Intelligent Control System of CNC Mill Machineing Based on the Feed-Driven Linear Motor

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Abstract

Taking the feed-driven linear motor mechanism as the control object, the SIMODRIVE 611D as the control system, establish mathematical model of the servo system. The relation between feed-axis current and cutting force is presented, the current and feed-rate are separately selected as feedback and output. Around the aim of the feed-axis constant current control, choose the fuzzy control as the control method of the linear feed-driven machining process. The simulation results indicate that the intelligent control system has fast response time and good performance of anti-jamming, also the experimental results show the efficiency of milling can be improved and tool be highly protected.

Keywords: Linear motor, Constant current machining, Constant cutting force, Fuzzy control

1. Introduction

With industrial development in recent years, the requirements for mechanical precision increase. In traditional servo feed ways, the rotating movement of motor via coupling (ball) screw nut and other transmissions, and other transformation series of intermediate links can be converted into linear motion. The middle part of the transmission accuracy reduced significantly, thereby affecting the processing accuracy.

Linear servo system has strong points of fast dynamic feature, simple structure, wide speed range and explicit allocation because of immediate driven method, while the tool wear rate increases with the high speed feed (Rahman M, Wang ZG & Wong YS.A, 2006) so in order protect tool and improve machining quality, a reliable system is needed to supervise the tool's wear (Xiaoli Li, R.DuBerend, Denkena B, et al, 2005)(P. Y. Sevilla-Camacho, G. Herrera-Ruiz, J. B. Robles-Ocampo, et al, 2011)(Fu P, A. D. Hope & G. A King, 1998). In 1990's, a self-adaptive optimizing supervising expert system was developed by OMAT, now it is widely used in many CNC lathes of Siemens, ABB etc. In 1979 Tsinghua University leaded the experimental research on current constraint self-adaptive control of milling process. In 1983 BUAA developed computer self-adaptive control system. In 1998 HUST developed self-adaptive control milling system of constant current milling. Despite these achievements the gap still exists compared to other counties.

The intelligent control system (Chintae Choi, Tsu-Chin Tsao & Atsushi Matsubara, 1995) (Lee JM, Choi DK, Chu CN. (1995) studied on this paper is to improve milling quality, efficiency and how to protect tool. Siemens 840D system is chosen as system platform, the feed-axis current of linear motor is selected as feedback, for the purpose of getting intelligent control of feed-axis of linear driven motor.

2. Modeling of Feed-Driven Linear Motor Control System

SINUMERIK 840D with matching servo drive system uses Siemens SIMODRIVE 611D digital AC servo drive system. It includes three control modules, named 3-loop control. According to the simplified Siemens SIMODRIVE611D driven system model and linear motor model are built. The servo system based on the model is shown in Figure 1. In the Figure $G_A(S)$ and $G_S(S)$ are separately current control transfer function and PMW amplifier transfer function $H_A(S)$ and $H_V(S)$ are separately current detection transfer function and speed detection transfer function and $G_v(s)$ is speed control transfer function.

The real machineing process is much more complicated than theoretical process, even cannot be presented with suitable expressions. In order to modeling and get the final simulation, cutting force is taken as constraint control output here. The total gain K of machineing process is expressed as:

$$K = 60 K_{e} K_{s} a f^{(m-1)} / (pn)$$

n—spindle speed, K_e —dynamometer conversion factor, K_s —cutting force, a—back engagement,

p—number of milling cutter teeth, 1 for drilling and turning, m—index, f—feed-rate;

According to the formulation, the gain changes with the change of back engagement, spindle speed and feed-rate.

3. Fuzzy Control of Linear Feed-Driven Machineing

Tool shape, milling depth, workpiece and tool material cannot be modified in a specified process. The main way to improve metal removal rate is to adjust feed-rate online. In order to realize feed-axis constant current control of machineing process, proportion of modified feed-rate is sent to lathe control system by PLC on this paper.

3.1 How to Choose Constraint Signal and Output Signal

From the model built before, cutting force can be expressed as:

$$F_{c} = K_{t}i - M\left(\frac{dv}{dt}\right) - Dv - F_{f} - F_{cog}$$

 F_{c} —cutting force, K_{t} —thrust coefficient, M —mass of mobile system,

D—damping factor, F_f —axis friction, F_{cog} —cogging force,

^v can be measured. In order to simply formulation, machineing process can be seen as constant force machineing, so dv/dt = 0, axis friction F_f can be neglected, F_{fcog} is a function associated with axis location, expressed as:

$$F_{\text{fcog}} = k_1 + k_2 + k_3 \cdot \sin(k_4 x + k_5)$$

 k_i i = 1, ... 5 can be determined by experience, so we get the relation between cutting force and linear motor current

$$F_{c} = K_{t}i - Dv - k_{1} - k_{2} - k_{3} \cdot (k_{4}x + k_{5})$$

3.2 Fuzzy Control of Linear Feed-Driven Machineing

Feed-axis current of linear driven motor is selected as the milling parameter to study on this paper. Figure 2 shows the fuzzy control structure of using feed-axis current as constraint, it consists machineing system current collection data processing and fuzzy control.

3.3 Design of Self-Adaptive Fuzzy Controller

Principle of the controller is as follows: the input signal is feed-axis current, after processed by fuzzy controller, we can get the output signal that is the adjustment of feed-axis speed. Control system acquires machine axis real time current signal enabling realizes real time control of lathe axis feed-rate, thus achieving constant current cutting of the lathe feed-axis.

After repeated experiments (Y. L Lee JM, Choi DK, Chu CN, et al, 2000), optimized value are

$$K_e = 0.02$$
, $K_{ec} = 0.01$, $K_u = 0.08$.

4. Modeling of Control System and it's Simulation

In the machineing model, the change of spindle speed material tool shape and it's wear are neglected, just the change of back engagement is taken into consideration which leads the change of cutting force. Figure 3 shows the process. After modeling we start the simulation and the results show in Figure 4.

From Figure 4, we can see the change of back engagement is opposite to the change of feed-rate, that is with back engagement increases, the feed-rate will decrease to maintain a constant cutting force within the constraints, and vice versa. And in addition to the amount of change in the back engagement when there was a substantial overshoot beyond, system output (cutting force) still has a good value on the constraint by the method of fuzzy control, so as to achieve constant cutting force control. Therefore, the control system can adjust the process feed-rate automatically to achieve constant force cutting process.

5. Experiments

During the online experiment testing whether a program written for constant current milling meets the requirements of intelligent control and to detect anti-jamming, stability and processing efficiency of the experimental platform.

Figure 5 shows online experimental processing. Figure 6 and Figure 7 compare the time that current is over 8mA with using or without using real-time control. From the experimental curves and processing proposal, we can see when the amount of cutting tool increases, Y-axis current increases too. Y-axis feed-rate will decrease with the increase of current; on the contrary, if the load reduces, the current will increase then the Y-axis feed -rate will increase in order to achieve constant current process. Comparing the time spent on these two processing methods, efficiency with using real-time intelligent control system is 20% higher than those without using real-time intelligent control system. The time with current is over 8mA takes 9% of the entire processing time. The time with current is over 8mA caused by load is greatly reduced and tool is protected effectively.

6. Conclusion

This paper presents the servo system model of feed-driven linear motor and constant cutting force model. From the fuzzy control simulation, the results indicate that the intelligent control system has fast response time and good performance of anti-jamming. And the experimental results show the controller can adjust feed-rate automatically according to real-time intelligent processing, improving the processing efficiency effectively and protecting the tool.

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Figure 1. Structure of Current Loop and Speed Loop



Figure 2. Fuzzy Control Structure of Using Feed-Axis Current as Constraint



Figure 3. Constant Cutting Force of Fuzzy Control Model Machineing Process



Figure 4. Simulation of Fuzzy Control Machineing Process



Figure 5. Online Experimental Processing



Figure 6. Current Curve of Y-Axis without Using Real-Time Control



Figure 7. Current Curve of Y-Axis with Using Real-Time Control