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SENSING TECHNOLOGY IN MACHINE TOOL

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ABSTRACT: Machine tools are usually used over a long period of more than 10 years, so providing appropriate services are significantly important. Machine tool manufacturers, who develop their businesses worldwide, locate their service bases and parts centers across the world to improve their service quality and provide prompt services to customers. Moreover, if necessary maintenance work is identified before machine tools break down, machine tool manufacturers can make plans to provide systematic services, and users can prevent machine stoppage. This paper describes the development of the sensing interface and the technology to analyze the operating status of machines to implement preventive maintenance.

1. INTRODUCTION

Machine tools ,which are used for fabricating various machines and processing equipment, can be categorized into two types—metal-cutting machine tools and metal-molding machine tools—according to their functions. Metal-cutting machine tools include lathes, drilling machines, milling machines, grinding machines, and planning machines; metal-molding machine tools include punching machines and shearing machines. A machine tool is composed of several parts. In the case of a drilling machine, milling machine, grinding machine, planning machine, and other machines that employ a rotating cutter, the most important part, i.e., the part that has the most impact on the processing quality, is the machine tool spindle. Therefore, machine tool manufacturers have strict criteria as far as the accuracy of the machine tool spindle is concerned. During the operation of a machine tool, the material characteristics of the processed work-piece, the addition of the cutting fluid, and other practical processing situations may directly affect the processing quality. The working state of the machine tool spindle is practically inspected after processing is completed. If the finished pieces do not meet the accuracy requirement, the machine tool spindle is adjusted or maintained in precision alignment; however, loss of work-piece is generated. In order to solve this problem, some manufacturers of machine tools have proposed that sensing devices such as an accelerometer, a thermometer, or a strain gauge be installed near the machine tool spindle, in order to measure the acceleration frequency, temperature variation, processing output torque, and other working parameters during processing. However, sensing devices cannot be installed adjacent to the cutter because of the generation of cutting waste and the sputtering of cutting fluid near the cutter. Further, the working parameters measured by the sensing devices do not give an accurate reflection of the working state of the cutter, and therefore, the parameters cannot be used for monitoring the processing state in real time or for improving the processing quality. The conventional sensing devices setup performed on an end-milling machine tool is equipped with a commercial wired PCB three-axis accelerometer (model number 356A18). The accelerometer is connected to a commercial TEAC charge amplifier (model number LX-10). The measurements were recorded on a commercial HP35670 spectrum analyzer .However, the cost in these commercial instruments is extremely high .As a solution to this problem, in [1], it has been shown that complex vibration spectra of rotors and machine tool spindles are primarily influenced by the bearing geometry, out-of-balance assembly, and a multitude of secondary effects due to surface anomalies of the interacting bodies. Sensors typically have a finite service life as they employ batteries or wired power systems; therefore, a self-powered system that can be energized by an electromagnetic vibration-powered generator has been proposed in [2,3]. An autonomous machine equipped with a cluster of multi-agent sensors has been proposed in [4]; this device can fully control diverse variables such as the cutting parameters, in-process dimensions of devices, and geometric and form defects. The machine is provided with individual wireless nodes as a result of which it can be placed in locations in which wired sensors cannot be placed. Wireless sensor networks open up new possibilities otherwise not feasible with wired sensors, such as the use of multi-sensor data fusion methods for estimating tool wear. In [5,6]the potential of wireless sensor nodes and networking in manufacturing environments has been investigated. However, the study does not consider the fact that manual maintenance would be necessary to replace the discharged batteries; in addition, most transformers with iron cores are relatively large, because of which these transformers cannot be placed upon the tool holder. Additionally, since the induction coil, sensing chip, and data transmission unit are quite close to each other, the magnetic field generated by the power supply unit directly interferes with the sensing chip or the data transmission unit; as a result, the sensing chip cannot acquire accurate data, and the wireless transmission of the data is affected .If a sensing device is installed outside the machine tool, the acquired working parameters do not accurately reflect the working state of the cutter; if the sensing device is mounted on the machine tool holder, the magnetic field of the induction coil used for generating electric power directly interferes with the measurement or wireless transmission, and the working parameters of the conventional machine tool spindle cannot be acquired in real time with sufficient accuracy .This paper presents a novel approach for developing next-generation intelligent sensor systems ;the approach involves the integration of a vibration sensor with solar power board and a wireless communication module .The proposed system comprises the tool holder body, a rotating mandrel, a cutter base ,and an internal sensing device, and is capable of monitoring the working state of the machine tool spindle in real time an feedback frequency signal to the machine controller.

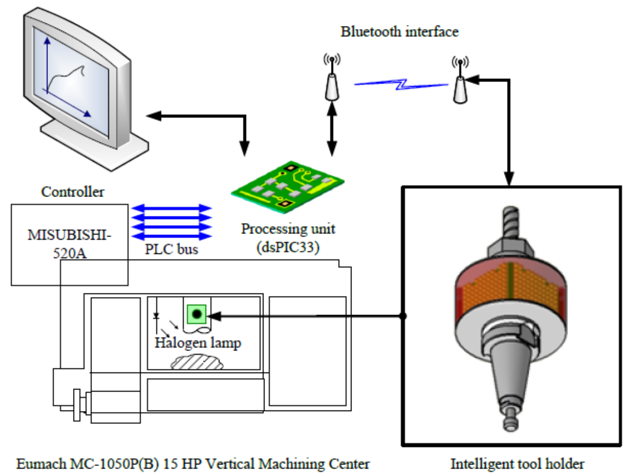

Fig.1 A wireless communication module,a FFT processing unit, internal sensing device, and is capable of monitoring working state of machine tool holder in real time[3].

2. Principle of smart machining tools

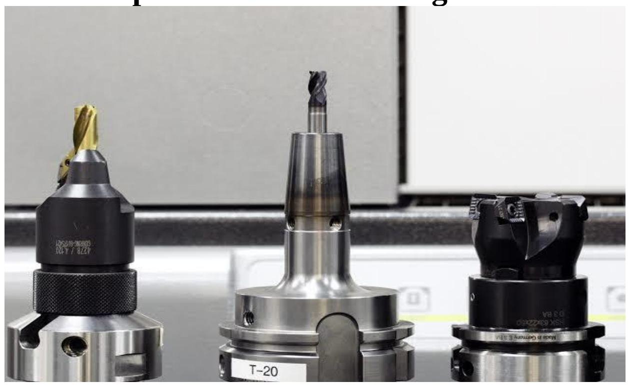

Fig.2 Different types of smart cutting tools[5]

Due to the cutting forces of machine tool nose during diamond machining processes the piezoelectric sensors integrated into the smart cutting tool will generate electrical signals according to the piezoelectric effect when subjects to small strain cavities of the special designed insert tool. The output electrical signals of the piezoelectric films can be amplified and processed to capable of monitoring the cutting force accurately.

2.1 Tool holder sensing architecture

The machine tool holder structure presented in this study can be used to measure the temperature, vibration frequency, torque, and other working parameters of the machine tool spindle during processing. A low-power accelerometer (Analog Devices ADXL 321) is used as the vibration sensor.

The accelerometer operates within ±18 g, and its bandwidth can be adjusted from 0.5 to 2500 Hz using external capacitors. This device can be used in condition monitoring applications wherein a change in machinery vibration often indicates that maintenance is required. The low power consumption of the device, which operates below 350μA at 2.4 V, is an attractive feature, given the low power available within the system

2.2 Fast Fourier transform

Fast Fourier transform (FFT) is an efficient tool for the analysis of vibration records. The Fastest Fourier Transform in the West (FFTW) [7]—an implementation of the discrete Fourier transform (DFT) that adapts to the hardware in order to maximize performance—is a widely used free-software library applied in various special cases. Let $x0$, …, $xN-1$ be an array of n complex numbers; then, the 1-D DFT Xk is given by the summation of exponential (sinusoids) functions, which is taken over the set of all integers N. The time-domain vibration signal was analyzed by FFT.

2.3 Cutting forces (dynamic and static)

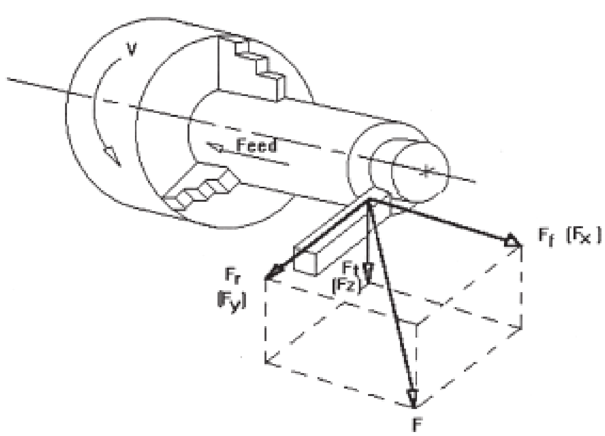

Fig.3 Cutting force components on a single point tool[10].

It has been widely established that variation in the cutting force can be correlated to tool wear [9,10,12–15]. In practice, application and interpretation of this parameter has been diverse with more effort concentrated on studying the dynamic characteristic of the cutting force signal and interpreting its relation to tool wear levels. This can largely be attributed to the fact that force becomes important in worn tool conditions as a result of the variations produced due to friction between cutting tool flank and the workpiece [13,14]. Existing force-based TCMSs typically operate independently of absolute force levels, measuring the relative change of force that occurs as a new tool wears [16,17] or when it fractures [11]. Experiments have shown that the three components of the cutting force (Fig.3) respond differently to the various wear forms occurring on the tool. For example, the feed (Fx or Ff) force is insensitive to crater wear whereas the feed and radial (Fy or Fr) forces may be influenced more by tool wear than the main cutting (Fz or Ft) force

3. Sensor application

sensors to monitor the spindle, table, ATC, magazine, and power consumption are all examples of what sensing items can be mounted on a machining center. Spindle vibration, coolant monitoring, and power consumption monitoring applications are explained in this chapter.

3.1 Spindle acceleration sensor

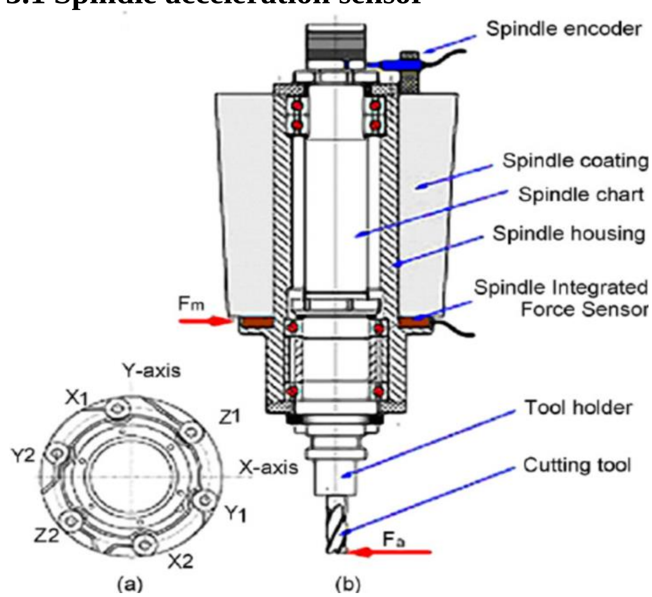

Fig.4 Integrated force sensors in monitor spindle[7]

The following two functions, namely MPC and MVC, are implemented using the installed spindle acceleration sensor. MPC (Machine Protection Control) is an application for preventive maintenance, which was developed to prevent machine damage and cutting failures. The application displays the spindle vibration and load during machining operation and changes in the spindle vibration level for the last 20 seconds. Generally, high-skilled machining technicians judge the spindle vibration using their own senses, whereas this system controls vibration by visualizing the vibration level during machining operation, based on the amplitude level. Moreover, the machining operation is stopped automatically in order to prevent the machine from being damaged when an abnormal vibration level is detected. MVC (Machine vibration control) is a chatter avoidance application. The chatter vibration level and frequency are detected by analyzing vibration frequency and tool information, and the appropriate spindle rotation speed to avoid chatter is displayed.

3.2 Coolant level sensor

A new approach for the measurement of the coolant level was developed in order to measure the coolant level for either water based coolant or oil based coolant, using a capacitance type sensor[7]. The electrodes of this sensor fall into nine areas. Each electrode pair has different capacitance values, depending on whether the electrode is in the air or submerged in coolant. The collected capacitance values are converted to voltage values and transferred to the EPM through the RS485 interface. Nine electrode pairs, as the sensor device, and the control circuit are on one circuit board, which makes the sensor less expensive than a currently available level sensor. Due to the simple structure of the sensor, mutual interference among the nine electrodes was found. Different types of coolant further complicate the measurement, owing to different permittivity, and coolant of some categories has much the same permittivity as the air. The 9-electrode voltages of water-based coolant and oil-based coolant measured by this sensor. For oil-based coolant, the change in voltage output for different coolant levels was too small to be detected by the threshold method. To find solutions to these challenges, we used a Neural Network (NN) that utilizes Machine Learning; it is a basic type, with one hidden layer. A sigmoid function was used as the output function of each node. Data sets of 9-electrode voltages with varied coolant levels and many types of coolant were collected in advance, and used as training data for supervised learning. The coolant level in the tank can be easily detected with this sensor. That is, monitoring the clean tank and dirty tank enables us to predict when the filter between the tanks needs cleaning or replacing. The timing is when the difference between coolant levels of both tanks becomes higher than a certain level.

3.3 Power consumption sensor

Reducing the power consumption of a machine tool is one of the most important themes. The authors have studied power saving and experienced that power consumption was reduced on actual machine tools by employing some of the technologies that were studied [8]. The next step is to monitor and visualize power consumption of each machine tool. A digital-computing-type power meter was developed for this. The voltage sensor and electric current sensor were attached to the three-phase power input area so that samples of the voltage and electric current could be collected simultaneously at a high speed. Analog data is converted to digital data, and instantaneous power is calculated by multiplying the data with the microprocessor .The result is processed by an averaging procedure for a period of one cycle (T), the active power P is calculated, and then it is displayed on a Human Machine Interface via Ethernet. This system measures power consumption and detects abnormal values, which enables us to judge machining processes and predict potential problems for the machine tool.

3.4 Vibration signatures

Vibrations are produced by cyclic variations in the dynamic components of the cutting forces.Usually, these vibrational motions start as small chatter responsible for the serrations on thefinished surface and chip thickness irregularities, and progress to what has come to be commonly termed vibration. Mechanical vibrations generally result from periodic wave motions. The nature of the vibration signal arising from the metal cutting process is such that it incorporates facets of free, forced, periodic and random types of vibration. Direct measurement of vibration is difficultto achieve because its determining characteristic feature, the vibration mode is frequency dependent. Hence, related parameters such as the rate at which dynamic forces change per unit time (acceleration) are measured and the characteristics of the vibration derived from the patterns obtained.

4. Summary

The proposed wireless solar-powered system can monitor the working state of the machine tool holder in real time ;the system comprises the spindle body, a rotating mandrel, a cutter base, and an internal inspection device A newly developed sensing interface can be utilized to measure high frequency spindle vibration, different types of coolant fluid level, and power consumption. Clearly, cutting forces (static and dynamic) and vibration (acceleration) are considered to be the most widely applicable parameters. Advances and increased sophistication in instrumentation technology employed for measuring these parameters make them viable, practical, cost effective, robust, easy to mount and have the quick response time needed to indicate changes for on-line monitoring.

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