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Quantitative Feedback Control of Linear Motor for Wood Cutting CNC Machine Tools Based on Model Parameter Identification

Chuansheng Tang[1], Lei Yang[2*]
[1]School of Intelligent manufacturing, Nanyang Institute of Technology, Nanyang, Henan, China
[2]School of Information Engineering, Nanyang Institute of Technology, Nanyang, Henan, China
*Corresponding Author.

Abstract:

High speed and high precision wood cutting CNC machine tools not only need high repeat positioning accuracy and low-speed motion stability, but also need high feed speed and acceleration and deceleration. Although the linear motor feed system saves the intermediate transmission link, the load and other external interference directly act on the linear motor, which makes the control of linear motor more difficult. In this paper, the model parameter identification method is used to control the linear motor together with the driver, and on this basis, the system model is established. In order to improve the positioning accuracy of linear motor feed system, the motion control of the system is studied. In this paper, quantitative feedback control is applied to linear motor and used as the driving device of machine tool feed system. The grating ruler is used as the feedback element, and the torque control mode is adopted to control the experimental linear motor. The experimental results show that the maximum acceleration of the linear motor direct feed system can reach 5g.

***Keywords**: wood cutting CNC, linear motor, feed system, parameter identification.*

I. INTRODUCTION

With the rapid development of high-speed machining, the traditional feeding system of CNC machine tools has also put forward higher requirements. The linear motion of traditional NC machine tools is converted from rotary motion by servo motor via ball screw nut pair [1-3]. This structure is reliable and stable. With the development of control technology, its transmission accuracy is also quite high. At present, most CNC machine tools adopt this

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method. However, with the growing market demand, the continuous progress of manufacturing industry and the popularization and application of high-speed machining, it also shows its shortcomings more and more [4-6]: (1) the transmission speed is low (the current maximum linear speed is less than 60 m/min), which is far from meeting the needs of high-speed machining; (2) The structure is complex, and there are many friction links, so the service life of components is generally short; (3) The motion stability is poor, especially in high-speed machining, which is easy to produce large noise and serious heat; (4) Repeated positioning accuracy is very low.

Because of this series of reasons, with the development of high-speed machining, linear motor has become the focus of people's research. Linear motor can produce continuous unidirectional or short-stroke reciprocating linear motion, which is a device that directly converts electric energy into mechanical energy of linear motion without any intermediate links. Using linear motor in the feed system of NC machine tool can realize "zero drive" linear drive device. Compared with the feed system with "rotating motor+ball screw" indirectly generating linear motion, it has obvious advantages [7]: (1) the driving force is generated in the air gap, and only the friction of linear guide rail exists, so the transmission is stable; (2) In theory, the travel is unlimited, and the motor runs wherever the second stage is laid; (3) The speed range is wide, from a few microns per second to 200m/s, and the acceleration can be as high as 20g; (4) Because of eliminating the intermediate links that affect the accuracy, the accuracy and repeatability are both high.

From the above analysis, it can be seen that the application of linear motor in CNC machine tools is the future trend, and it is also the need of high-speed machining technology. However, due to the particularity of linear motor, its control requirements are higher than the general control occasions, so the existing control technology can not keep up with the development needs of linear motor, so the control problem of linear motor will be a research focus.

II. MATHEMATICAL MODEL AND SIMULATION OF PERMANENT MAGNET SYNCHRONOUS AC LINEAR MOTOR

2.1 Control strategy of permanent magnet synchronous AC linear motor

With the rapid development of modern control technology and micro-computer technology, linear motor control technology is gradually developing to the economic and reasonable direction. Now the core control of linear motor can be composed of microprocessor, single chip microcomputer, PLC and DSP, while the peripheral devices can be realized by solid state relay, transistor and other devices. The research of control method is to use these components reasonably according to different control objects, different control requirements and different

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external conditions to achieve the optimal control effect. The key of permanent magnet linear synchronous motor control is not only the requirements of general servo system, but also the more complex disturbance, so we should pay more attention to its control algorithm. At present, there are three kinds of control methods commonly used.

1. Control strategy of traditional control

The traditional PID control algorithm is simple, robust and reliable, especially suitable for the deterministic control system which can establish accurate mathematical model. But for some non-linear and time-varying systems, the application of PID controller can not achieve the desired control effect because of the inability to establish a certain mathematical model.

2. Modern control strategy

According to the nonlinearity of the actual system operation, modern control algorithms are gradually developed. Adaptive control, variable structure control, robust control, H_∞ control and predictive control are commonly used. These methods can realize the self adjustment of PID parameters according to the working conditions.

3. Intelligent control strategy

With the development of control technology, the development of control gradually moves towards intelligence. Now the fuzzy control, neural network control, expert system and other methods, which should be the mainstream direction of the development of the control field in the future.

2.2 Simulation of Permanent Magnet Synchronous Linear Motor Based on MATLAB/Simulink

2.2.1 Overview of simulation

System refers to the organic whole with certain purpose or certain movement law which has certain functions, combined with certain laws, interacts and relies on each other. Generally, the system has three common attributes, namely entity, attribute and activity. Entity is the definite object that exists in the system. All the effective characteristics of entity are its attributes. Each process in which the state of the system changes is called activity.

Model is a tool for research system, cognition system, description system and analysis system. System model is an abstract of the actual system, and it is the expression of the essence of the system. It is the final result of people's repeated understanding and analysis of objective things, and through many similar processes such as transformation and integration. The system model has similar physical properties and mathematical descriptions as the system. It gives all the information of the system studied in various useful forms. The model of the system can

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reflect the main characteristics and motion rules of the entity more deeply and intensively, thus achieving the abstraction of the entity [8]. Therefore, in a way, the model is better than the entity. The system model mainly includes the solid model and the mathematical model.

2.2.2 System simulation

System simulation is a multidisciplinary comprehensive technology based on the similarity principle, system theory, information technology and related professional technology in the field of application, and using computer and various physical effect equipment as tools, and using system model to dynamically study the real or imagined system. Through the research of the model, the morphological characteristics and essence of the prototype are revealed, so as to realize the purpose of understanding the actual system. Because the present simulation is generally realized and completed by computer, it is usually called computer simulation.

System simulation is a comprehensive subject based on the theories of similarity theory, computer science, probability theory, system theory, mathematical statistics and time series analysis. Similarity theory is the main theoretical basis of system simulation [9-10]. The following similarities are generally used in system simulation: geometric similarity, physical similarity, discrete similarity, equivalence, sensory similarity and thinking similarity.

The relationship between simulation and mathematical solution can be described as follows: (1) The mathematical solution is a general solution, while the simulation is a special solution, which is a solution set under specific conditions. In other words, if the system has an accurate mathematical model and analytical solution, there is no need for simulation. (2) The mathematical solution is limited and needs simplification and abstraction. In principle, there is no limit to the complexity of the mathematical model, and sometimes it may be the only solution. (3) Mathematical solution is one-off, focusing on results; Simulation is an experimental method, which focuses on the process of multiple runs under different conditions and the analysis of a series of results.

The design and development of simulation and software are mainly based on the following software tools.

(1) general programming languages, such as FORTRAN, Basic, C, C++, etc. In actual use, because these languages and programs are not designed for system simulation, developers need to spend a lot of time and energy on programming grammar, basic operations and other issues, which is inefficient and difficult to popularize.

(2) Simulation software package. The so-called software package is a program which is compiled in general computing language and has simple functions and can solve special

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problems. Simulators can concentrate their computer simulation programs in the form of subroutine library and call them flexibly, but they still have certain specificity and lack flexibility.

(3) Simulation language. It is divided into two types of simulation languages: equation-oriented and block diagram-oriented, which are developed on the basis of high-level languages and aiming at special problems. It is translated automatically by the machine, so its speed is slow, but because it is directly oriented to users, it has strong simulation function.

(4) Integrated modeling and simulation environment. It includes modeling, software and hardware simulation, result analysis and processing, and final controller development and testing. It can be divided into two categories, one is general modeling and simulation tools, such as MATLAB and Simulink, which are the most influential modeling and simulation software at present. The second category is modeling and simulation tool software focused on a specific application field or especially strengthened in a certain link of simulation, such as ORCAD PSPICE, ADAMS, ANSYS, etc.

III.THEORETICAL BASIS OF INTELLIGENT CONTROL FOR LINEAR MOTION OF CNC MACHINE TOOL TABLE DRIVEN BY LINEAR MOTOR

3.1 Basic theory of fuzzy control

Fuzzy control is a kind of computer digital control software based on fuzzy set theory, fuzzy language variable and fuzzy logic reasoning. This theory was first put forward by the famous professor L. A. Zadeh of the University of California in the United States. Later, e.h.mamdani of England used fuzzy control statements to form a fuzzy controller for the first time, and applied it to the control of boilers and steam engines, which was successful in the laboratory. This work marks the formal birth of fuzzy control theory.

In the field of control, fuzzy control belongs to the category of intelligent control, which is essentially a kind of nonlinear control. One of the characteristics of fuzzy control is that it not only has a systematic theoretical system, but also has a lot of practical application background. However, the development of fuzzy control theory is not smooth. It was first popularized rapidly and widely in the East, especially in Japan. However, at the beginning, it encountered great resistance in the West. In the past 20 years, fuzzy control has made rapid progress both in theory and technology, and has become a very active and fruitful branch in the field of automatic control. Its specific application has been involved in many aspects of production and life, such as fuzzy air conditioning, fuzzy washing machine, fuzzy microwave oven, etc; In the field of industrial control, there are fuzzy fermentation process, fuzzy cement kiln and so on; In

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the special system and other aspects, there are automobile driving, elevator and robot fuzzy control.

The principle block diagram of fuzzy control is shown in Figure 1:

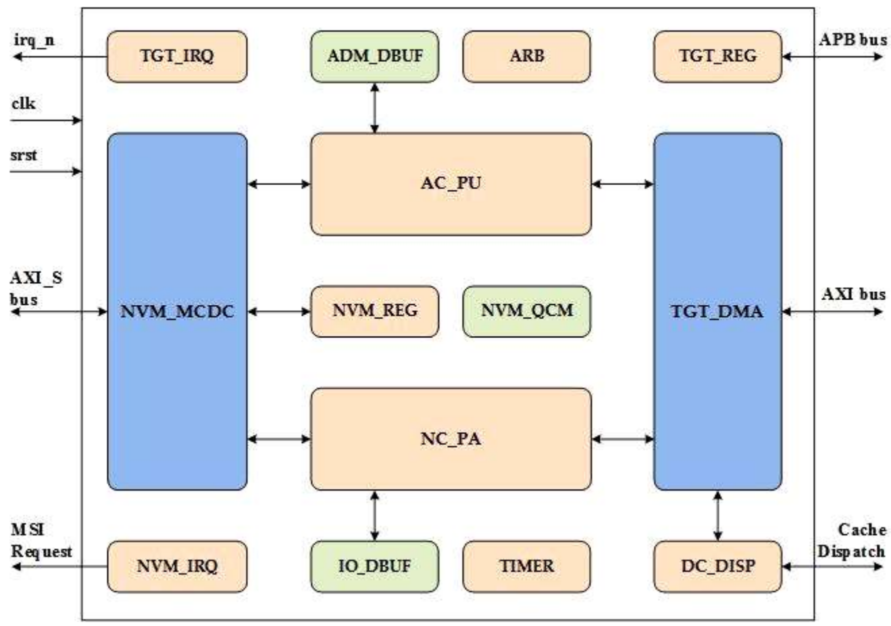

Fig 1: Principle block diagram of fuzzy controller

3.2 PID parameter self tuning fuzzy controller

PID parameter self-tuning fuzzy control system is a kind of adaptive control system which uses fuzzy rules to adjust PID parameters in real time. Its idea is to combine the idea of fuzzy reasoning in fuzzy control with the conventional PID control, take the error and error change rate as the input of fuzzy reasoning machine, and then carry out on-line self-tuning for the three parameters of PID. The schematic diagram of PID parameter self-tuning fuzzy controller system is shown in the figure:

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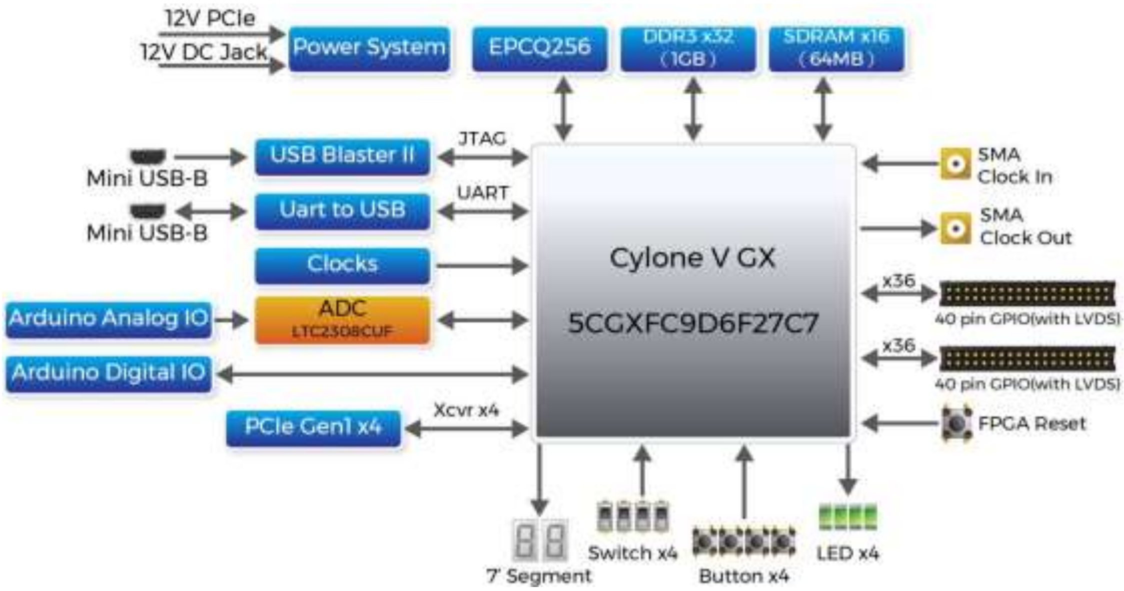

Fig 2: Schematic diagram of adaptive fuzzy controller

The working process of the fuzzy controller can be described as follows: firstly, the input of the controller is fuzzified; Then, fuzzy decision is made according to fuzzy control rules, and then the fuzzy output of control quantity is obtained by fuzzy reasoning algorithm Finally, the fuzzy quantity of the control quantity is accurately converted into specific control quantity and output. The specific implementation method is as follows:

1. Select input variables and fuzzify them

In general, most of us choose deviation E and deviation variation ec as the input of fuzzy controller, and △U or KP, KI and KD of PID as the control output of fuzzy controller. The universe e and ec = [-n, +n] of deviation e and deviation change rate EC are defined according to the change range of each parameter, and the universe of △U or output KP, KI, KD of PID and its membership function are also defined. The membership functions of variables have the forms of triangle and trapezoid, which can be freely selected according to specific conditions. For example, when the universe of a variable is defined as {-3, -2, -1, 0, 1, 2, 3}, its corresponding fuzzy subsets are {NB, NM, NS, ZO, PS, PM, PB}, which respectively represent negative big, negative middle, negative small, zero positive, positive small, middle and big.

2. Determine the fuzzy control rules of PID parameters

Next, we need to determine the fuzzy relationship between the three parameters of △U or PID and the input (deviation e and deviation variation ec), which is what we call the control

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rule. In order to realize on-line adjustment of output parameters by continuously detecting the changes of E and ec during operation.

3. Find PID control parameters

According to the previous control rules and membership functions, the input deviation e and deviation variation ec are calculated by fuzzy inference algorithm.

3.3 Description and characteristics of genetic algorithm

When solving various optimization problems, the common optimization algorithms are Newton method, simplex method, gradient method, etc. Compared with these traditional algorithms, genetic algorithm has some inherent characteristics. (1) The operation object of genetic algorithm is the code of decision variable instead of the actual value of decision variable. (2) Genetic algorithm uses objective function as direct search information. It directly determines the next search direction according to the fitness value of the objective function, which is much more convenient than the traditional algorithm which needs the derivative of the objective function or other information to determine the search direction. (3) Genetic algorithm uses implicit parallel multi-point search method. This method is superior to the single path search method adopted by the traditional algorithm, so it has higher efficiency. (4) Genetic algorithm adopts probability search method. Compared with the traditional search direction and inherent search algorithm, genetic algorithm shows its flexibility and convergence.

When genetic algorithm is used to solve the problems that need to be optimized in practice, it can be carried out according to the following steps: (1) First, the decision variables and constraints should be determined. (2) It is necessary to determine the type of objective function and its mathematical description method or quantitative method, that is, to establish an optimization model, which should be determined according to the requirements. (3) Determine the individual gene type and coding mode (either decimal or binary). (4) Determine the conversion mode from individual genotype to individual phenotype, that is, the decoding mode. (5) Establish fitness function, which is generally related to objective function. (6) Designing genetic operators (selection, proportion, etc.). (7) Determine the relevant parameters of genetic operation, such as population size, evolutionary algebra, crossover probability, mutation probability, etc.

IV. INTELLIGENT CONTROL SIMULATION OF NC MACHINE TOOL DRIVEN BY PERMANENT MAGNET SYNCHRONOUS LINEAR MOTOR

4.1 Vector control block diagram

According to the previous analysis, $i_d = 0$ control method is simple and suitable for the

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thrust control of permanent magnet synchronous linear motor. In this paper, secondary field oriented vector control and voltage space vector pulse width modulation are used to realize the speed regulation of linear motor. When $i_d = 0$, the mathematical model of linear motor can be simplified as follows:

$$u_d = -L_q i_q \frac{\pi}{\tau} v \quad (1)$$

$$u_d = Ri_q + L\frac{di_q}{dt} + \frac{\pi}{\tau} v\psi_f \quad (2)$$

$$F = 1.5\frac{\pi}{\tau}\psi_f i_q \quad (3)$$

$$F = F_L + Bv + M\dot{v} \quad (4)$$

At this time, linear motor and DC motor have the same mathematical model, and the transfer function block diagram is shown in the figure 3:

The model is relatively simple and close to the simulation model, which can be used as a preliminary adjustment model of PID parameters in control design.

4.2 Simulation and analysis of PID parameter self-tuning fuzzy control based on Matlab/Simulink

In order to improve the control accuracy, improve the influence of the non-linear and large time-varying factors on the control process and further improve the control effect, the paper adopts the parameter self-tuning fuzzy PID control algorithm in the design of speed loop control. In order to verify the superiority of the control algorithm, the traditional PID control algorithm is used to simulate, then the parameter self-tuning fuzzy control algorithm is used to simulate, and the simulation results are compared.

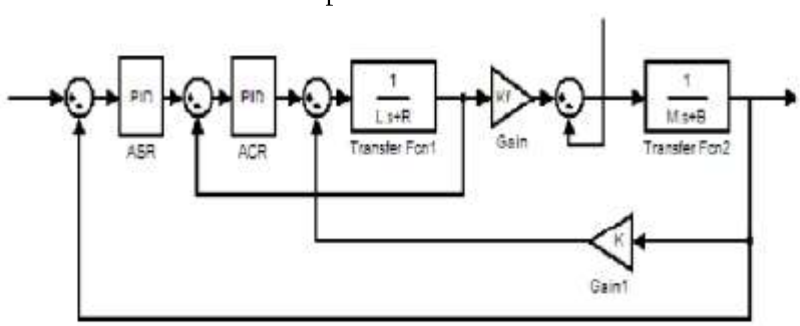

Fig 3: Simplified model of PMLSM

In this paper, because PI controller is used in speed loop, fuzzy PI controller with two inputs and two outputs is used here. The deviation E and the variation ec of deviation are used as fuzzy

Forest Chemicals Revew
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control inputs, and the outputs are △KP and △KI of PID controller, whose universe is defined as: E and EC={-3, -2, -1, 0, 1, 2, 3}; △KP、△KI={-6 , -4 , -2 , 0 , 2 , 4 , 6} ; Their corresponding fuzzy subsets can be set as: {NB, NM, NS, ZO, PS, PM, PB}, which are respectively expressed as negative big, negative middle, negative small, zero positive, positive small, middle and big. Their membership functions are all set as triangles, and the fuzzy algorithm adopts the barycenter algorithm, which can be realized by using the fuzzy control toolbox of MATLAB, thus avoiding tedious calculation links. The specific implementation method can be seen in the following simulation process.

1. Establishment of input/output language variables. Enter the Fuzzy logic toolbox by typing "fuzzy" command in Matlab Command Window, and build a Mamdani fuzzy controller. Because we choose the two-dimensional two-output fuzzy controller, we add one input and two outputs through the options of "edit/Addinput" or "edit/addoutput".

2. Establish membership function. Click the input and output variables to change the variable name; Double-click the module to modify their membership functions. In this paper, the triangular membership functions are selected, and their respective membership functions are "drawn" through modification.

3. Input and edit of fuzzy control rules Double-click the fuzzy control rule box to get the graphic interface. Enter the control rules formulated one by one. The fuzzy decision-making uses the center of gravity method, that is, centroid.

4. Check the correspondence between input and output. Using the rule viewer and surface viewer provided by the control interface, you can view the corresponding relationship between the input and output of the designed controller. At the same time, it can be observed whether the expected output value is near the center of the fuzzy control output theoretical space. If it is out of range, it is necessary to readjust the membership function or control rules until it meets the requirements. The corresponding relationship of the controllers designed in this paper is satisfactory, that is, reasonable.

5. Save the set fuzzy controller in the data file with suffix. fis and import it into the workspace so that it can be called during simulation.

6. Establish the simulation module of fuzzy control under Simulink as shown in the figure 4:

7. During the simulation, the file name of the saved suffix. fis should be input into the

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attribute box of Fuzzy Logic Contrlller, and the established data file. fis can be imported into the workspace by readfis fis and other instructions to start the simulation.

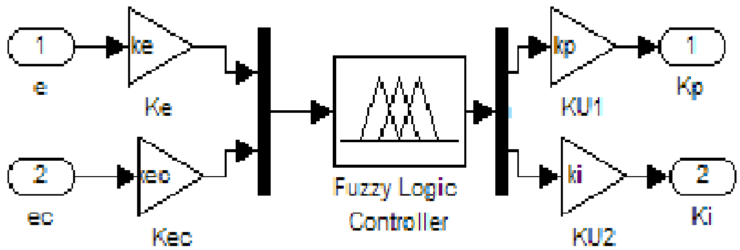

Fig 4: Fuzzy control submodule

The PID control, traditional sliding mode control and the method of this paper are compared by simulation experiment. The simulation parameter is shown as: T_S = 1 ms, total simulation time is 1s, Mn = 7.3 kg, Bn = 0.1 N•M / s, K_F = 109 N•A, expected position r = 1 mm. The load is added when t = 0.5 s, PID controller parameters K_p = 320, K_T = 7.5, K_d = 13. The traditional sliding mode control and the s in this paper are C = 18, q = 35; Traditional sliding mode control ε = 15. The simulation results of the three methods are shown in Figure 5.

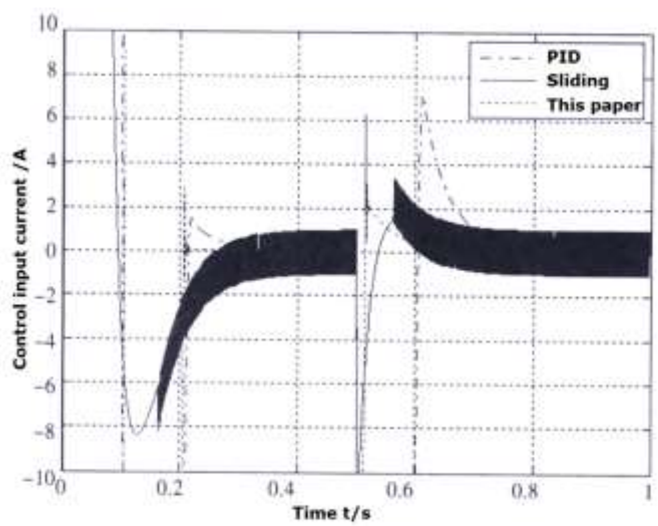

Fig 5: Simulation results

The simulation results show that: (1) Compared with PID and traditional sliding mode, the method in this paper can quickly track the position command signal without overshoot in the start-up phase; (2) When the external load changes suddenly, the proposed method can still track the position command very well, that is, the deviation value is much more accurate than the former two, and the proposed method can quickly return to the steady-state desired position at a speed similar to the hypotenuse of the right triangle; (3) Compared with the traditional sliding mode, the chattering performance of the control output is greatly improved. Therefore, the simulation results show that the proposed method can not only quickly and stably adjust to the expected value, but also has strong anti load ability, and can quickly recover to the desired position instruction.

V. CONCLUSION

NC machining technology has been widely used in automobile, aerospace and other fields. With the continuous development of technology, the requirements of CNC machine tool processing technology are constantly developing to the direction of high speed and ultra-high speed, precision and ultra precision. The linear servo feed system with high-speed response capability, namely "Zero drive" mode, emerges as the times require. The linear drive technology has also been widely used in the field of precision positioning. Compared with the traditional "rotary motor + ball screw" feed mode, the linear motor servo system eliminates some adverse effects brought by the mechanical transmission chain, but increases the difficulty of control. When high precision micro feed is required, more uncertainties such as perturbation and disturbance will directly affect the feed motion. This is also the inevitable consequence of realizing zero drive control. Therefore, we need to find an effective control strategy to achieve high precision and high speed machining requirements.

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