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Adaptive Cutting Force Control for NC Machine Based on the Current Restriction

Na Wang, Changsheng Ai, Xiangbo Ze and Guangwei He
School of Mechanical Engineering, University of Jinan
Jinan 250022, P.R. China

Abstract
Precision measurement for cutting force plays an important role in the machining accuracy and efficiency of the NC machine tools. For the traditional measurement has many deficiencies, a new indirect method of measuring cutting force was proposed in which the current signal of the servo motor was measured instead of cutting force. The relationship was analyzed in detail between the cutting force and the current signal of the servo motor. After the analysis in the frequency and the time domain, the current eigenvalue was found with the various load torque and the mathematical models were created. The experiment system and the achievement means of the intelligent adaptive control were proposed. Practical experiments have proved that the indirect measurement is reasonable and with an important application value.

Keywords - adaptive control, cutting force, servo motor, current

1. INTRODUCTION

Metal cutting processing is a basic method of material machining and parts molding. Currently, more than 80% of the mechanical processing is completed through the metal removal machine. With the emergence of new types of materials, the development of NC machine tools and the update of the computer technology, the modern metal cutting processing is developed in the technology direction with high speed, high precision and low cost. We can say that the constant improvement of the processing efficiency and precision is an eternal subject of metal cutting machining.

In the manufacturing industries, as a very important physical phenomenon, the cutting force directly affects the quality, the efficiency and the costs of the production.

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The reasonable cutting force is of great significance to raise processing precision, machining efficiency, cutter life and machine tool utilization. The cutting force can reflect the changes more rapidly and more accurately than the power and the torque during machining process, so the monitor and control of the cutting force become more important in practical machining (Jing et al, 2003; Cheng, et al, 2002).

Particularly in the digital control machining system, high-performance and high-precision servo drive control system permits NC machine tools to cut with high-speed, but in practical processing, due to the machining complexity and various characteristics, the machine tools can only work with limited cutting force. For this reason, most commercial CNC manufacturers provide the optional equipment with automatic control function to adjust the cutting speed in order to improve the machining efficiency. The automatic controller has a series of upper and lower limits of the currents of the spindle motor or the feed motor, which have to be input into the CNC unit before the machining stage. During the cutting process, the CNC monitors the current. If it goes beyond the upper limit, the CNC reduces the programmed feed rate of the motor. If it goes under the lower limit, the CNC increases the cutting speed. Thus the cutting speed can be restricted to a certain area and the machining efficiency can be improved. But in this way, the cutting speed can not be adjusted at all the time on line. This is greatly unfavorable to improve the efficiency of processing for NC machine tools.

Therefore many domestic and international experts are greatly interested in the further study of the cutting force, such as testing cutting force and making forecasts value of the cutting force more accurate online. So the metal cutting process and the work of the cutter can be monitored through the real-time measurement; and the feed speed of the cutter can be regulated on-line to achieve constant torque machining through the accurate forecasting cutting force. And the accuracy and efficiency of machining can be constantly improved.

2. THE TESTING METHODS OF THE CUTTING FORCE

Metal cutting processing is dynamic, nonlinear, random and strong coupling. In the manufacturing process, the cutting force will vary with these factors, including workpiece materials, cutter materials, cutter geometric shapes, cutting angle, cutting speed, cutting depth, cutting fluids and so on. Therefore the accurate measurement for cutting force has been a difficult problem in the manufacturing industry for a long time.

At present the traditional measurement of cutting force can be classified into two groups. One of them uses experience formulas (Sutherland & Devor, 1986; Kolarits & Devries, 1991). There are usually versatile experience formulas corresponding to different machining. The experience formulas are simple and convenient to be used, so they are widely used in manufacturing. But there are many factors, such as workpiece materials, cutter materials, cutter geometric shapes and other factors, to which are not given enough consideration in these experience formulas, so the result from this method is imprecise and can only be used as reference. The other uses force sensors to directly measure the cutting force in the machining process. The accuracy of this method depends on the working principle of the testing system and the accuracy of the components used in the measurement system.

At present, many kinds of force sensors are used to measure the cutting force, especially the resistance strain measure system and the piezoelectric crystal measure system which are commonly used in testing cutting force (Sun et al, 2001).

The resistance strain measure system is also divided into two styles, static and dynamic measurement. They differ mainly in the core element. The former has static resistance strain sensor, while the latter has the dynamic one. The cutting force is typically random and changes with the machining time and cutting conditions, thus we can only adopt the dynamic resistance strain measurement to measure the cutting force.

At present the dynamic resistance strain measurement is quite common to measure the cutting force. In the machining, the strain area and magnitude are varied with the different cutting edge and direction. According to this, the position of the strain element should be differently placed. Currently, the dynamic resistance strain measurement is successfully used to measure the cutting force of lathes. When testing the cutting force of the milling machine in the smooth-bore processing, it is difficult to fix the sensor on the cutter, so we fix it on the workpiece. In the machining, because of the shape and size of workpiece changing at all times, the stress distribution caused by the cutting force is changing over time. Therefore, it is difficult to attain the value of cutting force simply by measuring the response in milling process. And the resistance strain measure system has lower precision to measure the cutting force.

The other force sensor for accurately measuring the cutting force is the piezoelectricity crystal ergometer which is produced by the Kistle Corporation. At present, it is widely used to directly measure the cutting force. The core component of piezoelectric crystal measuring system is the force sensor which is made of piezoelectric crystals. It has high sensitivity, accuracy, inflexibility, linearity, self-vibrant frequency and preferable anti-jamming for the piezoelectric effect of the piezoelectric crystal material. So it is widely used in the dynamic measurement of the cutting force. But in the milling process, the piezoelectricity crystal ergometer can only be fixed on the workpiece because the cutter of the machine is rotary in the machining. Thus there are lots of disadvantages such as that: the ergometer can only be fixed on the workpiece like Fig.1; the configuration of the machine tool is destroyed because of the installation of the ergometer; the size of the workpiece is limited because of the bottom area of the ergometer; the quality of the finished product goes down to lower precision; it is expensive and discommodious experiment.

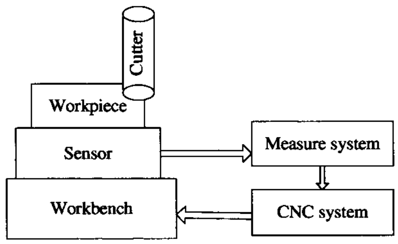


Fig. 1 The sketch of the piezoelectric crystal measurement.

In a word, it is very difficult to directly measure the cutting force online. To overcome the impracticability of a dynamometer, there have been many research works on the indirect cutting force measurement methods. For in the NC machining it is very simple and economical to test the current signals of the servo drive motors or the spindle motors, we propose an indirect method to measure the cutting force by testing the current of the feed servo motor instead of the cutting force.

Next we will analyze in detail the relation between the cutting force and the current signal of the servo drive motor in the NC machining from two parts: the theory and the experiment.

3. THE RELATIONS BETWEEN THE CURRENT OF THE SERVOMOTOR AND THE CUTTING FORCE

3.1 The Servo Drive System of the NC Machine Tool

The servomotor is widely used in NC machine tools, processing centers, industrial robots, printing machinery and other high-performance electromechanical equipments, because of the characteristics of the good control performance, the simple structure, the smooth low-speed operation, the small torque undulation and the high precision positioning. A servomechanism is a closed-loop control system in which the mechanism position or motion will be precisely controlled. And the output of the system will quickly and precisely respond to the input signal. So in the NC machine tool, the servomechanism is usually adopted to feed. Fig.2 shows the sketch of the servomechanism of NC machine tools.

In Fig.2, the servomotor generates electromagnetic torque T_m and drives precision ball screw assembly which serves to transform rotary motion into linear motion to move the workbench. Thus, the workpiece can be manufactured by the cutter of the machine.

From the sketch we can see, the Servo Drive System can be approximately divided into three sequential processes: the formation, the transmission and the conversion of the cutting force from mechanism to electrical system. First, the cutting force F_c is produced when the cutter turns against the workpiece which is droved by the feed servo motor. Then, the cutting force is transmitted throng the workpiece and transformed into the cutting torque T_c through the precision ball screw assembly. And the cutting torque T_c woks on the shaft of the servo motor to form the load torque together with the friction torque T_f and the additional friction torque T_0. Last, the servo motor current is adjusted to realize the balance between the load torque and the electromagnetic torque of the servo motor. Obviously in the three sequential processes, the cutting force is exactly the head parameter and the servo current is exactly the end parameter of the servo drive system. So we can research the three sequential processes to build the relation model between the cutting force and the servo motor current.

When the servomotor works in the stable state, the electromagnetic torque of the servomotor should be equal with the load torque which consists of the friction torque T_f, the additional friction torque T_0 and the cutting torque T_c. So there is the torque balance equation of the servo drive system, such as (1)

$$T_m = T_f + T_c + T_0 \ . \tag{1}$$

Where

T_m — electromagnetic torque;

T_f — equivalent friction torque;

T_c — cutting torque;

T_0 — equivalent additional friction torque with the pre-load.

And T_f, T_c and T_0 can be expressed as in the (2).

$$\begin{aligned} T_f &= F_0 L_0 / 2\pi\eta \\ T_0 &= F_{p0} L_0 (1 - \eta_0^2) / 2\pi\eta \\ T_c &= F_c L_0 / 2\pi\eta \end{aligned} \ . \tag{2}$$

Where

F_0 — the friction force of guides;

L_0 — the ball screw pitch;

η — the overall efficiency of the transmission chains;

F_{p0} — the pro-load of the ball screw;

η_0 — the efficiency of the ball screw without the pro-load;

F_c — the feed cutting force.

According the above equation, we can have the (3).

$$T_m = \frac{L_0}{2\pi\eta}[F_0 + F_{p0}(1-\eta_0^2) + F_c] \qquad (3)$$

Equation (3) is the mathematical model from the cutting force to the electromagnetic torque of the servomotor. Obviously, the corresponding relations exist between the electromagnetic torque T_m and the cutting force F_c. When the cutting force increases, the electromagnetic torque of the servomotor should show a follow-up increase.

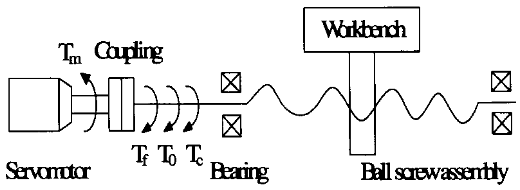


Fig. 2 The sketch of a servomechanism of the NC machine tools

According to the control theory of the electromagnetic torque of the motor, the current of the servomotor will also be augment. So we can do research and establish the relation modeling between the current and the milling force. Therefore, the indirect measurement of the cutting force is feasible through testing the current signal of the servomotor. Next we will establish the relation modeling from the current signal to the electromagnetic torque of the servomotor.

3.2 The Characteristics of the PMSM

At present permanent magnetism synchronous motor (PMSM) is widely used to drive machine tools in the NC machining for the simple structure, the good control performance and the high precision positioning. And here we take it for example to analyze the characteristics of the servomotor. Next, we use the vector conversion technology to illustrate the relation between the testing current and the electromagnetic torque of the PMSM. The vector conversion technology is used to analyze the motor current in the rule of forming the same rotary magnetic field. According to this, the three-phase electrical current of the servomotor can be equaled to two-phase electrical current to establish the d-q coordinate system. Thus we can control the servomotor just like controlling the DC motor through the vector conversion control.

Three-phase stator currents of the PMSM generate the rotary magnetic field, but the permanent magnetism poles of the rotor generate sinusoid magnetic field which is located on the rotor. So the rotor magnetic potential is attracted to rotate by the stator magnetic potential. In the coordinate rotation system, we take the rotor magnetic field as axis d, thus the three-phase stator currents of the PMSM (i_u, i_v, i_w) can be decoupled as Fig.3.

In the d-q coordinate system, the current can be expressed like (4).

$$\begin{aligned} i_u &= I\cos\theta \\ i_v &= I\cos(\theta + 2\pi/3)\ . \\ i_w &= I\cos(\theta - 2\pi/3) \end{aligned} \tag{4}$$

where

I — the amplitude of the stator current;

θ — the phase angle of the armature current.

And there is the balance relation in the three-phase current of the PMSM as (5) shown.

$$i_u + i_v + i_w = 0\ . \tag{5}$$

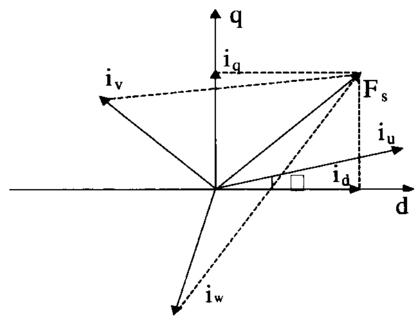


Fig. 3 The vector conversion technology

Through the vector conversion, the two-phase electrical current on the d-q coordinate system can be give like (6).

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos(\theta+\frac{2\pi}{3}) & \cos(\theta-\frac{2\pi}{3}) \\ \sin\theta & \sin(\theta+\frac{2\pi}{3}) & \sin(\theta-\frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_u \\ i_v \\ i_w \end{bmatrix}. \tag{6}$$

Apparently, the current I_d and I_q can be calculated through using either two phase current of the servomotor stator current in actual control. The common expression (Li et al, 1997) of the electromagnetism torque of the PMSM shows as follows (7).

$$T_m = \tfrac{3}{2} p[\lambda_m i_q + i_d i_q (L_d - L_q)]\ . \tag{7}$$

where

P — the pole of the motor;

λ_m— the amplitude of the rotor magnetic chain;

L_d, L_q—the stator equivalent inductance of axis d and q.

On the principle of the maximum ratio of the torque and current, we often adopt i_d =0. Then the electromagnetism torque can be simplified as (8).

$$T_m = \tfrac{3}{2} p \lambda_m i_q \tag{8}$$

When the gas magnetic field of the motor is distributed as sine wave, the λ_m is constant, so T_m is proportional to the armature current i_q. Therefore, the current measurement of the PMSM can reflect the variety of the electromagnetic torque of the motor.

3.3 The Mathematics Model of the Cutting Force and the Current of the Servomotor

When the feed servo system of the machining tool is in the stable state, from (3) and (8), we can obtain the (9) as follows.

$$F_c = \frac{3p\lambda_m}{2} i_q - \frac{L_0}{2\pi\eta}[F_0 + F_{p0}(1-\eta_0^2)]. \tag{9}$$

In a word, there is a linear relationship between the cutting force and the servo electrical currents. When the cutting force increases, the current increases, and vice versa. By measuring the stator current of the PMSM, we can achieve indirect measurements of the cutting force in the NC machining process. In actual control, the current signals respond slower than the cutting force. When cutting force is zero, the current value is not zero mainly because current signals are also subject to the effects of resistance along the way. Clearly, there is a lag in servo motor currents. While the current which can reflect the changes of the cutting force can be extracted to investigate the changes of cutting force after dealing with the motor currents in some methods such as intelligent adaptive control.

4. THE EXPERIMENT SYSTEM FOR INDIRECT CUTTING FORCE MEASUREMENT

4.1 The Component of the Experiment Setup

In order to prove the indirect method of measuring the cutting force, we design an experiment system to verify the relationship between the load torque and the feed servo motor current and to provide experiment means for the analysis of the conversion from mechanism to electricity of the servo drive system. The sketch of the experiment system is shown as Fig.4.

The experiment mainly includes the several components such as the magnetic particle brake which is used to simulate the cutting load in the machining, the Hall sensor which is used to measure the servo motor current, the servo amplifier which is used to control the servo motor, the signal processing and the power supply.

1) The Torque Simulation Platform

In the experiment, the magnetic particle brake is used as the loader to simulate the cutting force. The magnetic particle brake produces different load torque with the excitation current varying which is supplied by the WL-12 steady power supply.

Before using the magnetic particle brake, we should demarcate the relation between the torque and the excitation current. Based on the principle of the balance, the experiment data are measured and form the graph such as Fig.5, when the excitation current is increasing from 0 to 5A then decreasing from 5 to 0A.

From the curve of the graph, we can see there is the magnetic hysteresis when the excitation current of the magnetic particle brake changes from the loading to the unloading process and vice versa. In order to reduce the influence of the magnetic hysteresis, the excitation current of the magnetic particle brake is increasing continuously in the experiment. Thus there is linear connection between the output torque and the excitation current of the magnetic particle brake. So it can be used to simulate the cutting load during the NC machining process.

2) Hall Sensors

Three methods are wildly used in the current measurement such as the resistance, the mutual inductance and Hall sensors method. The Hall method is usually used, because it not only can achieve the reliable isolation between the testing circuit and the main circuit but also has lots of advantages as follows:

(a) measuring the current signal with discretionary wave. It has wide transmission bands and can measure various signals from direct current to 1000 Hz AC.

(b) preferable linearity, widely measuring scope and high precision.

(c) quick response. The delay-time and response time are all less than 0.1μs.

When the measure parameters greatly exceed the limit, the inner circuit and magnetic circuit have the ability to limit the amplitude, thus the sensor can't be damaged.

So in the experiment system, HYH-SB-13-10A sensors are applied to measure the servo motor current. For a long time, it is difficult to fix the cutting force sensor, while it is easier to fix the Hall sensors, which can be loaded on the motor. In actual detection, the either two phase circuit of servo motor can pass through the centre hole of the Hall sensor and the current output of the Hall sensor can be easily attained by the computer. The sketch of the testing current circuit is shown as Fig.6.

In the testing circuit, there is strictly linear relation between the input current and the output current. The maximum of the input current is 6 A while the output is 25 mA. In the sketch, the sampling resistance R_m is used to convert the current signal I_m into the voltage signal U_m which is convenient to be attained by the computer. Thus the current signal I is in direct proportion to the current I_m, I_m in proportion to U_m. So we can know the magnitude of the servo motor current though measuring the voltage U_m.

In the measurement with the Hall sensor, there are several points to which should be given enough attention. The secondary circuit is not allowed to be open when we test the big direct current and the Hall sensor should be supplied with 15V power before measuring the current. Otherwise it is easy to damage the Hall sensor. The Sampling resistance R_m may not be oversize, also not excessively be small. According to the need of this experimental system, we select the resistance R_m as 500Ω.

3) The Servo Drive System

The servo drive system contains the FANUC digital servoamplifier and the three-phase permanent magnet synchronous motor in the type of C 121/200 in α Series of FANUC. So we can simulate the feed servo-drive system of the numerical control machine with the FANUC servomechanism in the experiment.

4) The Signal Processing Unit

In the experiment system, the current signal of the three-phase servo motor is collected through the Hall sensor measurement and stored in the computer. Then the current waveform is processed to find the relation model between the load torque and the feed current of the servo motor.

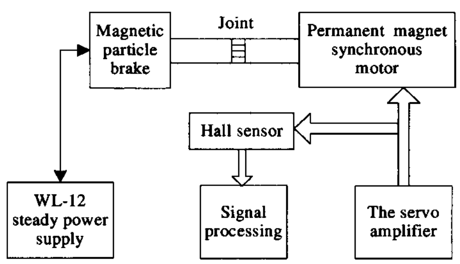


Fig. 4 The sketch of the PMSM experiment system

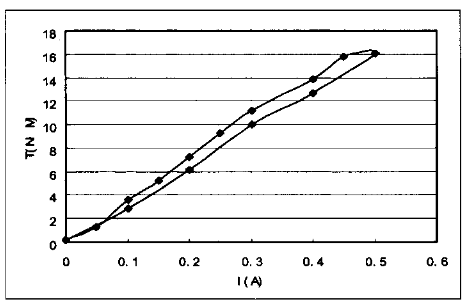


Fig. 5 The relation of the excitation current and the load torque

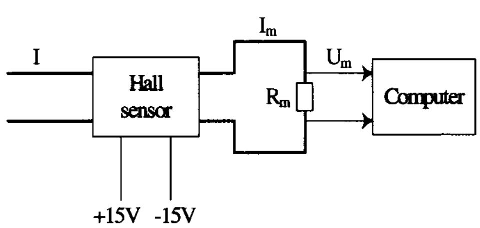


Fig. 6 The sketch of the testing current circuit

4.2 The Analyses of the Experiment Result

In order to confirm the feasibility and the importance of the indirect measurement, the simulation test has been carried on. In the experiment, when the excitation current of the magnetic particle brake is 0, 0.01, 0.02A and so on, the current of the servo motor is measured to form the curve just as Fig.7 shows. From the graph we can see, the current waveform isn't the standard sine wave but includes fundamental wave and various harmonic waves. So we should analyze the signal to find the eigenvalue of the servo motor current with the various load torque.

Through the Fourier transform or the wavelet transform, we can analyse the current signal of the servo motor in the time domain, the frequency domain or in both domains. Then we can obtain the eigenfrequency spectrum of the current signal under the various load torque. According to the eigenvalue spectrum we can establish the relation model between the load torque and the feed current of the servo motor.

The power spectrum of the signal describes the distribution of the signal energy in the frequency range. The amplitude of the waveform is varied with the different frequency in the frequency spectrogram. The important characteristic of the static data can be described in detail in the power spectrum. So the method of the spectrum analysis is widely used especially with the appearance of the Fast Fourier Transform (FFT).

Through analysing the spectrogram of the electric current signal of the servo motor, the signal energy of the stochastic noise is greatly attenuated while the periodic signal energy is enhanced. So we may find the sensitive frequency band which is related to the change of the load torque and confirm the relations of each other.

We analyse the frequency spectrum of the current signal shown as Fig.7 and obtain the frequency curve just as Fig.8.

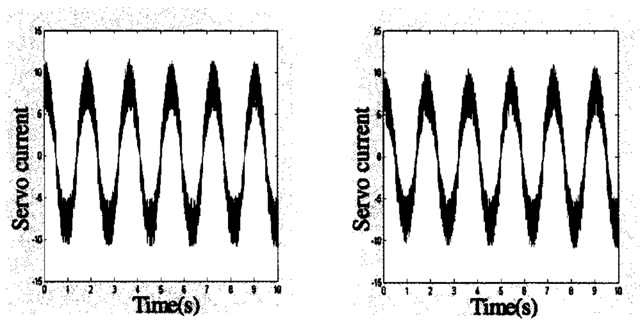
From the spectrogram we can see the stator current signal of the servo motor mainly comprises fundamental frequency composition and also includes the high frequency component and the noise signal distributing in the entire frequency scope. The angular frequency of fundamental wave is near the 0 rad/s and its frequency band width is very small. Thus we can not pinpoint the eigenfrequency of the stator current signal with various load torque. So we should magnify the spectrogram in order to find the eigenfrequency.

Next we take the A-phase current of the servo motor for example. When the excitation current of the magnetic particle brake is increasing unceasingly, the load torque of the servo drive system is increasing, and the A-phase current of the servo motor is measured through the Hall sensor by the computer.

We analyse the current waveform in the frequency domain and draw the frequency spectrum which should be amplified. The amplificatory spectrograms of the A-phase current are shown as Fig.9.

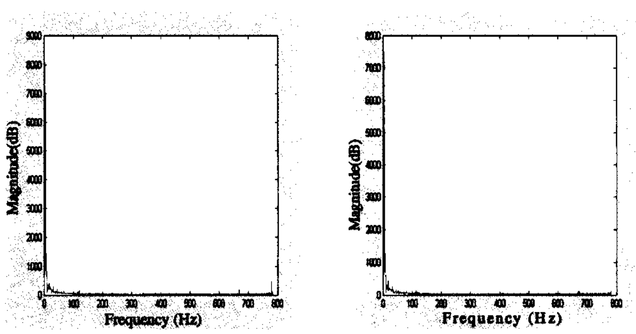
From the chart, we can see there is a peak value in the 4HZ frequency area in the spectrogram of the servo motor current. And when the excitation current of the magnetic particle brake is increasing from 0.05A to 0.08A, the peak value is also gradually increasing. This indicates that there is the corresponding relation between the magnitude of the load torque and the frequency band which takes the peak value as the central frequency. According to formula (3), the cutting force of the cutter is linear with the load torque in the NC machining. Therefore, the cutting force is related to the eigenfrequency of the servo motor current in the low frequency band. When the cutting force rises, the corresponding power spectrum value of the low frequency band is obviously increasing

Through the spectrum analysis, we have confirmed the current characteristic quantity of the feed servo motor which varies with the change of the load torque. In order to determine the mathematic model between the load torque and the characteristic quantity of the current, we can filter the electric current of the servo motor which has been measured using the software such as MatLab.



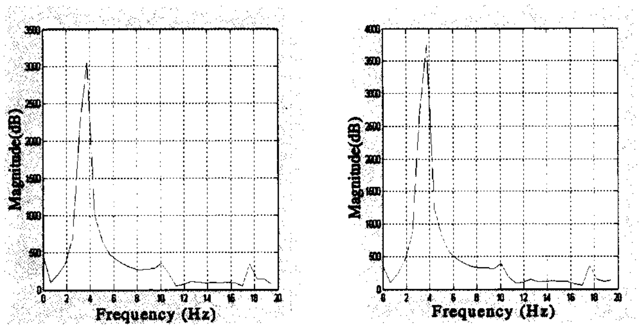
(a) the A-phase current (b) the B-phase current

Fig. 7 The servo motor current (the excitation current of the magnetic particle brake 0.1A)

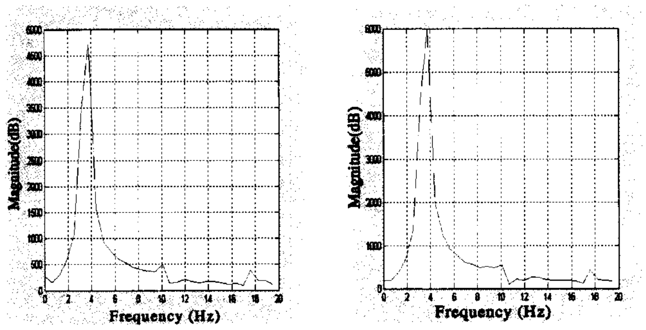


(a) the A-phase current (b) the B-phase current

Fig. 8 The spectrum analysis of the current



(a) the excitation current If =0.05 A (b) the excitation current If =0.06 A



(c) the excitation current If =0.07 A (d) the excitation current If =0.08 A

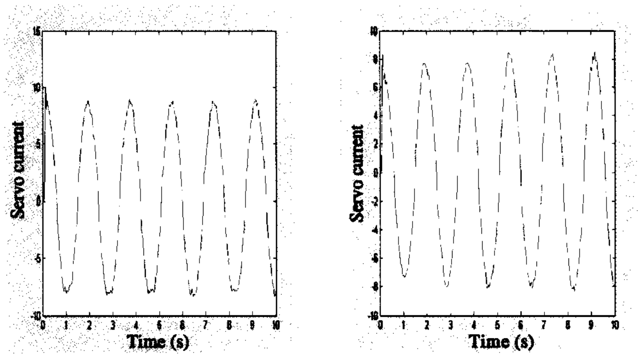
Fig. 9 The frequency spectrum of the servo motor current with various excitation current of the magnetic particle brake

The MatLab provides multifarious filter such as Butterworth filter, Chebyshev filter, Bessell filter and so on. Butterworth filter has the most greatly smooth amplitude-frequency characteristic in its frequency band. And when the exponent number N of Butterworth filter is higher, the response curve is nearer to the rectangle, and the transition band is narrower.

In order to completely filter the frequency component which is higher than the fundamental wave frequency, we use Butterworth filter whose exponent number is 10 to filter the servo motor current. For example, the current waveform of the servo motor in the Fig.7 is shown as Fig.10 after filtering with Butterworth filter.

After filtering the current of the servo motor, we can use the root-mean-square (RMS) value statistical method to calculate the size of electric current to the different load torque. The root-mean-square value statistical method is an analysis method in time-domain and it reflects the average of all samples. For it is very simple and reliable, the method is wildly used for the stable random signal analysis. Through the root-mean-square value statistical method, we can find the amplitude of the feed current signal change when load torque changes. Thus we can draw the relation curve between the load torque of the PMSM and the root-mean-square quantity of the three-phase current signal just as Fig.11. From the graph we can see, there are linear relations between the servo current and the load torque. But the idle current of the servo motor is not 0A with zero loads. And when the load is certain, the servo current will have a little change at various speeds. For example, Fig.12 shows the relational curve of the idle current at the speed of the 50mm/min, 100mm/min, 150 mm/min, 200mm/min and so on.

In a word, the experiment proves that the indirect measurement of the cutting force is feasible through testing the current signal of the servomotor.



(a) the A-phase current (b) the B-phase current

Fig. 10 The current from the servo motor after filtering (the excitation current of the magnetic particle brake 0.1A)

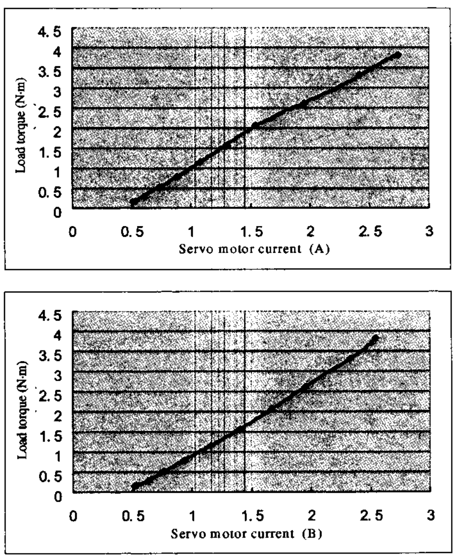


Fig. 11 The relation between the servo current and the load torque

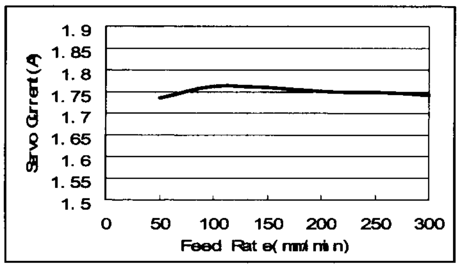


Fig. 12 The relation between the servo current and the feed rate

5. THE INTELLIGENT AND ADAPTIVE NC SYSTEM FOR THE CUTTING FORCE RESTRICTION

In the diversification of machining process, the intelligent adaptive numerical control can automatically adjust machining parameters such as machining velocity, machining depth, feedrate and so on. So it can dramatically improve the machining quality and productivity.

In the NC machining, the most direct method to improve the machining efficiency is to enhance the metal removal of the workpiece in the permission scope. In order to enhance the metal removal we should adjust the feed rate to change the cutting force on line. There are two ways to adjust the feed rate. First, the feedrate instruction is directly input into the numerical control system. Secondly, the feedrate instruction is input into the feedrate controller, then into the numerical control system. The first method is quite difficult to be realized because the feedrate signal is read in the computer with other signals such as the spindle speed, the cutting depth and so on, while the second method is quite easy for only reading the speed signal. So we can adjust the feedrate to change the cutting force.

The intelligent adaptive NC system is designed to adjust the feedrate on the basis of the relation model between the servo current and the cutting force in our laboratory. In the system, the controller reads or receives the cutting parameters and calculates the next cycle cutting force to give the servo unit the suitable cutting speed instruction. Thus the federate of the numerical control machine can be adjusted on time and the adaptive control can be realized to improve the machining efficiency.

5.1 The Intelligent Adaptive NC System

The system is composed of the adaptive controller, the CNC unit, the servomechanism, the cutting tool, the measuring instrument and the mechanism. The principle diagram is shown as Fig.13.In the system the servo motor current is measured by the Hall sensor to calculate the value of the cutting force of the next machining cycle based on the relation model between the servo current and the cutting force. The adaptive controller can determine the rate of feed speed according to the calculated cutting force and the given limit of the cutting force. Then the federate is transmitted to the CNC of the NC machine through the serial communication and is used to control the servo motor speed by the servo amplify. So the cutting force can be adaptively controlled and the machining efficiency can be greatly improved in the intelligent adaptive NC system.

In our laboratory, the research of an intelligent adaptive NC (ANC) system has been developed based on the Y116B vertical machining center with FANUC18M control system. The FANUC system adopts half-closed loop control and it mainly consists of two parts: numerical control unit and adaptive control unit (Ouyang, 2003; Li, 2001). Fig.14 is the connecting diagram of ANC system.

Part1 is NC unit which mainly consists of axis control units, the servo amplifier, the serial pulse coder and the servomotor. The chief tasks of NC unit are servo control, NC machining, information exchange timely with the intelligent adaptive control unit, cutting parameter adjustment and so on. M184 and M185 of the axis control unit are standard interface and they connect with other parts through the cable. The control instruction is transmitted from M184 interface to the CN1 servo amplifier and then to servomotor to control the rotate speed. The feedback signal of the system is sent out from serial pulse coder to M185 to adjust the rotate speed of the servo motor. The CN1 servo amplifier can complete the position control and the speed control after receiving the control instruction from the axis control unit through the interface M184. So the servo motor can drive the machine with high precision.

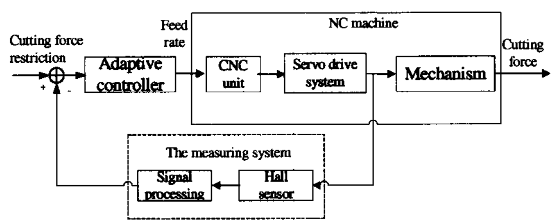


Fig. 13 The principle diagram of ANC system

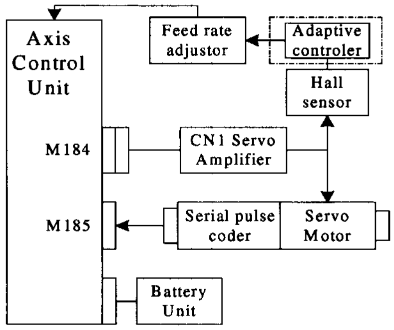


Fig. 14 The schematic diagram of ANC system

Part2 is the intelligent adaptive controller. It is chiefly composed of microcomputer control unit, feed rate adjustor and Hall sensor. MCU forecasts the cutting force based on the measurement of the servo current signal from servo amplifier unit and achieves the automatic adjusting of the feed rate. Then the signal can be transmitted to axis control unit to control the rotate speed of X, Y, Z-axis to achieve adaptive control. The main function of the intelligent adaptive controller is to check machining state real time, to optimize cutting parameters timely, to calculate the ratio of feed rate adjustment and transmit them to NC unit. So the intelligent controller can improve the adaptive ability and intelligent level of the NC machine tool, exert the machining potential and improve cutting efficiency under the conditions of assuring certain machining quality.

5.2 The achievement means of intelligent adaptive control

The main interfaces between the controller and the feed rate adjustor play a great important role on the intelligent adaptive control unit. The interface design becomes the key of the research because the main function of the controller is to automatically adjust the feed rate of servo drive system.

In this system, the feed rate of servo is coded with 16 grades in the feed rate adjustor. So the feed rate switch should have 4 fan-outs and can receive the 16 grades output signal. The input port of the switch can be connected with the predetermined ports on the I/O board through the cable. We distribute 4 points M1-13, M1-14, M1-15 and M1-16 of the Y116B to the 4 ports of the feed rate adjustor. And the corresponding address of the ports is X20.7, X20.4, X20.3, and X20.2 like Fig.15.

We can address every feed speed grate in the program and set the corresponding state table of the mapping word through which we can judge the final working state. In the electronic circuit, we adopt photoelectric isolation circuit and realize such functions as:

(1) detaching the input earth and output earth in the power supply;

(2) achieving voltage conversion;

(3) improving drive ability and control stability.

6. CONCLUSION

The text analyses the relations between the servo motor current and the cutting force in detail and establishes the model based on the AC servo drive system of the NC machining. The new method is very important for the actual production process. Based on the mathematics model, the method of intelligent adaptive control is proposed in NC cutting process, which is simple and effective. The intelligent adaptive controllers provide a technical method with reliability, reasonability and simple structure in achieving adaptive control in the process of cutting. The intelligent adaptive controller has the ability of adjusting parameter on-line, the robust ability of adaptation and the better dynamic performance. It can also adjust the feed rate timely and keep the restriction round the cutting force in the NC interpolation process. As a result, the intelligent adaptive controller can increase machining efficiency, protect the tools and assure machining accuracy. So it will be invaluable and have a bright prospect to get popularly used.

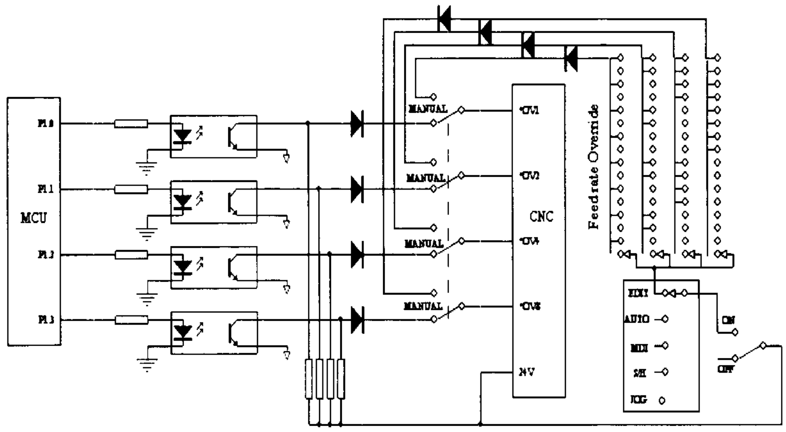


Fig. 15 The output control interface circuit

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