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Study of Acoustic Emission Sensor Techniques for Monitoring Machining Processes

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Abstract: Condition monitoring of machining process denotes a control system that measures certain output variables, which are in turn used to control speed and or feed. The popular process variables that have been used to monitor the machining process are force, torque, cutting temperature, vibration amplitude and horsepower. However, this study deals with the application of the Acoustic Emission (AE) sensor for monitoring the machining processes. The application of this AE technique to machining processes started only two decades back and prior to that only very little work had been done in this field. Hence, a presentation has been made to highlight the works of various investigators from 1999-2005 using acoustic emission as a tool in monitoring machining process. The research done in monitoring machining processes using AE Techniques have been grouped into mainly 2 categories of monitoring Via, Turning, Milling and they are discussed accordingly. Some trails to take full advantage of the AE sensor for tool condition monitoring will be conducted relating to the sensor mounting and the signal processing. As a practical solution for the AE sensor mounting, for example, the coolant stream is successfully used as a medium for transmitting the AE wave in the case of milling processes monitoring. The sensor has mounted in the coolant pump nozzle l with other necessary drives so that the AE signal can be transmitted to the outside of the cutter by radio. By applying these methods, it has become possible to take the AE signal from the rotating tools. In terms of AE, signal processing for identifying an emerging technique for in process monitoring of various machining process.

Key words: Acoustic Emission Sensor (AE) sensor, condition monitoring, machining process

INTRODUCTION

The achievement of high production efficiency in automatic manufacturing operations is the major goals that had boosted the development in different kinds of monitoring facilities for machining processes. Since tool wears, tool chipping and tool breakage are the major factor influencing the quality of product manufacturing. The productions down time and consequently the production cost, the methods have been investigated for the monitoring these tool conditions (Byrne *et al*., 1995).

New demands are being placed on monitoring systems in the manufacturing environment because of recent developments and trends in machining technology (For example high-speed machining, hard cutting and dry cutting). The present monitoring system should become more reliable and flexible. Numerous different sensor types are available for monitoring aspects of the monitoring situation (Sukvitayawong *et al*., 1993). Among those sensor. AE sensor is considered one of the best tools for monitoring the machining processes. This study introduces some practical application for monitoring cutting with a single point as well as multipoint cutting tools. Major targets to be monitored and detected are tool wear, tool breakage, chatter vibration, chip tangling and the cutter life.

For the practical application of the AE sensor for monitoring the machining processes, the first problem to be solved is how to mount the sensor on the tools (it is most suitable to mount the sensor on the cutting tool to kept the distant 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. Two practical solutions to solve this problem will be introduced in the study. The second problem to be solved is to improve the reliability and the flexibility of the sensor system by applying some effective signal processing technologies (Dan *et al*., 1990).

THE BASICS OF THE ACOUSTIC EMISSION SIGNAL

Internally generated stress waves, liberated during dynamic processes in solid materials, can result in sudden irreversible release of elastic waves generally called Acoustic Emission (AE). In the present case, the principal

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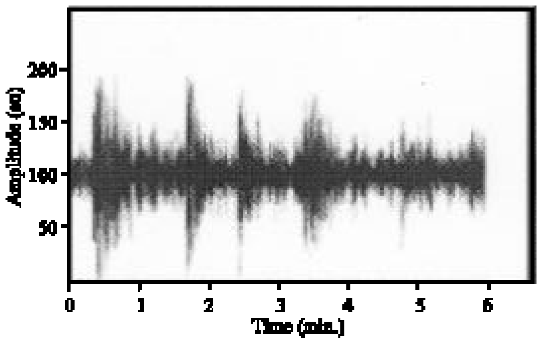

Fig. 1: Time series illustrating both continuous AE components and burst AE events

sources of these signals can be attributed to surface deformations (and possibly below the surface) as well as to detachments that take place at the interface between the machined sample and the work tool. In the analysis of AE signals generated during tool machining processes, two rather well distinct parts can be identified: A continuous emission and the burst emission exhibiting strong intermittence and relatively high amplitudes (Inasaki *et al*., 1998). These AE signal features are well shown in the time splice of Fig. 1.

The above discussion provides us with the possibilities of detecting some malfunctions in the cutting processes, such as chip tangling, chatter vibration and innovative breakage and identifying the tool wear state, which is essential for predicting the tool life by means of the AE sensor.

MONITORING OF THE TURNING PROCESS

It is well known that there are several different cutting states in the turning operation. In the case of the most desirable cutting state, the chip is broken in the proper length without generating chatter vibration and without forming a built up edge. Other cases, which are rather undesirable in practice, are cutting states with continuous chip, with chatter vibration or with built up edge. These undesirable cutting stages must be monitored and controlled to obtain the desirable one (Li *et al*., 1992).

The method to detect continuous chip formation and chatter vibration as the representative malfunctions in the turning operation and to monitoring the source of AE signals is introduced below Fig. 2. Identified the plastic deformation zones in the metal cutting process (primary, secondary and Tertiary deformation zone) and indicates the main location of the fracture mechanism (breakage of chips and the cutting edges) were burst type AE signals are generated.

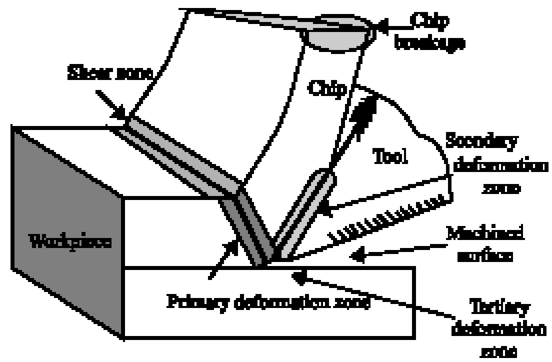

Fig. 2: Sources of acoustic emission signals

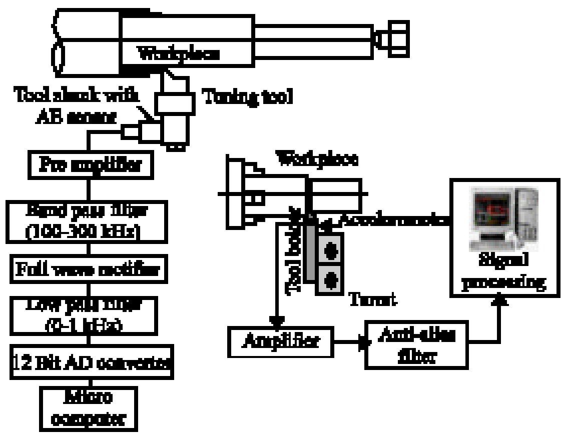

Fig. 3: Monitoring systems for the turning process

Set up for monitoring the turning process: In Figure 3 the general experimental set-up for the monitoring system for the AE sensor and refining the AE signals are seen.

The AE signals are generated in the cutting process, which will be refining and further analyzed, is detected with an AE sensor mounted inside the tool shank. Owing to the high sensitivity of the sensor, this is capable of detecting frequencies up to 1 MHz; several different sources of noise such as the mechanical vibration of the driving system are also detected. In order to reduce the influence of this low frequency vibration, a band pass filter with a range of 100-300 kHz is used.

Furthermore, due to the fact that the online digitizing capacity of a computer system for such a high frequency signal is not available, the signal is full-wave rectified and low-pass filtered. A low-pass-limiting frequency of 1 kHz determines the enveloped curve of the AE signals, which will be further analyzed. All the cutting experiments were conducted on an NC turning machine.

- A feed rate range of about 0.05-0.5 mm rev^{-1} and
- A Cutting speed ranges of about 200-400 m min^{-1} were applied for the cutting tests.

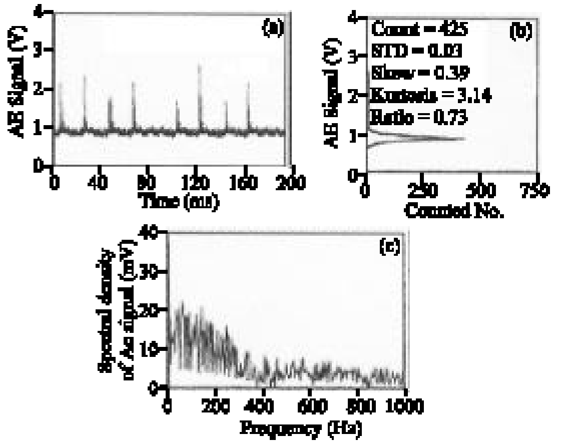

Fig. 4: AE signal sampled during cutting with discontinuous chip

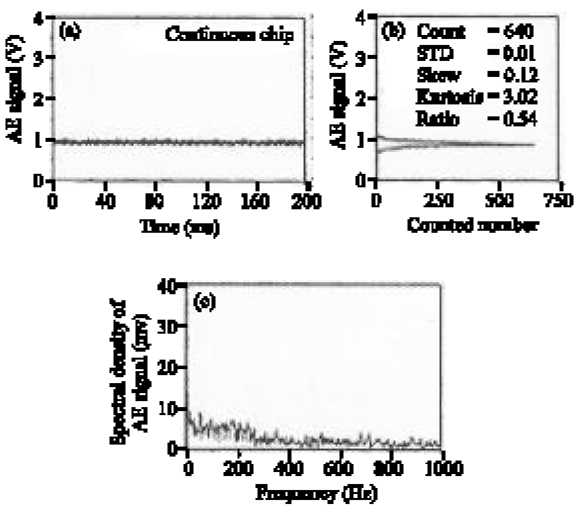

Fig. 5: AE signal samples during cutting with continuous chip

Chip form identification: In the turning operation, where the cutting tool is continuously removing material for long duration, a continuous chip can become entangled with the tool, workpiece or the machine tool elements. Therefore, chip breaking is the fundamental element of the chip control. If chips are broken into small, regular and handle able sizes, they can be disposed effectively. The sample of typical refined AE signals during cutting with the discontinuous and continuous chips and their distribution curves are shown in Fig. 4 and 5, respectively.

The burst-type signals sampled during cutting with the discontinuous chip increase the number of large amplitude effects in the distribution curves and deform the power spectrum in the range of 5-200 Hz in comparison with the AE signals sampled during cutting with the continuous chips.

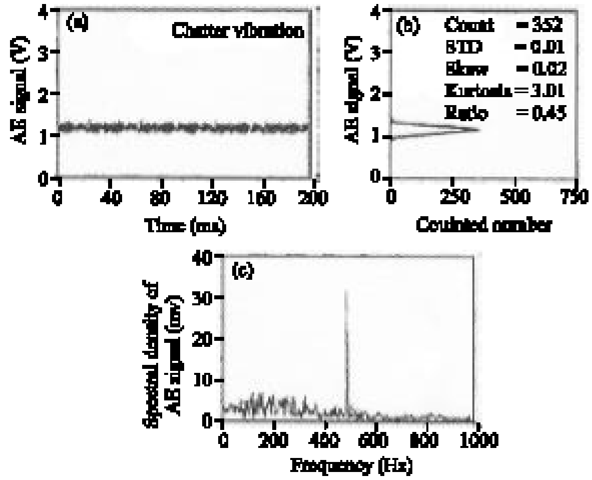

Fig. 6: AE signal sampled during cutting with chatter vibration

Thus, the standard deviation, the Skew, the Kurtosis, the counted number at mode value and the power spectrum ratio of 5-200 Hz to 200 Hz-1 kHz are applied to identify the chip from during cutting.

Chatter vibration detection: A machine tool has some rather serious stability problems that can be observed in the form of chatter vibration. Chatter vibration deteriorates the surface finish and reduces the tool as well as machine life. Therefore, in manufacturing system instability-like chatter vibration cannot be allowed to occur and needs to be controlled immediately.

Cutting with chatter vibration provides AE Signals in the time and frequency domains as shown in Fig. 6.

Just as in chip identification, the chatter vibration can occur at any frequency depending on the structure dynamics, it is necessary to hope with the change in the frequency. In order to detect chatter vibration under any cutting conditions with respect to the maximum value and consider as the input AE signals.

Tool condition monitoring: The AE mode value is proposed to identify the tool wear states. The reason why the mode is used is because this particular value only refers to the continuous-type AE signals as burst-type signals do not have any significant influence on the mode. Figure 7 shows the relationship between the normalized AE mode and the flank wear land.

The repeatability of the relationship is demonstrated by 5 cutting tests conducted under the same cutting conditions. Form a practical application point of view, however, it should be noted that the correlation between the flank wear and the AE mode is not high enough and

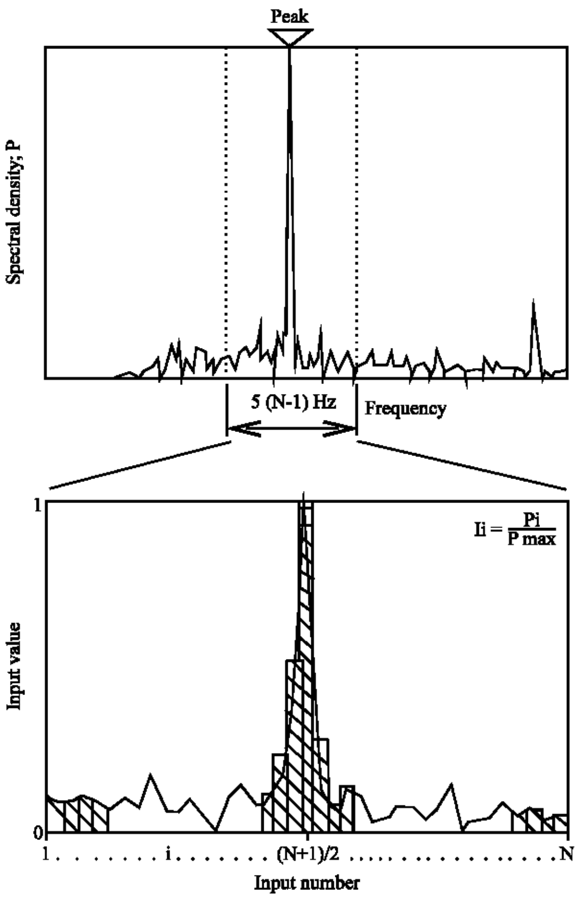

Fig. 7: Normalized AE power spectrum

further improvements appear to be necessary. In addition to the tool wear monitoring it is conceivable to detect the tool chipping or breakage, paying attention to the sudden change in the AE mode.

Monitoring the cutting process on multipoint cutting tools: It is somewhat easy to mount the AE sensor on the 'work piece side' (for example on the machine tool table or the pallet) for monitoring the milling as well as the drilling processes, which use multipoint rotating cutting tools.

However, this generates several difficulties. For example, the amplitude of signal detected with the sensors mounted on the machine tool table is not constant throughout the cutting process (Elbestawi *et al.*, 1991). This is because the distant between the cuttings point where the tool is engaged with the work piece and the sensor location varies because of the movement of the table and/or spindle head. In difference, the difficulty in detecting the signal from the rotating part stems from the problem of how to transmit the detected signal by radio (data lines).

As a direct result of the industry's need to detect AE signals associated with the machining process from the 'rotating tool side' some practical sensor coupling devices, which can cope with the problem relating to transmitting the signal by data, lines have been developed.

DATA ACCUSATION SYSTEM THROUGH CUTTING FLUIDS SYSTEM

There are some workable methods to transmit the sensor signal from the rotating spindle to the non-rotating part; for example, using radio (data lines) or optical methods. However, such techniques are still not economically feasible. Either the reliability of the system is not sufficient, or the necessary expensive system devices and change in the construction of the machine head does not make for practical usage in the machine shops.

As one of the practical solutions to meet the requirement in terms of the signal transmission, Fig. 8 illustrates the proposal to successfully utilize the cutting fluids as the medium for transmitting the AE signal (1). The AE sensor is attached to the cutting fluids' supply nozzle so that the AE signal generated at the cutting point. It can be transmitted through the fluids and consequently detected by the sensor.

Algorithms for detecting the tool failure: The detection of tool breakage or chipping and the determination of the cutting tool state that is problematic due to the use of multipoint cutting tools. A non-steady chip thickness throughout the cut and the fact that more than one cutting edge might be active at the same time requires a new monitoring algorithm (Hauptmann *et al.*, 1991).

By conducting a large number of cutting tests, it has been confirmed that the ratio of two characteristic peaks in the power spectrum of the refined AE signals changes due to tool chipping. Figure 9 displays two characteristic power spectra of enveloped AE signals associated with the milling process using a new tool and using a chipped tool. On the left, two characteristic peaks can be observed. The first peak, named P_s, is associated with the rotational speed of the spindle. A chosen spindle speed of 800-rpm creates a peak at a frequency of 13.75 Hz. The second characteristic peak P_c, has a high amplitude and corresponds to the rotational frequency of the spindle times the number of cutting edges.

For this cutting test, an end mill cutter with four cutting edges was selected. This leads to characteristic peak frequency at 55.5 Hz. These marked frequency peaks provide the basis for the calculation of a chipping coefficient (k)

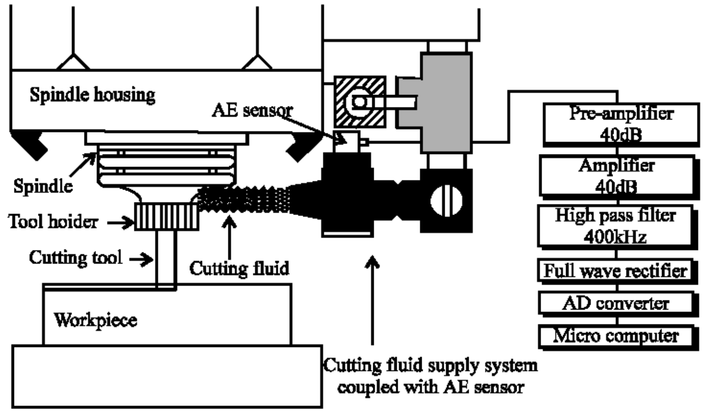

Fig. 8: The proposal for transmitting the AE signal (1)

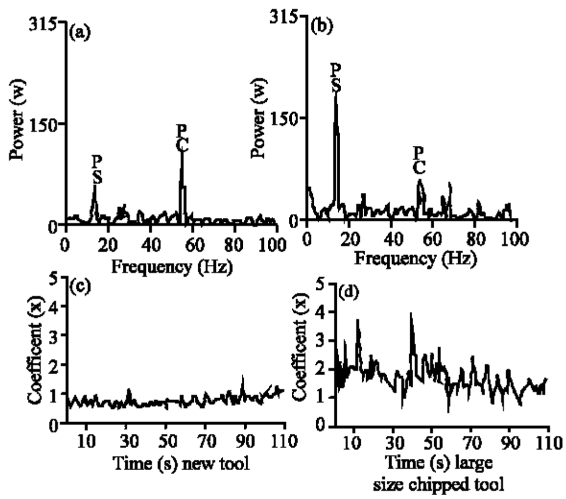

Fig. 9: Characteristic power spectrum and typical behaviour of coefficient k for a new tool and for a chipped tool

$$\text{Chipping coefficient} \quad k = P_s / P_c$$

The power spectrum obtained through cutting with a chipped tool shows a significantly different pattern compared with the first case, although the two characteristic peaks P_s and P_c are still visible. The amplitude of these marked peaks changes with the tool chips shown in Fig. 9.

While defining the amplitude ratio of the marked peaks as a chipping coefficient 'k', a change in the amplitudes reflects an increase coefficient. This makes the coefficient 'k' a representative parameter describing the state of the multi point cutting tools. The change in the amplitude of the characteristic peaks in the power spectrum is considered to be due to a change in the cutting situation. An increased chip thickness for the engaged cutting blade that follows the already chipped cutting on the end mill cutter is through to be the reason for the change in the amplitude of the marked peaks. Any thing in excess of the chosen threshold value of the coefficient 'k' allows for reliable identification of the end mill cutter.

CONCLUSION

Application examples of the AE sensor for monitoring the machining processes were introduced taking as examples turning and milling. This particular sensor is quite effective in monitoring these machining processes and detecting some malfunction. However, it is also true that the AE sensor is too sensitive to the process state that and consequently and further improvements are necessary to make the monitoring system utilizing this sensor a more reliable one. One of the talented ways to take full advantage of high sensitivity of the AE sensor is the combination with other type of sensors such as the force sensor.

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