 ISSN 1213–2489
e-ISSN 2787–9402

DOI: 10.21062/mft.2024.067 http://www.journalmt.com

Linear Motor System Identification and Simulation Experiments Based on LabVIEW

Xiaoyan Wu (0000-0002-4040-1971)[1], Shu Wang (0009-0003-9235-9466)[2, *]
[1]Hubei Key Laboratory of Intelligent Convey Technology and Device, Hubei Polytechnic University, 16 Guilin Rd. (N), Huangshi, Hubei, China; School of Mechanical and Electrical Engineering, Hubei Polytechnic University, 16Guilin Rd. (N), Huangshi, Hubei, China. Email: 201091@hbpu.edu.cn
[2]School of Mechanical and Electrical Engineering, Hubei Polytechnic University, 16 Guilin Rd. (N), Huangshi, Hubei, China. Email: 201081@hbpu.edu.cn

There are currently many control methods for linear motors, and the focus of controlling the motor should be different for different application needs. In general applications, simple PID control can meet the application requirements, but in precision motion situations with high requirements for motion accuracy, response speed, and stability, PID control is often difficult to achieve satisfactory control results, which requires the application of more advanced control strategies to complete. At present, combining multiple control algorithms and concentrating the advantages of each algorithm while trying to overcome each other's disadvantages has become a major trend in the development of motor control theory. High speed, high efficiency, high precision become the development direction of the current numerical control equipment, linear motor because of its unique performance, now widely used in a variety of precision positioning occasions. Aiming at the requirements of high speed response and high precision of linear motor, the linear motor system is designed based on LabVIEW software and NI acquisition card, including hardware composition and software algorithm. In the LabVIEW simulation environment and the actual control system, the conventional PID algorithm and fuzzy PID algorithm are used to control, and the control results are compared. The experimental results show that compared with the PID control, the fuzzy PID algorithm has obvious advantages in improving the control accuracy, anti-interference ability, reducing the overshoot and improving the system response speed.

Keywords: Linear motor, System identification, LabVIEW, Fuzzy PID, Simulation experiment

1 Introduction

Traditional control theory, represented by PID control, is a control strategy based on error elimination. This control method has a simple structure and high reliability, so it is currently widely used in industrial control. PID control is a linear approximation process that requires the mathematical model of the control object to be determined and the operating environment to be stable. Its best control object is a second-order linear inertial system. Moreover, when the parameters of the controlled object model change, the PID control response is relatively slow and the robustness is not very good. In addition, the parameter tuning of PID control is quite complicated, and the interaction between parameters makes it difficult to achieve the most satisfactory control effect [1]. To address these issues, many researchers have combined traditional PID control with other control methods to form a composite control method. Fu Ziyi combines PID control with fuzzy control to form fuzzy PID control, achieving self tuning of PID parameters, greatly improving the robustness of the motor control system and improving the control effect [2]; For example, Jang Hwan Kim et al. introduced a disturbance observer to weaken the influence of time-varying parameters on the control system [3]; Guo Qingding et al. used a neural network based IP position controller to adjust the gain of IP online through a recursive fuzzy neural network, improving its tracking performance[4]; Deng Zhongliang applied the self optimizing digital PID correction control algorithm to the permanent magnet DC voice coil motor, improving the response speed and tracking displacement accuracy of the linear motor [5].

Worldwide, the application of linear motors is mainly concentrated in industrial equipment, logistics systems, information and automation systems, transportation, civil and military areas [6]. In recent years, the development of linear motor mainly presents the following characteristics: 1) the performance continues to improve; 2) the coverage of varieties is becoming more and more extensive; 3) Installation and maintenance is very convenient, high reliability; 4) decreasing costs; 5) high degree of commercialization [7]. Therefore, in the control system of linear motor, the displacement and velocity detection components must meet the high resolution and dynamic response ability, but also hope that the designed controller can have strong robustness to study the appropriate control strategy to control stability of the control system.

2 Linear motor servo system

The function of the servo system is to control a certain state of the object, so that the controlled object can accurately display the requirements of the system input command. A servo system whose control quantity is displacement is called a position servo system. Position commands generally have linear displacement and angular displacement. The main task of the position servo system is to make the control object achieve accurate positioning and tracking according to the given speed and trajectory and can still move regularly according to the instructions under the action of sufficient load, and ensure that the error between input and output is kept within a certain range [8].

The linear motor position servo system takes as the control object. If the linear motor used is a core-free permanent magnet synchronous linear motor, it is called an ILPMLSM servo system, which mainly includes linear motors, motion controllers, servo drives, position detection components, etc. [9]. Its structure is shown in Fig. 1.

The movement platform driven by non-core permanent magnet linear motor mainly includes single axis, two axis and multi-axis. Fig. 2 shows a motion platform linear motor, which is composed of X, Y, Z and W four axes, designed to meet the requirements of high precision and high acceleration of linear motion platform in lead-bond integrated manufacturing system.

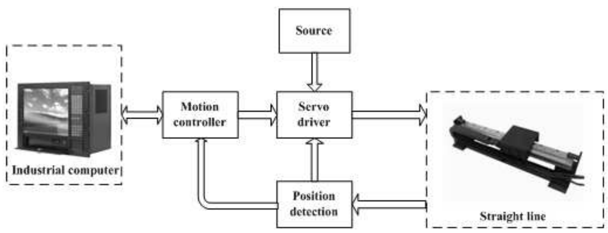

Fig. 1 *Linear motor servo control system*

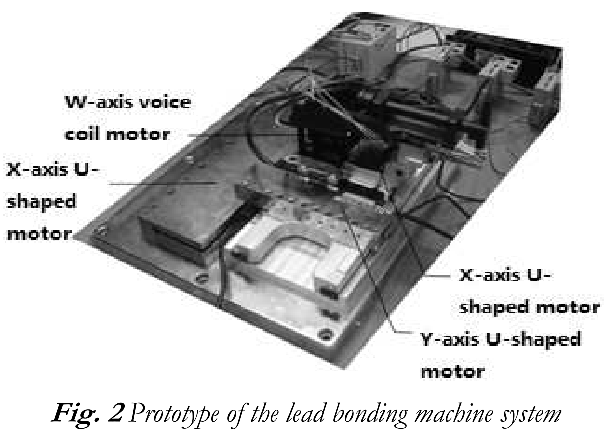

Fig. 2 *Prototype of the lead bonding machine system*

The linear motor platform used in this paper is single axis. The sensors often used in the non-core permanent magnet synchronous linear motor platform are Hall sensors and position sensors. The Hall sensor is usually installed together with the coil assembly. When designing the platform, attention should be paid to leaving enough space for convenient assembly and protection against collision. To realize the normal work of the position sensor, the distance between the reading head and the grating ruler is required to be within a certain range, so the sensor bracket is generally installed during the design, leaving the operation space for convenient adjustment and maintenance.

3 Modeling and identification of linear motor system

3.1 Principle and structure of linear motor

The structure of the linear motor can be considered to be obtained by opening the rotating motor along its radius and expanding its circumference into a straight line. Therefore, it can be considered that the structure of the linear motor and the rotating motor is similar [10]. The stator of a rotating motor is called primary on a linear motor; A rotor on a rotating motor is called a secondary on a linear motor.

In addition to the structural similarity, the linear motor is also similar to the rotating motor in the working principle [11], as shown in Fig 3. Due to the end effect caused by the break of the two ends of the actuator, when this factor is not distribution principle, except that the linear motor magnetic field is distributed along a straight line, called the traveling wave magnetic field. It interacts with the excitation field generated by the excitation body to produce electromagnetic thrust. Under the action of electromagnetic thrust, the stator is in a fixed position without movement, so the stator and its movement speed is the same as the linear speed of the rotating magnetic field on the surface of the inner circle of the stator (called the synchronous speed) [12].

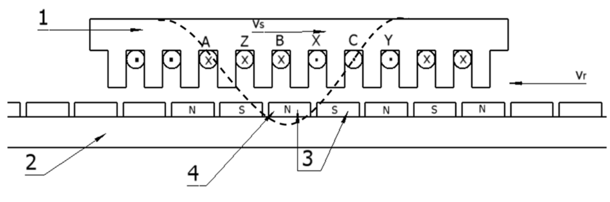

Fig. 3 *working principle of linear motor*

Where:
1…Actor (primary),
2…Stator (secondary),
3…Permanent magnet (N, S poles),
4…Traveling wave magnetic field.

The motor is a U-shaped permanent magnet synchronous linear motor without iron core, and its working principle is the same as that of general linear motors. The stator is composed of a permanent magnet array with alternating N and S pole permanent magnets and back iron, and the actuator is mainly composed of a coil winding. The basic structure is shown in Fig 4.

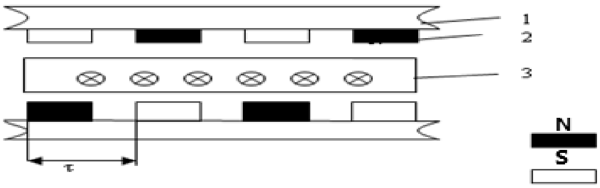

***Fig. 4** Structure of U-shaped linear motor*

Where:
1…Stator soft iron,
2…Permanent magnet,
3…Actuator coil,
τ…Pole distance of motor.

3.2 Derivation of mechanism model

This paper adopts the combination of theoretical analysis and related identification methods to obtain the linear motor model, so the theoretical derivation of the linear motor model is carried out first. For linear motors, voltage balance equation and dynamic balance equation are two important equations, which are given by Equation (1) and equation (2) [13]:

$$u = L\frac{di}{dt} + Ri + Blv \tag{1}$$

$$F = ma \tag{2}$$

$$F = NBil \tag{3}$$

Where:
u…The voltage at both ends of the coil,
i…The working current of the linear motor,
L and R…The inductance and resistance of the coil,
v…The speed of the actuator,
a…The acceleration,
F…The traction force of the motor,
N…The number of turns of the coil,
B…The magnetic field strength,
l…The length of the coil.

Substituting v and in Equations (4), (1) and (2) by y˙and y ¨, respectively, and applying Laplace transformation, we obtain:

$$U(s) = LsI(s) + RI(s) + BlY(s) \tag{4}$$

$$NBlI(s) = mY(s)s^2 \tag{5}$$

After derivation, the transfer function of motor servo system is obtained as follows.

$$\frac{Y(s)}{U(s)} = \frac{2NBRlh}{LJs^3 + Jrs^2 + 2NB^2R^2l^2s} \tag{6}$$

Since the inductance L of the coil is relatively small, LJs^3 can be omitted, so the above equation can be simplified as:

$$\frac{Y(s)}{U(s)} = \frac{2NBRlh}{Jrs^2 + 2NB^2R^2l^2s} \tag{7}$$

At this point, the motor servo system can be regarded as a second-order system.

3.3 Model parameter identification

System identification, state evaluation and control theory are three fields that permeate each other in modern cybernetics. The functions of establishing mathematical models of objects to be studied mainly include: system simulation, system prediction, system design and control, system analysis, fault diagnosis, and verification of mechanism models [14]. The so-called system identification is to determine a model equivalent to the measured system according to the characteristics of the input and output information. To estimate the parameters of the system through experimental data or to determine the mathematical model of the system, system identification techniques are needed. At present, identification technology has been widely used in many fields, such as chemical process, nuclear reactor, power system, aerospace vehicle, biomedical system, socio-economic system, environmental system, ecological system, etc. [15-17].

The basic steps of system identification are shown in Fig 5. The essence of identification is the process of obtaining the mathematical model of the system through the input signal and output data of the system.

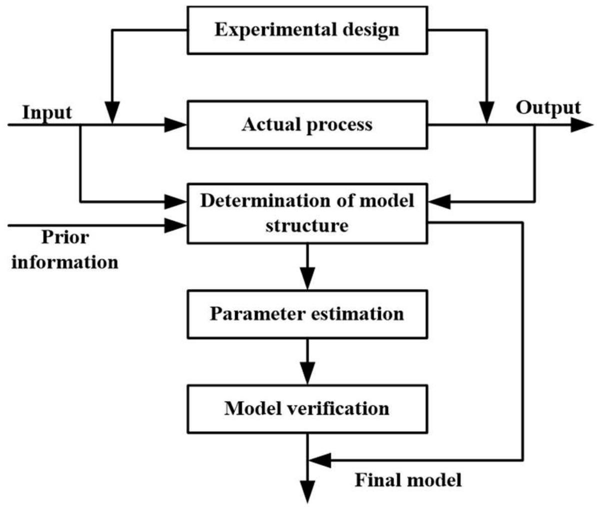

***Fig. 5** Steps of system identification*

4 Control implementation and data acquisition of LabVIEW

4.1 Identification experiment design

The main role of experimental design is to use the available data to obtain as much information as possible about the system. To obtain the real system more accurately, it is necessary to conduct effective experiments on the motor. The selection of experimental methods and experimental signals will directly affect the effect of identification. When designing an experiment, it is necessary to understand the research object, the variables to be observed and the control method. It is necessary to detect all the relevant variables as far as possible, and some constraints that may be encountered in the experiment should also be considered.

In general, the design content of the system identification experiment mainly includes: the design of the input signal, the design of the sampling time and the scheme of the parameter estimation, and the selection of the experimental equipment.

In order to obtain a better identification effect, choosing a reasonable signal is the key. In order to make the system identifiable, the input signal needs to meet certain requirements, the most basic of which is that the input signal must continuously stimulate the dynamic response of the system during the entire identification process.

M-sequence signals meet the requirements of the input signals of the system identification. In the classical identification, M-sequence is often used, that is, the two-bit shift register is composed of several flip-flops with shift function in series. Under the action of shift pulse, the new state of the flip-flop will be equal to the original input. The shift register shifts the number to the right by one bit, and the part of the state of each level is added modulo 2 and fed back to the input of the first level.

The M-sequence used in this experiment can be generated by Matlab/simulink construction, as shown in Fig 6. It is worth noting that the output obtained from the shift register is Boolean data and cannot be used directly, so it needs to be converted to double type by the data type conversion module before it can be used. In addition, the conditional switching module should be used to obtain the desired output signal amplitude [18].

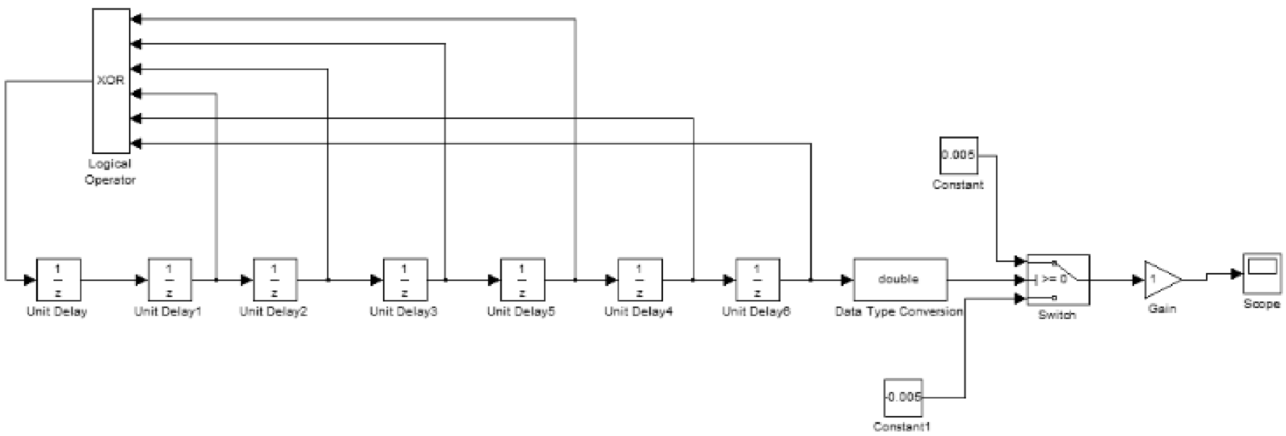

***Fig. 6** Procedure for M sequence generation*

4.2 Data collection

After the M-sequence is determined, the DSP outputs the pseudo-random input signal to the identified system through DA and feedback the displacement signal of the linear motor through the position sensor. The output signal of the sensor is collected by DSP, and it is displayed on the program interface designed by LabVIEW through RS232 to complete the data collection, that is, the system response signal corresponding to the M-sequence. This is shown in Fig 7.

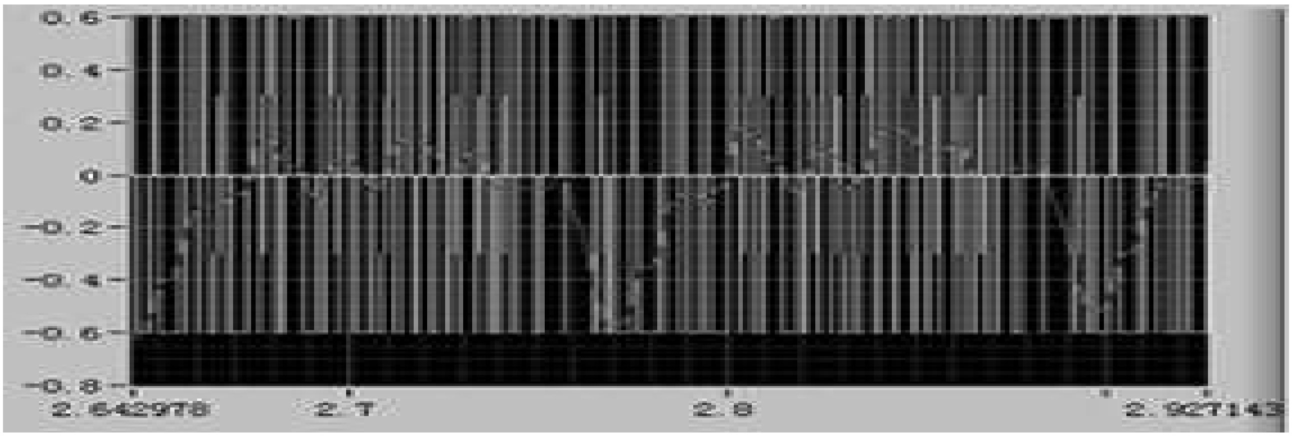

***Fig. 7** Data acquisition*

4.3 System identification

After the completion of the previous data collection, the data processing, that is, the process of model identification, the process through the system identification toolbox provided by Matlab to complete the corresponding processing and calculation.

Before identification, the system need to be imported into the workspace of Matlab, and then the program interface of the system identification toolbox can be opened by inputting ident in the command window of Matlab. The program interface mainly includes data storage area, data preprocessing area, identification data area, identification algorithm area, model output area, etc.

After entering the system identification interface, click the list box in the upper left corner of the interface, select the Time-domain Data option under the Import Data column, fill in the Input u and Output y of the system in the input and output columns, and set the sampling Time to 0.001s. Click the Import button to complete the data entry.

In addition, the statistical characteristics of the input and output numbers are required to be independent of the statistical time starting point, and the mean value is 0. However, the original data collected may contain DC components, trend terms, etc., whose influence on the identification accuracy cannot be eliminated by any method. Therefore, it is necessary to preprocess the experimental data before identification. In the Preprocess drop-down menu in the model identification interface, Remove means and Remove trends can be used to complete the task of removing DC components and trend items, and filtering, resampling and other functions can also be completed here [19-24].

After the preprocessing step of the data, the next step is to identify the system model. Drag the obtained Data to the Working Data area and click the Estimate menu, where parameter models and process models can be identified. In this paper, process models are selected [25], and the output of identified model data is shown in FIG. 8.

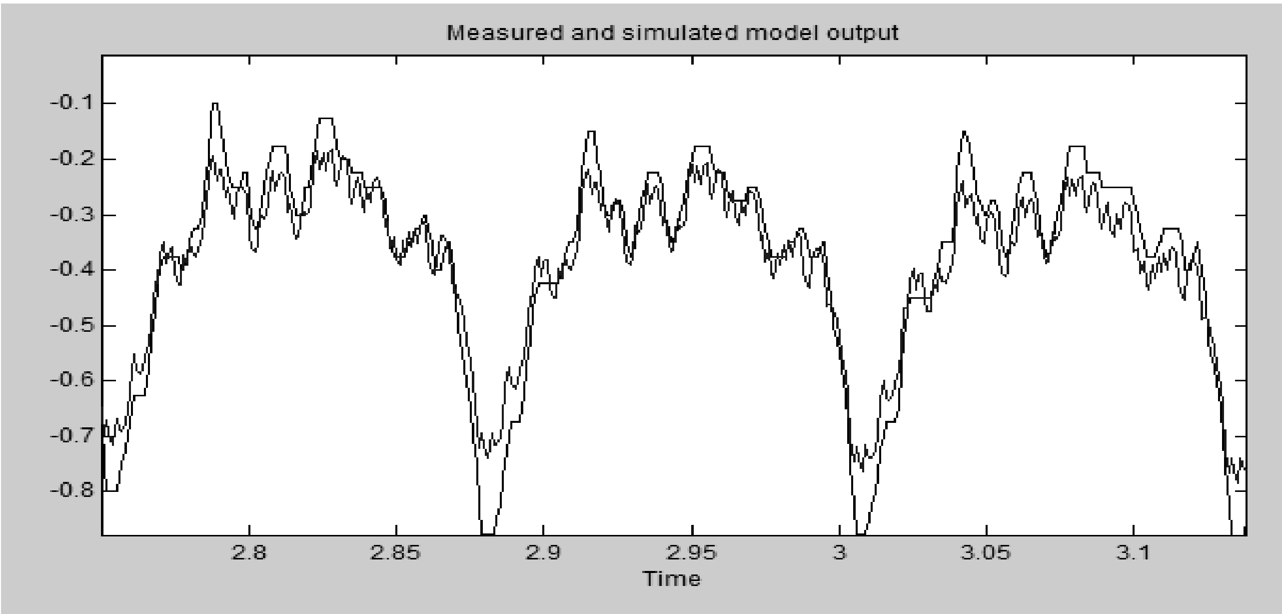

Fig. 8 *The output of the identification model*

So far, the linear motor system can be obtained as follows.

$$G(s) = -173.77\frac{1-0.0019201s}{(1+2.3866s)(1+0.002592s)} = \frac{-0.311s+161.647}{s^2+386.205s+161.647} \tag{8}$$

Through the identified model, we can use different control algorithms to conduct control experiments on the motor in the simulation environment and provide a basis for actual motor control experiments.

5 Linear motor control experiment and analysis

The simulation model of linear motor in the system has been given through system identification. In the simulation environment of LabVIEW, the position tracking experiment is carried out on the motor model under PID control and fuzzy PID control, and the tracking effect of the system under different control methods is observed by tracking different displacement curves. The simulation source program for the step response is shown in Fig 9.

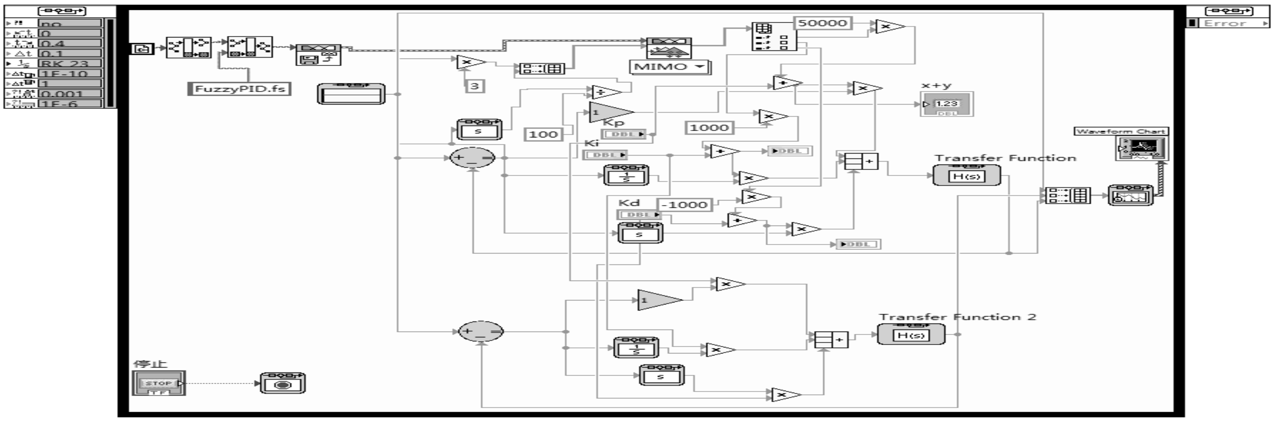

Fig. 9 *Control system simulation program*

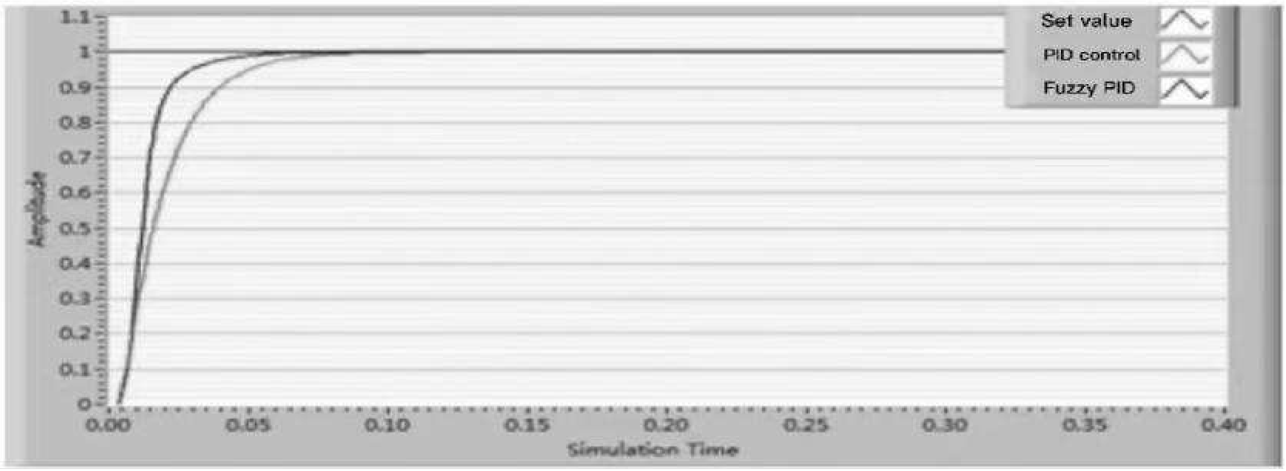

Fig. 10 *Position step response curves*

Fig. 10 shows the position step response curve of the system, the blue curve is the command value, the red curve is the tracking effect under PID control, and the black curve is the tracking effect under fuzzy PID control. As can be seen from the figure, the adjustment time of position step response under the traditional PID control is 0.12s, while the adjustment time under the fuzzy PID control is 0.07s, and there is no overshoot and oscillation in the process, the system is stable and responds quickly.

It can be seen that compared with the traditional PID control, fuzzy PID control can make the response speed of the system faster, and there is no overshoot and oscillation, the control effect is better than PID control.

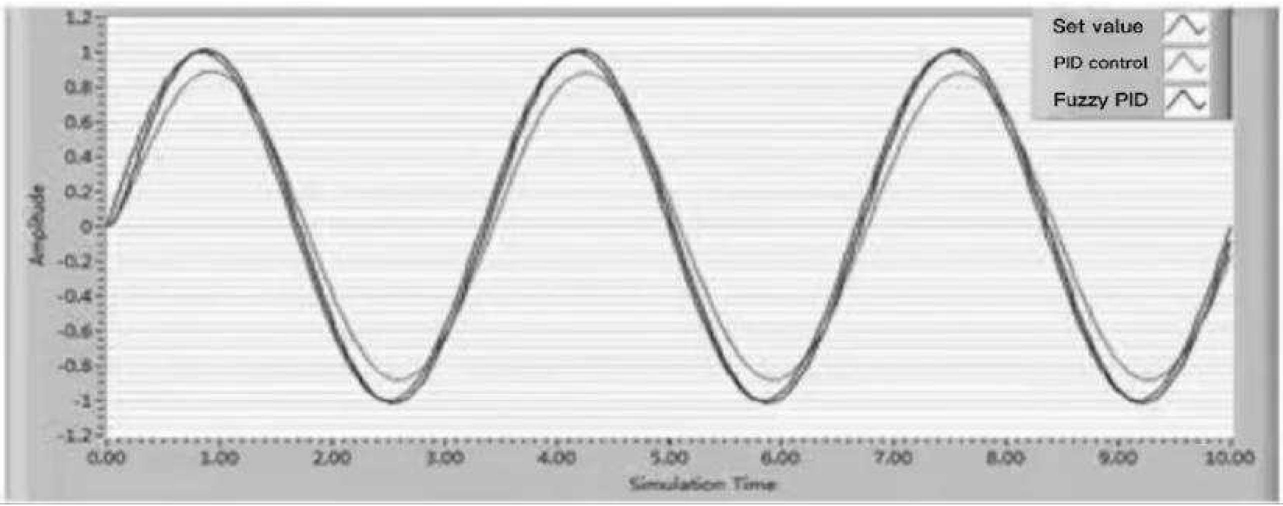

Fig. 11 *Position tracking curve of sinusoidal signal*

Fig. 11 shows the tracking of sinusoidal signals under the two control methods. It can be seen from the figure that the black curve under the fuzzy PID control coincides well with the set value curve and the error is small, while the red curve under the PID control is far away from the set value and the error value is large. This experiment shows that the control accuracy under the fuzzy PID control is higher than that under the PID.

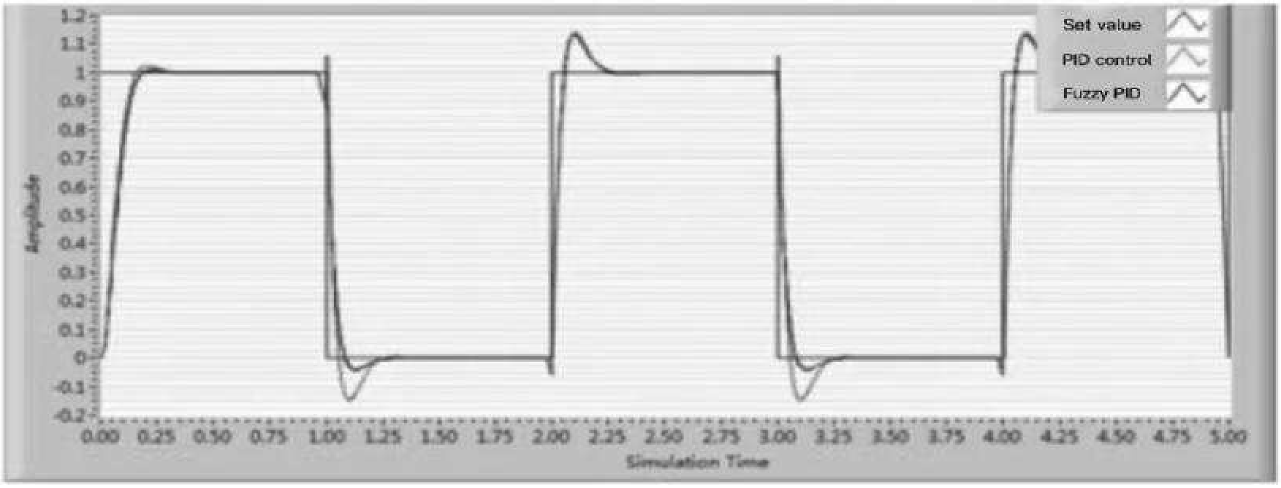

Fig. 12 *Position response curve of square wave signal*

Fig. 12 shows the tracking situation of the position signal of the opposing wave in the system. It can be seen from the figure that there is no significant difference in the control effect of the two in the upper part of the curve, but when the displacement is close to zero, the red curve under PID control shows a large overshoot, while the tracking curve under fuzzy PID control shows a small overshoot, indicating that fuzzy PID is reducing the overshoot. Improving the control accuracy is better than PID control, and the control performance is better.

6 Conclusion

In the LabVIEW simulation environment, control experiments were conducted on the servo control system of linear motors using conventional PID algorithm and fuzzy PID algorithm. Through comparative analysis of experimental data, the experimental results showed that compared to traditional PID control, fuzzy PID algorithm has significant advantages in improving control accuracy, anti-interference ability, reducing overshoot, and improving system response speed. The research results of this article will be beneficial for applying to precision motion situations with high requirements for motion accuracy, response speed, and stability, providing a control strategy for system identification and control optimization of linear motors.

Acknowledgement

This work was supported by Key Projects of Hubei Provincial Natural Science Joint Innovation Fund (2023AFD002), Young and Middle-Aged Talent Project of Hubei Education Department (Q20214502), The Teaching and Scientific Research Project of Hubei Polytechnic University (2021A06).

References

[1] QIN YI, ZHOU YONGPENG, DENG ZHONGHUA, et al. *Modern AC servo system*. Wuhan: Huazhong University of Technology Press, 2020.

[2] FU ZIYI, ZHANG HUA. Research on Fuzzy PID Control of Vertical Motion Permanent Magnet Linear Synchronous Motor. *Industrial and Mining Automation*, 2021, (4): 10-13.

[3] JAN HWAN KIM. High precision position of linear permanent magnet synchronous motor for surface mount device placement system. *Power Conversion Conference*, 2022, l(l):37-42.

[4] GUO QINGDING. Precision Control Technology of Linear AC Servo System. Beijing: China Machine Press, 2020.

[5] DENG ZHONGLIANG. Research on High Frequency Response Precision Displacement Linear Motor and Its Control. *Chinese Journal of Electrical Engineering*, 2019, 19 (2): 41-46.

[6] SEAMUS GORDON. Development of a high speed CNC cutting machine using linear motors. *Materials Processing Technology*, 2019166:321-329.

[7] FA-JENG LIN. On-line gain tuning using RFNN for linear synchronous motor. *Power Electronies Specialists Conference*, 2021, 2:766-771.

[8] BOWERS R. Scanning Our Past from London Using Yesterday's Engineering Tomorrow: Eric Laithwaite. *Proc.* IEEE, 2021, 89(2):214-216.

[9] SONG SHUZHONG. Development and Application of Linear Motor. *Control Engineering*, 2016, 03: 199-201+277.

[10] B. RAISON, F. FRANCOIS, G. ROSTAING, AND J. ROGON, Induction drive monitoring by neural networks, *Proc.* IEEE Int. Conf. Industrial Electronics, Control Instrumentation, 2020:859-863.

[11] SHAO XIAOQIANG. Current Situation and Development Direction of Linear Motor. *Electrical Technology*, 2021, 07:58-60.

[12] GUILLEMOT F, SOUQUET A, CATROS S, et al. High-throughput laser printing of cells and biomaterials for tissue engineering. *Acta Biomater*, 2020, 6(7):2494~2500.

[13] MA RONGHUA. dSPACE-based PID controller for a linear motor driven inverted pendulum. *Proceedings* of International Conference on Mechatronics and Machine Vision in Practice, Xiamen, China, 2019:68-72.

[14] THORNTON RICHARD D. Linear synchronous motor design. IEEE Electric Machines and Drives *Conference*, MA, US, 2019:1555 - 1560.

[15] SEITZ H, RIEDER W, IRSEN S, et al. Three-dimensional printing of porous ceramic scaffolds for bone tissue engineering. *J Biomed Mater Res B Appl Biomater*, 2019, 74(2):782~788.

[16] DHAOUADI, R. Design and implementation of an extended kalman filter for the state estimation of a PMSM. *IEEE Transactions on Power Electronics*, 2019, 6(3):491-497.

[17] FAN HAIMIN. Linear Motor Control System Based on Smiht Preestimator. *Applied Science and Technology*, 2021, 29(5):27-29.

[18] K. YOSHIDA. Deeooupled-control method for levitation and propulsion in amphibious train marine- express. *Memories of the faculty of engineering Kyushu University*, 2022, vol.55, No.4, PP467-489.

[19] QUADRANI P, PASINI A, MATTIOLLI-BELMONTE M, et al. High-resolution 3D scaffold model for engineered tissue fabrication using a rapid prototyping technique. *Med Biol Eng Comput*, 2020, 43(2):196~199.

[20] SHI, Y., ZHU, Y. 2023. Research on Viewpoint Planning Method for Multi-view Image 3D Reconstruction. M*anufacturing Technology*, 23, 532-537.

[21] ABIAN, M., HUŇADY, R., KUPEC, F. 2022. Reverse Engineering and Rapid Prototyping in the Process of Developing Prototypes of Automotive Parts. *Manufacturing Technology*, 22, 669-678.

[22] ZHANG DAILIN. Control Strategy and Experimental Research of Permanent Magnet Synchronous Linear Motor Servo System. Huazhong University of Science and Technology, 2019.

[23] SMITH C M, ROY T D, BHALKIKAR A, et al. Engineering a titanium and polycaprolactone construct for a biocompatible interface between the body and artificial limb. *Tissue Eng Part A*, 2020, 16(2):717~724.

[24] SHAO, S., XING, Y., QU, L., LI, X. 2021. An Automatic Generation Method of Exploded View Based on Projection. *Manufacturing Technology*, 21, 691-699.

[25] NOROTTE C, MARGA F S, NIKLASON L E, et al. Scaffold-free vascular tissue engineering using bioprinting. *Biomaterials*, 2019, 30(30):5910~5917.