Design of tool-state monitoring system based on current method

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Abstract: Tool failure is one of the main causes of failure in CNC machine tool machining. The real-time online monitoring technology of CNC machine tool is studied, which is helpful to improve the efficiency of failure-free operation of CNC machine tool and reduce the probability of scrap and equipment failure due to tool failure. Here, the correlation between inverter input current and tool wear condition was studied first, based on which a new method about how to calculate line current on inverter input side was defined, according to definition of current virtual value. Then, a real-time monitoring system for online tool wear is designed and developed. The experimental results show that the system can reflect the tool wear condition and remind to change tool timely.

1 Introduction

As the rapid development of electronic technology, automation technology, and electromechanical integration technology, numerical control machine is gradually important in modern machinery manufacturing, which is related to the national strategic status and reflect the national comprehensive national strength level of the important basic industry. Its’ level is the core indicators of modernisation degree of country manufacturing.

In machining process, tool wear is inevitable phenomenon. It is called the wear failure when the machining precision was affected by excessive wear and severe wear. According to the investigation, failure of machine tools which were caused by tool wear failure occupied large proportion, and the parking time caused by cutting tool failure were >20% of the total machine downtime [1]. In machine tool processing, tool condition is in the process of changing under different processing conditions. When the tool faults, the machine tool is still in work if you are not equipped with cutting tool monitoring system, which may lead to the whole process interruption, and the most serious situation is likely to stop running the whole system. Then, it can increase the time and cost. The data show that CNC machine tool downtime with tool failure condition monitoring system will be reduced by 75%, production efficiency will be increased by 10–60% and machine tool utilisation will increase by 50% [2].

Tool wear condition monitoring technology has become key technology which was recognised by all countries [3–5]. It not only plays a vital role in intelligent manufacturing, but also can greatly reduce the labour costs and improve production efficiency. In the traditional mechanical condition monitoring, the tool-state identification usually adopts the sensor technology and the dynamic test technology [6–8]. This method is relatively simple, which is mainly applied in the case of better working conditions, but it has great limitation on the occasions with large vibration interference, and the results are often not satisfactory. Comparing to other methods with the method of current analysis, current signal has the advantages of low cost and strong anti-interference, which contains a large number of cutting tool-state information [9–11]. It is a kind of practical industrial application methods.

Here, a real-time monitoring system for online tool wear is designed and developed.

2 Monitoring principle

Drive motor in NC machine tool is mainly divided into two categories, the spindle motor and feed motor. The current research which were using the current method for cutting tool monitoring is mostly using frequency converter output current signal of the spindle motor or feed motor. The inverter output voltage is constantly changing due to using SPWM modulation, and output current will vary with voltage in certain cases, which can lead to erroneous judgement of tool wear state. Meanwhile, part of the processing centre's servo motor is not controlled by the inverter, as shown in Fig. 1.

If all motor current is measured from the output side, we need at least 12 current sensors because the servo motor has used three-phase power supply, which greatly increases the equipment cost. However, the input-side voltage of the power supply is fixed, so the current size will depend greatly on the demand of the output-side load. So we can know that the current signal can be measured from the input side and only three current sensors are needed. Meanwhile, input voltage value of power supply is fixed, so the measuring current signal not only can solve the problem but also the spindle motor and feed motor current signal can be merged into

Fig. 1 Driver circuit of NC machine
the measurement. This can improve the reliability of the tool wear condition monitoring.

In order to calculate the effective value of the input-side current of the converter, a calculation method is proposed based on the valid value of current. The calculation formula of current effective value of single phase current is as follows:

\[ I = \frac{1}{T} \int_{0}^{T} i^2 \, dt \]  (1)

The formula is discretised, we can know:

\[ I = \frac{1}{T} \sum_{k=0}^{n} i_k^2 \]  (2)

where \( n \) is the total number of sampling points in the integral period \( T \). The frequency converter should be three-phase equilibrium when it is working, namely the three-phase line current should be equal, so we can take three-phase line current RMS average as current RMS converter input side, hereinafter referred to as the average current value effectively.

\[ \bar{I} = \left( I_1 + I_2 + I_3 \right) / 3 \]  (3)

\( I_1, I_2, \) and \( I_3 \) are the current effective values of \( U, V, \) and \( W \).

3 System construction of tool wear condition monitoring

Tool wear condition monitoring system can be divided into two parts, hardware and software. The hardware mainly includes display input module, power module, data processing module, communication module, and sensor module, as shown in Fig. 2.

3.1 Hardware selection

The acquisition communication module is mainly divided into two parts: the acquisition card module and the power module. In addition, for the convenience of disassembly, a variety of wiring ports need to be designed. USB-4711A collection card was used in data collection, where the 5-channel digital input is used to receive the 8421BCD code signal issued by the machine tool, and the working state of the machine tool is monitored regularly. Nova gzm-h40d12-12r was used in power module, input of which is 220 V 50 Hz AC voltage, while the output is positive and negative 12 V DC voltage, which can match the requirement of sensor input voltage.

The CHK-100R1 open-loop hall current sensor was used. The sensor is suitable for collecting the input-side current signal of the transducer. Its measuring range is 50 ∼ 500 A DC, AC, or pulse current. The current measurement window is designed for easy installation and disassembly.

3.2 Software selection

The cross-platform Qt is adopting as the development framework [12]. The designed can be divided into three functional interfaces: Home Page (as shown in Fig. 3), data acquisition (as shown in Fig. 4), and tool wear condition monitoring (as shown in Fig. 5).

The homepage is a welcome interface, which mainly introduces the name of the software, the functions of various circles, and the system research and development unit.

The page is divided into four parts: (i) the parameter setting area, which is mainly used to set the collection card, communication correlation parameters, and data saving path. (ii) the effective current display area, which is mainly used to show the effective current curve after operation. (iii) the instantaneous current signal display area to display the instantaneous line current of the three-phase alternating current. The area 4 is used to display the data acquisition status and control the beginning or ending of data collection.

The page is still divided into four sections, but slightly different from the learning data collection page. Area 2 is still parameter setting area, but no longer used to set the collection card. Area 2 is used to display the reference curve, warning line, and current curve. Area 3 is used to display the reference curve, warning line, and current curve of all segments. Area 4 has the same function as the learning data collection page, which can be used to display the
working status of the current machine tool and to start or stop monitoring.

3.3 Tool maintenance system

Tool maintenance system, which is convenient for checking the condition of monitoring system, is set up. Nowadays, mobile phone or the tablet is very convenient and portable intelligent devices. So an APP which works on phones and tablets is a good choice. Android Studio is a compilation and development environment for the Android system launched by Google. The main language used is the Java language. The software interface design is shown in Fig. 6.

4 System testing and results

In order to test the system, it is applied to the VMC850 vertical machining centre. Hard alloy flat milling cutter were used, which had four blade, with coating, and tool diameter was 10 mm. The blank material is 45 steel with a size of 160*65*80 mm. The experimental conditions are as follows:

The spindle speed is 4000 r/min, feeding speed is 1000 mm/min, back feeding knife is 1 mm, and side feed knife is 5 mm, with cooling liquid.

Different wear states can be shown in Fig. 7.

Through the tool-wear monitoring system software of the monitoring function, we can see the change of the current intuitively (as shown in Fig. 8). The current amplitude also have obvious increase, when serious tool wear was happened. When the appropriate threshold value was setting, the software will issue a warning if the tool has serious wear and tear, as shown in Fig. 9.

At this point, the tool maintenance system corresponding to the station number of turns red icon to indicate the abnormal workstation (green icon indicates the workstation is online and normal working, grey represents the workstation is offline).
Clicking the icon, we can view the information, as shown in Fig. 10.

5 Conclusion

The relevance between input side current of the machining centre and tool wear status was studied, based on which a method of tool wear condition monitoring was put forward. The hardware and software of tool wear condition monitoring system are designed and written. The experimental results show that the method is more obvious than traditional method and easy to monitor, which can improve the processing quality and automation degree.

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Fig. 7 Different wear states
(a) Light wear, (b) Moderate wear, (c) Severe wear

Fig. 8 Tool wear condition monitoring page

Fig. 9 Alarm interface
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