển một hệ thống nâng từ thực trong phòng thí nghiệm. Bộ điều khiển làm cho hệ thống ổn định với chất lượng cao so với bộ điều khiển PI. Các luật mờ dựa trên kinh nghiệm thu được từ mô phỏng và không sử dụng mô hình toán của hệ thống nâng từ thực.
Từ khóa: *Điều khiển mờ, hệ thống nâng từ, điều khiển PID, vi điều khiển*

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Phản biện khoa học: *ThS. Nguyễn Tiến Hưng - Trường Đại học Kỹ thuật Công nghiệp - ĐHTN*

* *Tel: 0917 987683, Email: hoainam@tnut.edu.vn*