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CONDITION MONITORING OF TURNING PROCESS USING AE SENSOR

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ABSTRACT
Machining processes have to deal with deformation of the cutting tool, the machine tool, and the work piece. Acoustic information has been associated with the state of the cutting tool for many years. In metal cutting operations, Acoustic Emission (AE) results especially from the plastic mechanical processes of crack formation and chip removal, and from surface friction. Tool wear alters the contact surfaces between tool and work piece, and hence the intensity of AE too. Usually the AE RMS energy is studied to detect tool wear. A dramatic increase in energy can be observed as the wear land increased. Statistical techniques are applied to the AE RMS energy recorded during progressive tool wear to attempt to minimize the sensitivity of the signal to process parameters for tracking of tool wear. Advance warning of tool breakage is sometimes given by the appearance of micro cracks in the tool, which cause AE signals. This may be utilized for quality and tool monitoring or process control.

Keywords: Condition monitoring, Acoustic emission, AE sensor.

1. OBJECTIVES
An excellent review of the state-of-the-art, technological challenges and future developments of these systems has been described. This paper describes in great detail the physical parameters to be analysed for industrial control applications, together with their appropriate sensory systems. Among these, acoustic emission (AE) signal analysis has been demonstrated to be one of the most efficient TCM techniques that can be applied to machining processes control, as the impressive amount of literature on this subject shows. Using this framework, our paper tackles the problem of gaining greater insight into the fundamental statistical properties of AE signals generated during turning machining processes, so that an appropriate implementation of AE sensor-based devices will lead to efficient TCM systems.

The objectives of this work are: (i) To explore advanced signal processing techniques that can correlate machining processes and acoustic emission signals. (ii) To develop a tool kit comprising sensors, instrumentation and software for in-process machining monitoring, namely turning.

2. METHODOLOGY

2.1 Acoustic Emission in Machining
In many manufacturing processes machining forces in tools and materials generate high-frequency acoustic emission (AE). Various investigations in recent years have shown that AE signals can be used to analyse and monitor machining operations. The use of acoustic emission techniques for process monitoring has the potential of ensuring high product quality while minimizing the total cost of a product. Processes such as cutting, grinding, forming and joining all generate acoustic emission for reasons unique to each process. In many cases, the emission can be monitored to characterize the process, to detect defects and to detect finishing quality.

Principal areas of interest with respect to AE signal generation in metal cutting are in the primary generation zone ahead of the tool where the initial shearing occurs during chip formation. The secondary deformation zone is along the chip/tool rake face interface where sliding and bulk deformation occur. The third zone is along the tool flank face/work piece surface interface. Finally, there is a fourth area of interest that associated with the fracture of chips during the formation of discontinuous chips.

AE sensor is considered to be one of the most practical technologies to use for certain applications in machining operations. Major conditions to be monitored and detected are tool wear, tool breakage, chatter vibration, chip tangling and the tool life. For the practical application of the AE sensor for monitoring the machining processes, the first problem to be solved is how the sensor should be mounted on the tools (it is preferable to mount the sensor on the cutting tool to keep the distance between the sensor and the cutting point constant). This requirement causes difficulty when mounting the sensor on the rotating tool in the case of milling and grinding.

The basic AE signal generated in turning due to the material deformation inherent in chip deformation and chip/tool contact is complicated by noise and periodic interruptions of the cutting process. This is in contrast to the relatively stationary single point turning generated AE. It is shown in Fig. 1.

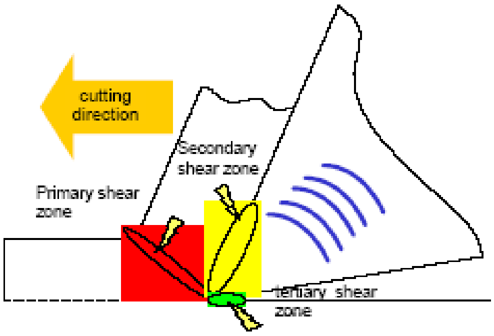

Fig 1. AE Sources at Tool/Chip Interface

The major sources of acoustic emission identified in metal cutting include:

• Plastic deformation of work piece material in the shear zone;

• Plastic deformation and sliding friction between chip and tool rake surface;

• Sliding friction between work piece and tool flank surface;

• Collision, entangling and breakage of chips are generated in the shear zone, at the chip/tool interface and at the tool flank/work piece surface interface while burst signals are generated by chip breakage during or after formation or by insert fracture.

2.2 Acoustic Emission Sensors

The fundamental of a successful process monitoring system is the right selection of sensors. A wide variety of sensors have been utilised to monitor machining process. Most of the attentions are focused on force measurements and tool condition monitoring (TCM), which includes tool identification, tool wear monitoring, tool breakage and tool life. Most practical approaches to tool condition monitoring have been developed utilising indirect measurements of tool performance that are easier to achieve than direct measurements in most environments.

Acoustic emission sensors are used on a test object's surface to detect dynamic motion resulting from acoustic emission events and to convert the detected motion into a voltage-time signal. This voltage signal is used for all subsequent steps in the acoustic emission technique. The electrical signal is strongly influenced by characteristics of the sensor and since the test results obtained from signal processing depend so strongly on the electrical signal, the type of sensor and its characteristics are important to the success and repeatability of acoustic emission testing.

A wide range of basic transduction mechanisms, capacitive transducers, displacement sensors or even the laser interferometers, can be used to detect acoustic emission. But acoustic emission detection is commonly performed with sensors that use piezoelectric elements for transduction. The element is usually a special ceramic such as lead zirconate titanate (PZT) and is acoustically coupled to the surface of the test item so that the dynamic surface motion propagates into the piezoelectric element. The dynamic strain in the element produces a voltage-time signal as the sensor output. It is shown a typical AE sensor in fig. 2.

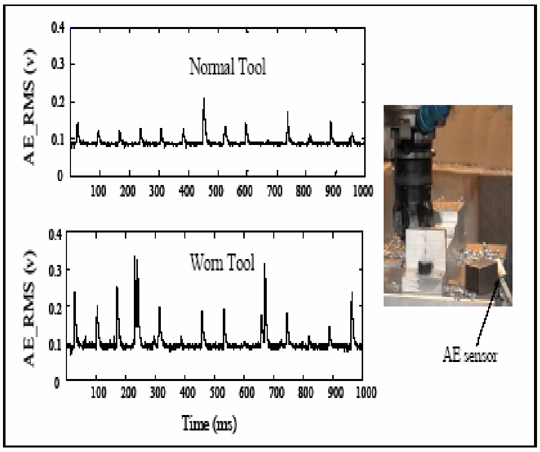

Fig 2. A typical AE Sensor

Surface motion of a point on a test piece may be the result of acoustic emission. Such motion contains a component normal to the surface and two orthogonal components tangential to the surface. Acoustic emission sensors can be designed to respond principally to any component of motion but virtually all-commercial acoustic emission sensors are designed to respond to the component normal to the surface of the structure. Since shear and Rayleigh wave speeds typically have a component of motion normal to the surface, acoustic emission sensors can often detect the various waves.

Mostly acoustic emission sensing is based on the processing of signals with frequency contents in the range from 30kHz to about 2 MHz. In some special applications, detection of acoustic emission at frequencies below 20 kHz or near audio frequencies can improve testing and conventional microphones or accelerometers are sometimes used.

Acoustic emission sensing often requires a couplant between sensor and test material. The purpose of the couplant is to provide a good acoustic path from the test material to the sensor. A sensor hold-down force of several Newton is normally used to ensure good contact and to minimize the couplant thickness.

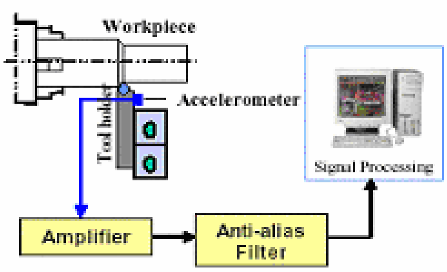

Fig 3. Experimental Set-up

Figure 3 shows the experimental set-up in this study. Both force/torque sensor and AE sensor were deployed in a PC-controlled turning Lathe machine. This report only discusses AE sensor and signal processing.

Figure 4 shows all the components, which are required for monitoring and control of a machine tool. Perhaps the most important element of the control system is the signal processing methodologies for feature extraction and decision-making.

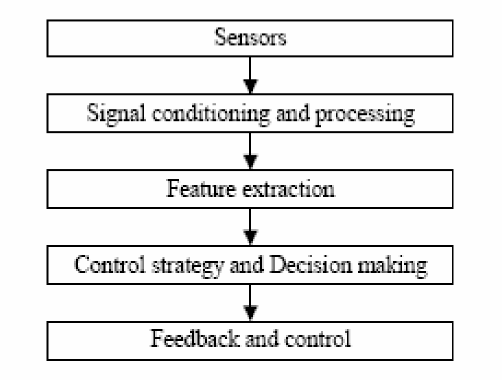

Fig 4. Components for monitoring

2.3 Advanced Signal Processing Techniques

Acoustic emission signals are sound waves generated in solid media, which are similar to the sound waves propagated in air and other fluids but are more complex. The signal is affected by characteristics of the source, the path taken from the source to the sensor, the sensor's characteristics, and the measuring system. Generally the AE signals are intricate and using them to characterize the source could be difficult. Information is extracted by methods ranging from simple waveform parameter measurements to artificial intelligence (pattern recognition) approaches. The former often suffices for simple tests. The latter may be required for on-line monitoring of complex systems. Interpretation of the signals generated during the process often required advanced signal processing.

Both time domain and frequency domain analysis have certain limitations. A more sophisticated approach to machining process monitoring is to analyse the time-frequency spectrum of the signal for patterns corresponding to the process characteristics of interest. The ability to detect these time-frequency characteristics is important, since the distribution of frequencies provides information about processing status. This approach has a potential advantage of insensitivity to signal intensity variations due to noise or other similar problems. By analysing the time-frequency spectrum of signals, a larger amount of information can be extracted than investigating frequency spectrum only. Wavelet analysis is one such time-frequency analysis method.

It is impossible to reduce both time and frequency localization arbitrarily. Wavelet analysis provides an interesting compromise on this problem. Applying windows with different sizes can change the resolution of time and frequency. Wavelet analysis allows the use of long intervals when more precise and low frequency information is needed, or the use of shorter intervals when high frequency information is needed.

Calculating wavelet coefficients at every possible scale is arduous and time consuming. If scales and positions are based on powers of two, the analysis will be much more efficient. The key point of wavelet analysis is to extract information from the original signal by decomposing it into a series of approximations and details distributed over different frequency bands. The characteristics of frequency domain and time domain are preserved simultaneously. Further processing is then carried out after selecting several decomposition sequences suitable for the given application. It is noticed that the frequency band of every level is decomposed into two equal sub-bands, the detail and the approximation. The result of wavelet translation is a series of decomposed signals belonging to different frequency bands.

3. RESULTS

Various experiments on turning operation have been conducted on CNC Lathe machine to acquire and analyse AE signals. Figure 5 shows AE signals for feed rates of 9.84 mm/min and 4.92 mm/min respectively. The spindle speed was 4000 rpm. Although the signal amplitudes are

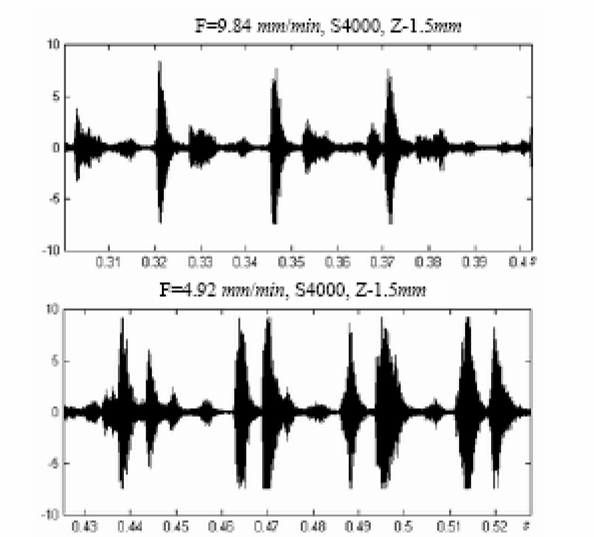

Fig 5. AE signals in different feed rate

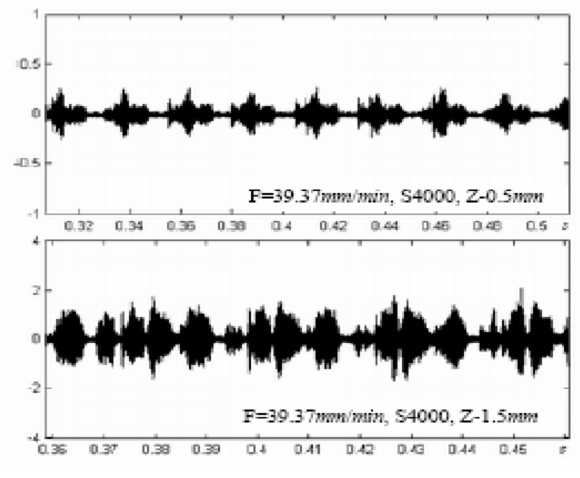

Fig 6. AE signals in different cutting depth

similar, the peak features are very different. At the higher feed rate, each cycle (rotation) has only one dominant peak, while at the lower feed rate, it has double distinct peaks. Figure 6 shows AE signals for different cutting depth 0.5 mm and 1.5 mm by keeping the feed rate as 39.37 mm/min.

4. CONCLUSIONS

From the above discussions, the following conclusions can be made:

To ensure the optimal performance of these complex systems, sensors are needed for process monitoring and feedback to controllers. It is necessary that these monitoring systems are reliable, relatively easy to apply, and that they yield an output closely correlated to the cutting conditions under surveillance.

It is possible to observe tool wear level related features both in AE time series and their RMS values. Particularly interesting are the statistical properties of the AE time series, in which power law characteristics have been identified. This behaviour has already been observed in the properties of acoustic emission signals in numerous other fields. The frequency distributions of the RMS values have also been studied as a function of wear, showing that even in this case it is possible to identify discriminating features.

Acoustic emission sensor for it is easy to install and good relationship to cutting condition can be used for effective in process monitoring of a machining process. Signals are accompanied with a lot of additional confusing data. In order to provide an accurate interpretation or feature extraction of the information produced an advanced signal processing and analysis is needed. Time-frequency domain analysis has yield encouraging results.

Process monitoring has evolved extensively over the years, with significant advances having been made in several areas. Despite these achievements, there are still areas that require continued work to further enhance the capability of the process monitoring. Among these are process modelling; open architecture/multi sensor fusion; signal processing/image processing and feature extraction.

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