On-Line Tool Condition Detection Based on Acoustic Signal

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Abstract

Along with the rapid development of high speed machining technology, cutting speed and productivity increased ， but also come with increased tool wear and tool life reduction. This paper first introduced the modern testing technology to online tool detection in principle, and then raised the establishment of online detection system of tool condition using sound signals in the cutting process. This method can be used in practice for tool condition monitoring in order to timely adjust machining parameters, or change tool to ensure high efficiency and quality of machining.

Keywords: High-speed cutting, Tool wear, Online detection, Sound signals

1. Introduction

In modern manufacturing systems, in order to achieve high efficiency and low cost processing, modern automated processing equipment use a higher cutting speed, risk of cutting process is much larger than traditional. In order to ensure the safety of automated processing equipment and processing quality, there is a pressing need to address the process of inspection and monitoring issues. [1] The cutting tool is a direct effect of the object; its degree of wear and tear directly affects the quality of the work piece, and may even cause the machine to malfunction. Traditional tool status recognition is often through cutting time, color or cutting tool wear measured after removal which is difficult to meet the real-time detection of cutting tool condition. The tool life tend to be randomness and uncertainty, a conservative estimate of its life limit will allow the use of performance tools can not be fully realized, the wear and tear of information collection and analysis tool can not be timely feedback in turn lead to decreased quality of the work piece, the machine damage and other problems. Therefore, the application of modern testing techniques for real-time monitoring of tool condition to increase productivity and tool utilization rate is important.

2. On-line Tool Detection Technology

Tool monitoring refers to the product in machining process, by detecting various types of sensor signal changes, measure the wear of cutting tools, control system automatically controls the tool feed based on the results of monitoring tools, compensating for dimensional and form accuracy of tool wear parts changed. Researchers did a lot of works to tool monitoring studies using information carriers passing through the cutting process, such as light, power, heat, sound and vibration signals.[2-4] Over the last decade, at home and abroad in terms of tool breakage monitoring has made great progress, but some monitoring methods only apply to conduct online detection tool in a particular processing conditions, some are still in the laboratory stage, the actual application production still need to make great efforts.

Currently, tool condition monitoring methods used at home and abroad can be grouped into two categories, one type is direct monitoring method, it is direct detection of cutting tool cutter parameters such as tool shape, the amount of wear and other tool parameters, downtime is generally required for testing, which usually has a certain impact on the machining process. This method includes contact method, optical imaging method and so on. The other is indirect method, it indirectly measures related physical quantities that have changed with the cutting process in work piece machining, and establishes a rational mathematical model between the relevant physical quantities and tool wear or breakage, thus deduces that the cutter is worn out or threatened for tool breakage will occur, so as to achieve the purpose of real-time tool monitoring. This method is often less intrusive to the cutting process and easy to collect information, which includes cutting force, spindle motor power, cutting vibration, acoustic emission, cutting temperature, the process of sound measurement method and the like. Involved in sensor and mounting position as shown in Figure 1.

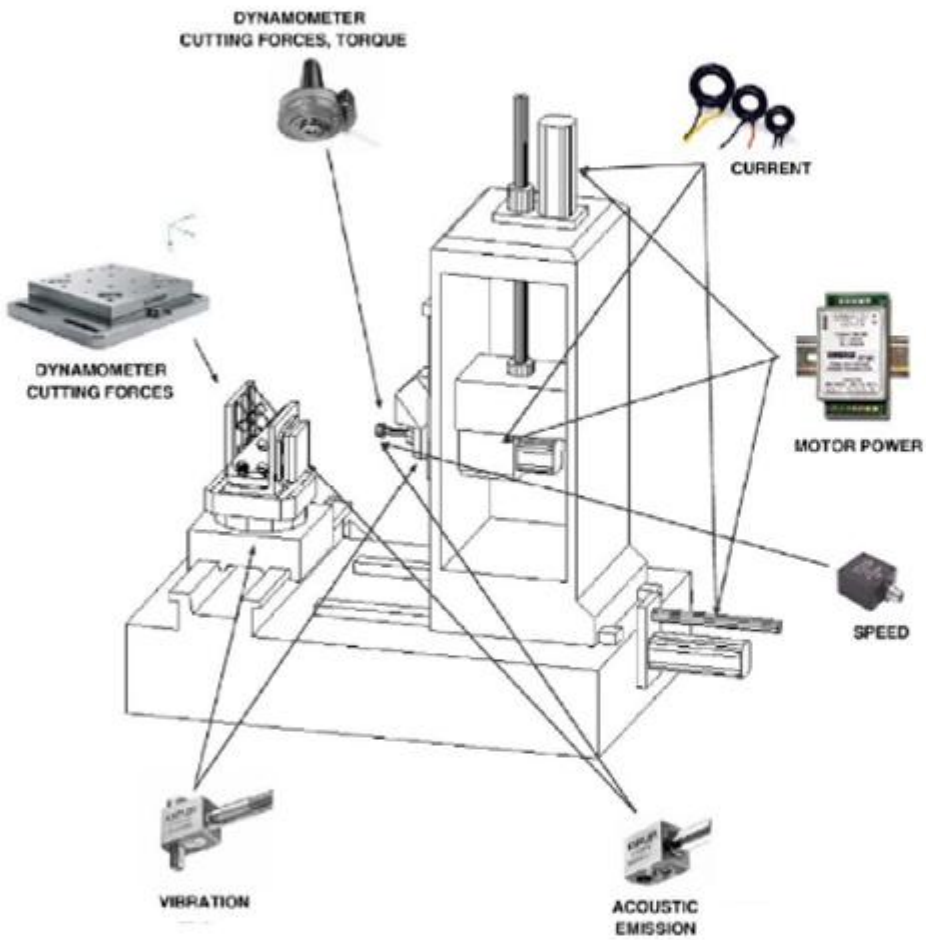

Figure 1: Indirect Monitoring Sensors and Measurement Location

Select the appropriate monitoring object, detecting the signal to other related in the process of cutting provides new methods and ideas for tool condition detection.

Integrated advantages and disadvantages of each method above, the main issues that online detection system of tool condition currently faced are the diversity of tool, cutting parameters variability, tool blunt randomness and conditions of the actual production environment restrictions. In order to improve the versatility of the tool online detection system to adapt a variety of subjects (such as turning, milling) and adapt a variety of processing conditions, and in view of the sensor technology, voice recognition technology [5] and signal processing technology matures, this paper presents the on-line tool detection system based on sound signals, Establishing the analysis of the correlation between sound signal and tool wear in cutting process, to achieve on-line tool condition inspection applications in the production practice.

3. On-Line Tool Detection System Based on Sound Signals

3.1 Detection Theory Based on Sound Signals

In the whole of cutting process is accompanied by a sound signal, sound study of general machine tools include: (1)The total sound constitution in the cutting process, such as lathes transmission, electrical systems, environmental background noise and other factors. (2)The pure cutting sound, the noise generated during the cutting process, which includes: the acoustic emission signals and the sound signals within audible threshold (20Hz-20000Hz) generated by vibration of cutting system. Materials for localized energy source quick-release transient elastic waves generated the phenomenon known as acoustic emission (AE). Acoustic emission method has high sensitivity in high frequency region (above 2000Hz), Avoiding of audio signals and vibration from low frequency disturbance serious area during the processing, relatively strong anti-interference ability. But its characteristic parameters of vulnerable to the influence of work piece and tool materials, high frequency noise often result in miscarriage in the actual environment, AE Sensor installation location and processing methods have more demands, there are many inconveniences in practical application. Thus this paper mainly focuses on the sound signals within audible threshold using for on-line tool detection.

In the cutting process are accompanied by generation of the sound signals within audible threshold of cutting, the sound signals within audible threshold itself contains a wealth of machining information [6], and the sound signal has the advantages that information carriers of other signal do not has:(1) Measurement of the sound signal itself belongs to the non-contact measurement, data acquisition and measurement do not affect processing. (2) Formation of a sound signal measurement system is relatively simple and does not need to change the structure of the machine itself and no need to more equipment. Wu Jianhua, Tianjin University, research on the flank wear at different stages in the variation of the cutting sound audible sound range, studies show that the center frequency of the band sound pressure level of cutting sound can be used as discriminating tool wear characteristic quantities. [7]

Ai Changsheng, Tianjin University, research on tool wear classification recognition based on sound signal HMM, studies show that a corresponding relationship between the characteristics of the sound spectrum with its cutting tool wear, tool wear condition information and sound signal with synchronization effects arising from, real-time access to information, found faults or dangers in advance. [8] Xie Zheng, Shanghai Jiao Tong University made a study on tool condition monitoring based on milling noise, tests showed that in the frequency range 2 kHz ~ 3 kHz, cutting noise and tool wear has a good correlation. [9]

Thus the sound signal as a tool selected state detection signal is workable and practical value, the key issue seen by analyzing the sound signal within audible threshold chosen to be addressed is the formation of cutting acoustic signal acquisition and processing system, and Exclusion of low frequency noise signal interference, extracting tool condition recognition effective sound signals, giving cutting tool State distinguishing of high efficiency and high reliability real-time online, thus providing strong support for automated production of machine tools.

3.2 Machining Status Monitoring Method

Machining process is a complex physical and chemical processes, online monitoring of machining process involves a number of related technologies, such as sensor technology, signal processing technology, computer technology and automation technology, artificial intelligence, as well as the cutting mechanism.

Typically, process monitoring system mainly consists of signal detection, feature extraction, identification and decision-making and control components, as shown in Figure 2.

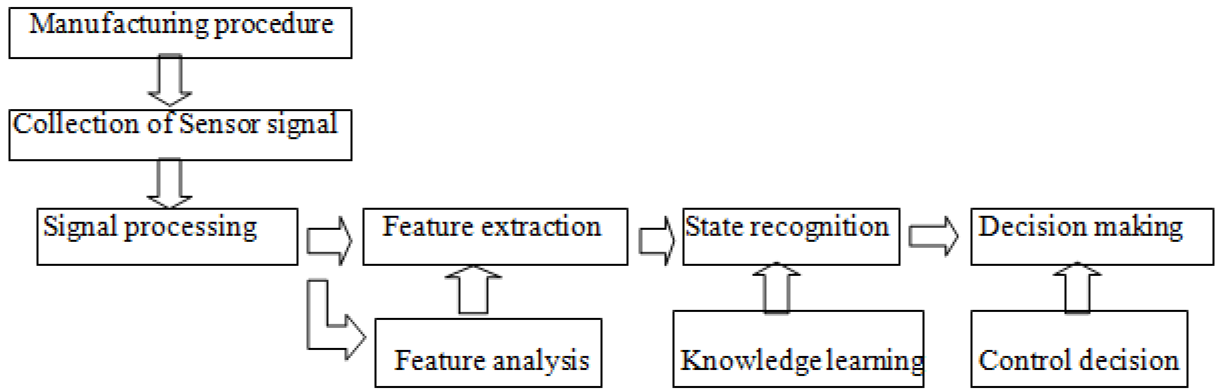

Figure 2: The General Structure of the Process Monitor

(1) Signal Detection: The first step in the monitoring system, the processing status of many signals from different perspectives reflect changes in tool condition, requiring monitoring signals accurately reflect changes in the status of the tool, easy on-line measurement, which does not change or change the structure of manufacturing system as little as possible and have strong anti-interference ability.

(2) Feature extraction: the detection signal is further processed to extract the tool status changes related parameters from a large signals, the aim is to improve the signal to noise ratio, improved anti-jamming capability. The main analysis methods are time domain analysis, frequency domain analysis and time-frequency analysis methods. [10] Quality characteristic parameters have a significant impact on the performance and reliability of the monitoring system.

(3) State recognition: To establish a reasonable model, according to the characteristic parameters of acquired from real-time status of the tool, and take a classification Classifying, establishing the mapping of the state of characteristic parameters and tool.

(4)Decision and Control: According to the results of state recognition, verdict the state of tool wear or breakage in a decision model and make the appropriate controls and adjustments, such as changing the cutting parameters, or replace the cutter.

Typical tool wear has three stages: the initial wear, the normal wear and the severe wear. The goal, online detection system of tool condition eventually wants to achieve, is to use the law of wear curve of tool in three different stages and establish corresponding relationship with time-frequency characteristics of sound signal to automatically determine the tool stage wear, the State of tool in real time of discriminating is on the basis of this, and thus to select the appropriate compensation or tool change measures.

3.3 Construction of Detection System

(1) Determine the research object.

Lathe cutting process is relatively smooth and continuous, multi disc cutter as each tooth will have contact with the work piece following with collision, need to avoid the interference, from collision of audio signal amplitude, on the cutting tool State distinguishing.

(2) Determine the actual detection range.

Work piece tool material and the selection of cutting parameters have an impact on the cutting process, thus need to extract common features, so that detection can be applied to all processing conditions.

(3) Sensor selection and installation.

The system uses noise sensors to acquire sound signals, Superlux ECM888B capacitors test microphone can be used, and it has the following features, shown in Figure 3:

1) A very wide range of frequency response, from 20 ~ 20K Hz. Sound frequencies covering the audible threshold can be used for experimental studies.
2) 1/4-inch industry standard measurement of the diameter.
3) Pickup clear, non-directional mode wide range pickup, and even contribute to the phenomenon of serious occasions can guarantee sound quality.
4) Metal structure, durable, and has good resistance to sweat, moisture resistance properties, unaffected by temperature technique pointers.

For the main performance parameters of the detection system concerns are as follows:

Sensitivity (1,000 Hz Open Circuit Voltage): -43dBV/Pa (7.1mV/Pa)
SNR: 72dB
Equivalent noise level (A-weighted): 22dB

Therefore, the sensor can be used to implement the monitoring system for the amount of acoustic measurements such as the sound pressure, sound intensity, and sound power.

(4) sound signal amplification and transmission.

Between a computer and a microphone, it is necessary to signal transmission and transformation, including signal sampling, quantization and coding. Data acquisition card can implement these features, it is mainly composed of multi-channel selection switch for sample-and-hold, consists of the a/d converter and buffer. When application of the data acquisition system in the device to be monitored, the sensor device of the voltage or current signal sample and hold, and take into A / D converter becoming a digital signal, the signal is then sent to the FIFO. When the data is stored in the FIFO to a certain number, reading is from the FIFO by the ARM7 and the interface to the host computer via RS232 or Ethernet ARM7. Since the computer's sound card itself has a good sound acquisition and conversion functions, so the system can be used as a German RME FireFace UCX sound as a sound signal acquisition and processing equipment. The sound card is integrated signal amplifier, do not need to add an additional signal amplifier to magnify the sound signals and has 8 analog input/output channels, sampling rate can be as high as 192kHz., converting analog signals to digital signals with 24-bit precision, can guarantee a sound signal without distortion very well to ensure accuracy and completeness of the sound signal.

(5) Study the signal in time domain and frequency domain characteristics. Determine the reaction tool wear characteristics.
(6) The method used to select the most appropriate mathematical tool wear can reflect the feature vectors.
(7) Establish the mathematical model between tool signal characteristics and states to detect judgment.

3.4 The Applications of LabVIEW in the System

Using the LabVIEW software, graphical programming language can be used to easily set up a practical measurement systems and instrument panel, without the need to write complicated computer code. [11]. The System uses Microphone and computer's sound card as sound signals acquisition hardware, In the LabVIEW development environment for computer audio acquisition and analysis system. Collecting sound signals of various conditions of environment, features such as signal save, recall, and playback can be realized, simultaneously can achieve a variety of time-domain analysis, frequency domain analysis and time-frequency analysis of the sound signals. The method provides an effective tool for the sound signal research and tools state recognition. System software design framework in LabVIEW environment.

4. Conclusion

This paper introduces the modern testing technique and its application in tool condition detection, use of non-contact measurement with cutting signals, to detect the processing status reflecting tool wear and breakage, providing a reliable method for cutting tool state distinguishing. How to give out a rational analysis based on genetic algorithm and neural networks for signal processing, and establish reliable mathematical model between detection signal and tool condition, as well as the study on the application of multi-sensor fusion technology are the main development direction in the future.

References

Ning he. (2011).High speed cutting technology. Shanghai, China: Shanghai science and Technology Press

Ruhai Yi., &Mingqiu Wang. (2006). Research on tool monitoring system by combination of power, cutting force, AE signals. Tool Engineering, 7, 80-83.

Jianglin Hu., Shaowen Zhang., &Liang Li. (2012). Research on tool wear monitoring by acoustic emission technology. Tool Engineering, 3, 69-71.

Min Huang., Xiuli Liu., &Houzheng Xie. (2012). Fault detection methods and experimental system of high-grade CNC machine tool wear. Journal of Beijing Information Science & Technology University (Natural Science), 1, 19-24.

Yubo Zhang. (2004). Process and Method of Voice Pattern Recognition Based on Signal Processing, Computer Simulation, 21(9), 134-137.

C. S. Ai., Y. J. Sun., G. W. He., X. B. Ze., W. Li., &K. Mao. (2012). The milling tool wear monitoring using the acoustic spectrum. Int J Adv Manuf Technol, 61, 457–463

Jisuo Zhang., Jianhua Wu., &Wei zheng. (1995). Acoustic signal recognition cutting tool wear. Journal of Xiamen University (Natural Science), 1, 51-56.

Changsheng Ai., Baoguang Wang., Quancheng Dong., Ning Fan., &Honghua Zhao. (2005). Speech Recognition Based Tool Wear Status Online Monitoring. Modular Machine Tool & Automatic Manufacturing Technique, 12, 63-65.

Zheng Xie., Min Wang., &Wei Fan. (2008). Study on Cutting Sound Characteristics of Tool Condition in Milling. Tool Engineering, 7, 19-21.

Dayou Ma., &Hao Shen. (2004). Handbook of acoustics. Beijing, China: Science Press

Wenli Kang., Shumei Yi., & Yongxia Lu. (2004). The application of LabVIEW on the data acquisition and storage of the cutting force. Modular Machine Tool & Automatic Manufacturing Technique, 8, 97-98.