Modeling and simulation of servo feed system of CNC machine tool based on Matlab/Simulink

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Abstract

In the industry, CNC machine tools play an irreplaceable role. It not only realizes the rapid industrial production, but also saves manpower and material resources. It is the symbol of modernization. As an important part of CNC machine tools, feed system plays a very important role on the processing process; it refers to the product's quality problems. According to the principle of mechanical dynamics, I establish a mathematical model of machine tool feed drive system and use Simulink(dynamic simulation tool) in MATLAB to construct the simulation model of the feed system of lathe. We also designed the ANFIS-PID controller to cope with the mathematical model of the complex object and the model uncertainty that exists when there is external noise. These efforts offer effective foundation for the improvement of CNC machine tool.

Keywords-CNC machine tool, Feed system, MATLAB/Simulation, ANFIS-PID, Modeling

1. Introduction

Servo feed system is an important part of CNC machine tool. In a certain extent, servo systems of the static and dynamic performance determine the CNC machine tool accuracy stability, reliability and efficiency of machining.

Based on PID control of CNC machine tool servo adjusting controller parameters is the key to the CNC system [1].

Many occasions are using the simplified model and the actual operation experience to determine the parameters of the regulator. The simplified model will give the PID parameter tuning result error.

However, adaptive control theory has recently emerged, and it is used for control of various objects such as process control. One of them is ANFIS-PID control theory which adaptively adjusts the gain of the PID controller according to the characteristics of the object. [2]

This paper prepared a mathematical model of the feed system of a CNC machine tool and designed a new servo feed system that can guarantee its feed accuracy even if there is uncertainty in the system.

Then the effectiveness was verified through simulation.

2. Modeling of feed servo system for CNC machine tool

The motor of the servo drive system adopts PMSM. In the Matlab/Simulink environment establishing and combining the vector control simulation model, PID controller simulation model , Sinusoidal Pulse-Width Modulation(SPWM)simulation model, PMSM and inverter simulation model and other functional modules. [3]

Speed and current double closed loop simulation model of permanent magnet synchronous motor control system is constructed.

The simulation model of PMSM vector control system is shown in Fig.2.

The mechanical transmission mechanism is composed of the drive motor, coupling, ball screw pair, screw bearing, screw nut bench, etc[4]. The input of mechanical transmission system is the angular displacement of the servo motor($q(t)$); the output is the movement of the execution unit ($X(t)$). The schematic diagram a gram of the mechanical transmission mechanism, as shown in Fig.3.

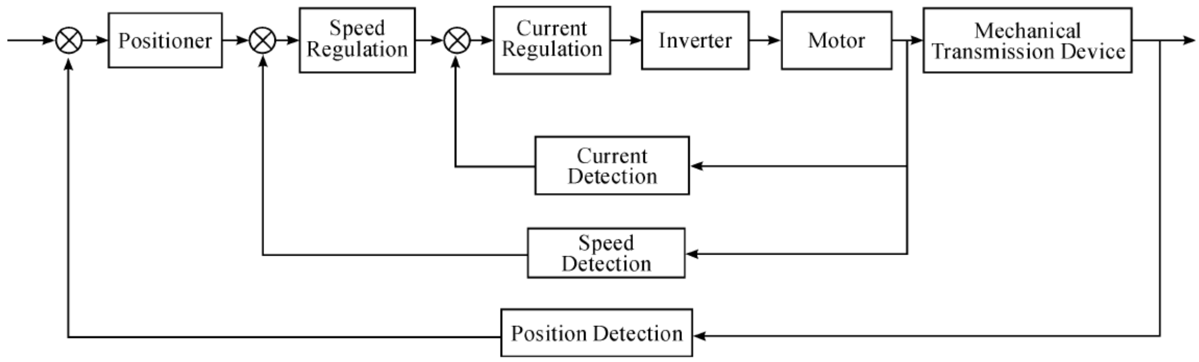

Fig.1 The structure diagram of the CNC machine tool feed system

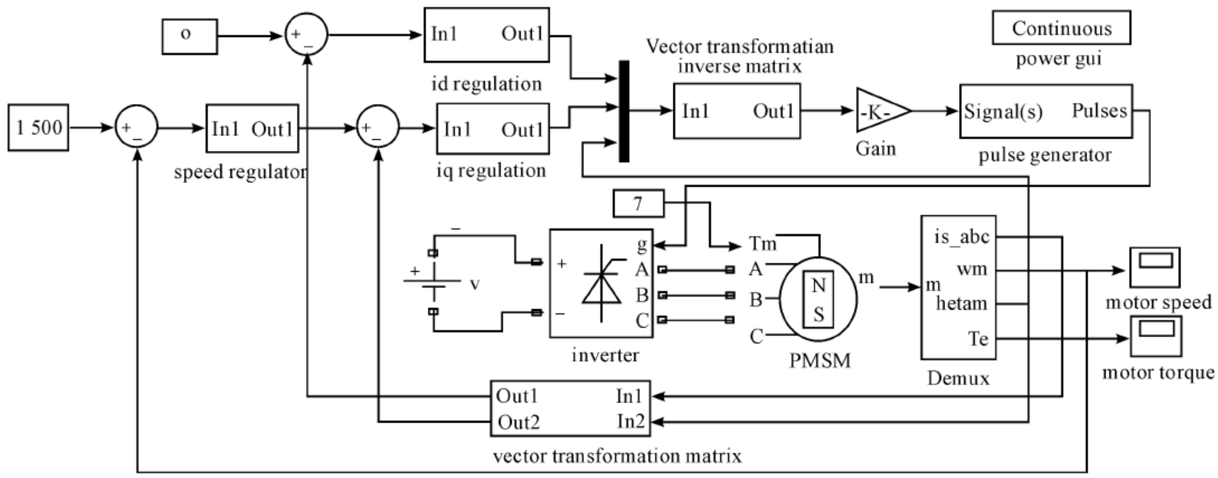

Fig.2 The simulation model of PMSM vector control system

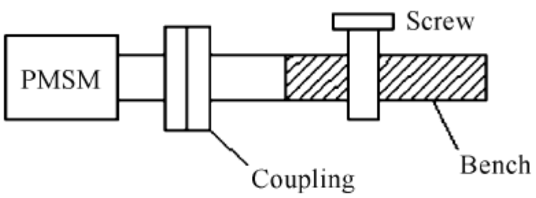

Fig.3 The schematic diagram of the mechanical transmission mechanism

In Fig.3, there are rigid elements and viscous elements. Damping and torque are preventing in each moment of inertia. The system can he divided into three units: motor, screw, bench[5].

As shown in Fig.4, the stiffness, inertia, damping and disturbance torque of the mechanical transmission device are distributed among the units and units.

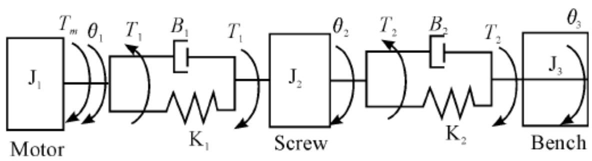

Fig.4 The dynamic model of the mechanical transmission device

In Fig. 4, the coupling is equivalent to an elastic coefficient K_l, damping coefficient B_1.

The screw nut is equivalent to the elastic coefficient K_2, damping coefficient B_2. Moment of inertia of the motor and coupling equivalent to the moment of inertia of the motor shaft-J_1. The moment of inertia of the screw is J_2, and the moment of inertia of the bench is J_3. Driving torque of the motor is T_m, driving torque of the screw is T_1, and driving torque of the bench is T_2. The output angle of the motor and shaft is equivalent to the output angle of the motor shaft-q_1 .The output angle of the screw is q_2, the output angle of the bench is q_3 [6].

3. Modeling of feed system

Servo system structure is shown in Fig. l, the position loop(outer ring) in many of the transmission parts such as precision lead screw, nut vice friction characteristics, clearance, rigid is nonlinear, so the system is a multi-variable and time-varying parameters, nonlinear and strong coupling systems[7]. Conventional PID setting method because of the low accuracy, adjust the parameter will not be able to meet their demands for dynamic performance, etc.

In the simulation study, assume that the servo system of the mechanical part has rigid connection. Ignore the time delay of the system.

The electrical part approximately ideal.[8]

Available transfer function of servo motor is as follows:

$$G_{(s)} = \frac{4973}{s^3 + 85 s^2 + 4973 s}$$

4. ANFIS-PID control system design

4.1. Principle of PID Controller

PID controller [9] is a linear controller, it according to the given value *r(t)* and the actual output value *u(t)* to contro1 deviation *e(t)*, namely:

$$e(t) = r(t) - u(t)$$

Deviation ratio (P-proportion), integral (I-integral) and differential (D-differential), through the linear combination of control volume, to control the controlled object, therefore calls the PID controller, the control law(expressed in transfer function) as follows:

$$G(S) = \frac{U(S)}{E(S)} = K_P (1 + \frac{1}{T_i \cdot s} + T_d \cdot s)$$

In the computer control, the discretization of the digital PID controller, the basic algorithm is as follows:

$$u(k) = K_p e(k) + K_i \sum_{j=0}^{k} e(j) + K_d [e(k) - e(k-1)]$$

In the equation:

u(k)- *k* moment control of PID controller output;

K_P - ratio;

K_i - integral coefficient;

K_d - differential coefficient;

e(k) - *k* time error.

4.2. Design of ANFIS-PID controller

An ANFIS-PID controller consists of two PID controllers and an ANFIS controller, its structure is shown in Fig 5.

Fuzzy self-tuning PID design idea is to find out the three parameters of PID and fuzzy relationship between deviation and deviation rate, in the work through continuous testing e and e_c, in according to the principle of fuzzy control three parameters of PID correction online, to meet different e and e_c to the controller parameters.

The different requirements, and make the controlled object has a good dynamic and static performance. Its working process can be roughly divided into several steps: first, the controller input blurred; Secondly, on the basis of fuzzy control rules, fuzzy logic reasoning, it is concluded that the fuzzy output of the controller; Third, the fuzzy output multiplied by the quantitative factors to get accurate quantity namely three PID parameters adjustment quantity; Finally, the three parameters of PID adjustment amount respectively with PID initial value addition get new PID control parameters.

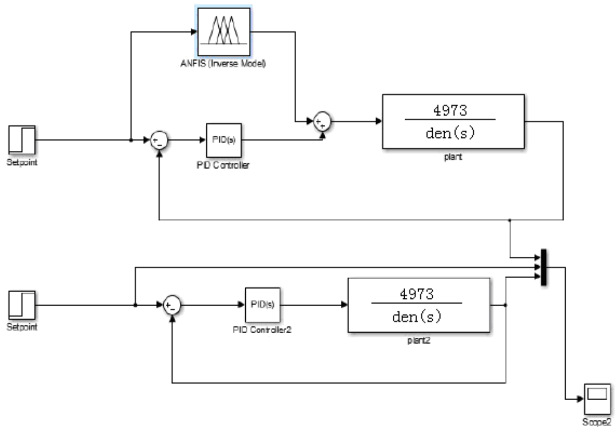

Fig. 5 Configuration of the block diagram of ANFIS-PID control system

Fuzzy self-tuning Pm controller to adjust the PID parameters calculation formula is:

$$K_p = K_p' + \Delta K_p$$

$$K_i = K_i' + \Delta K_i$$

$$K_d = K_d' + \Delta K_d$$

In the formula:

K_P', K_i', K_d` is the initial value of K_P, K_i, K_d

$\Delta k_p, \Delta k_i, \Delta k_d$ is the adjustment of the control output of the output value.

The controller output value is the feed rate of the feed servo motor.

The following steps are used to create a mathematical model using MATLAB.

1) Select a morphological model (paper: Sugeno model)

2) Select the following membership function (paper: gaussmf)

3) Proceed to place the membership function according to the set interval and create the ambiguity rule. (Paper: Write 49 rules)

4) Expressed as ANFIS

5) When the rule creation is completed, it is saved as a * .fis file.[2]

Figure 6, 7, and 8 show constructed the fuzzy rule by the fuzzy editor and the neural network model.

As shown in Fig. 5, we construct the control system and proceed with the simulation.

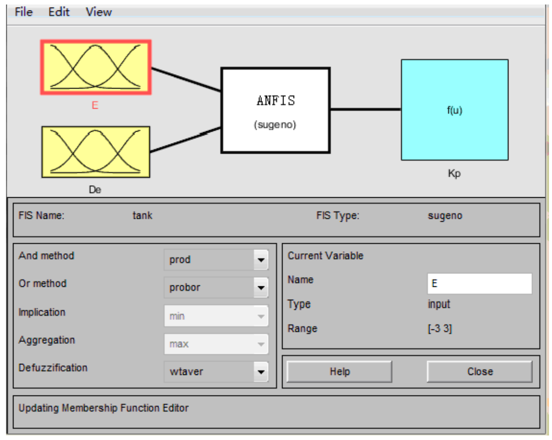

Fig.6 2 input 1 output fuzzy model creation

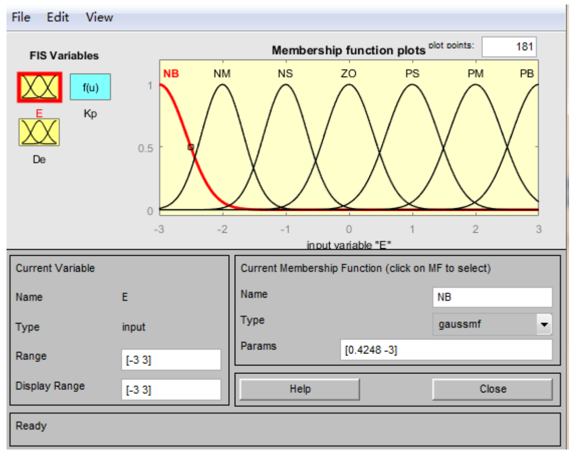

Fig.7 Set membership functions

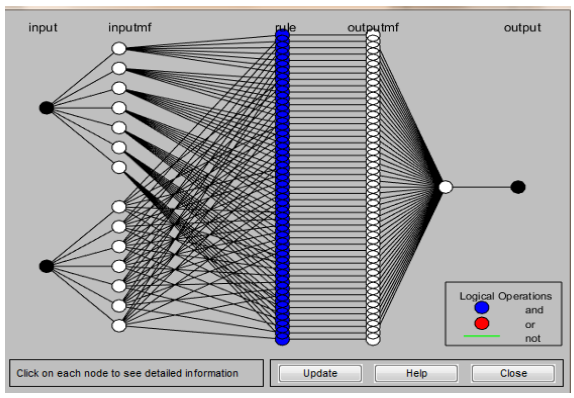

Fig.8 Adaptive neural network form representation of fuzzy rules

Using the controller designed as above, we constructed the CNC machine tool control system and simulated it.

We conducted simulations by applying high-frequency noise to the steering object.

As you can see in the Fig 9, adaptability, stability, and acceleration are completely improved compared to the PID control system.

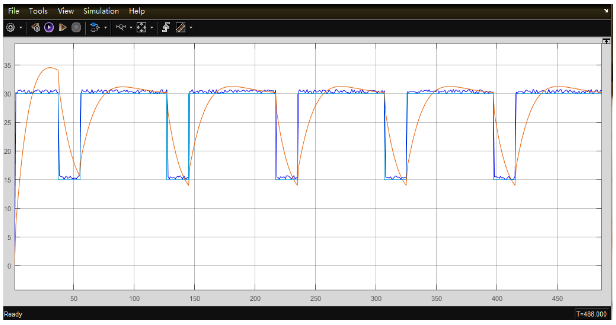

Fig. 9 Simulation result

As a result of designing and applying the ANFIS-PID controller, which is an intelligent manipulation model, the modeling of the feed system of the CNC machine tool, the newly designed manipulation system is very good and stable in adaptability and inertia compared with the previous PID manipulation system.

We reaffirmed through research that designing and applying most of the control systems applied to the machine tool delivery system can be very effective.

Conclusion

In this study, the transfer function is created based on the dynamical model of the feed system of CNC machine tool and the simulation is made in MATLAB/SIMULINK.

Also, we applied intelligent steering which adaptively follows the amplified sides of previous PID controller to respond quickly to the change of target characteristics.

The ANFIS-PID controller responds to the model uncertainty of the object and exits the result so that it can respond very quickly and accurately.

This has been proven from the simulation results.

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