World Engineering Congress 2010, 2nd – 5th August 2010, Kuching, Sarawak, Malaysia
Conference on Manufacturing Technology and Management

CETE91
TOOL CONDITION MONITORING USING AE SIGNAL IN TURNING OF ASSAB-705 STEEL

Choudhury, I.A[1], Lee, C.Y, Bhuiyan, M.S.H, and Nukman, Y.
Department of Engineering Design and Manufacture, Faculty of Engineering
University of Malaya, 50603 Kuala Lumpur, Malaysia.
[1]Email: imtiaz@um.edu.my

ABSTRACT

The progressive wear of cutting tools and other occurrences involved with chatter vibration often pose limiting factors on the achievable productivity in machining processes. An effective in-process monitoring system for tool condition therefore offers the unique advantage of relaxing the process parameter constraints and optimizing the machining production rate. This paper briefly presents a monitoring technique using acoustic emission (AE) signal in turning. An interpretation method of the AE signal using FFT is explored and attributed the signal to the tool condition .The tool wear; the chipping and the tool breakdown all have their own effect on acoustic emission (AE) signal generated during turning. The AE generated from the sources is investigated based on the energy dissipation principle. Cutting tests were conducted to determine the amplitude relationship between RMS AE and tool condition using FFT. The result shows that in gradual tool wear, the dominating frequency range lies between 20 Hz – 260 Hz for the tool-work-material combination used. It is shown that the FFT is capable to describe the AE signal and it deserves to extract features of the signals.

Key words: *Acoustic emission, Fourier transform, Tool condition monitoring.*

INTRODUCTION

Tool condition monitoring using AE sensor is still not a professed technique. But the application of AE in other applied field is widely accredited. The acoustic emission (AE) is the transient elastic wave generated by the rapid release of energy from a localized source or sources within a material. The AE sources belong to the state of stress inside the material, and the energy release is associated with the abrupt redistribution of internal stresses. During the AE process a stress wave is propagated through the material. The stresses are originated from the material internal structural change, such as dislocation motion, directional diffusion, creep, grain boundary sliding and twinning. The results of this effect appeared as plastic deformation, phase transformations, vacancy coalescence and decohesion of inclusions and fracture which are sources of acoustic emission. But only the plastic deformation and fracture have major significance in metal cutting [1].

All the modern techniques that are using in the industry are working in the same purpose to retrench the cost of product as well as to develop the product quality. Now a days the manufacturing industries have started to use the process monitoring system to increase the production rate and to conforming the accuracy of product.

Tool condition monitoring is essential in machining to anticipate any kind of unexpected occurrences. On the other hand the achievement of high production efficiency in automatic manufacturing operations is the major goal which had boosted the development in different kinds of monitoring facilities for machining processes. Numerous different phenomena can be employed for this purpose and a variety of sensor types are available in the market such as optical, laser, electric, magnetic, acoustic emission etc. Where-as the optical and laser system are quite difficult to use in such a clumsy environment, the electric and magnetic systems always need conductive and magnetic material respectively, the AE system have no such complexity. The AE is generated due to fundamental process events, like shear at various zones, chip friction, chip collision and breakage, and tool wear and breakage. Due to a strong dependency of AE on process variables, it is used to keep tool under surveillance during the machining. The major advantage of using AE to monitor tool condition is that the frequency range of the AE signal is much higher than that of the machine vibrations and environmental noises, and does not interfere with the cutting operation [2].

To make the tool condition quantifiable using AE, need to pre and post process the signal. Three basic steps are associated with the AE monitoring system namely;
a) AE signal acquisition,
b) Signal Preprocessing, and
c) Signal post processing/signal analyzing.

AE signal acquisition system performs a vital role in tool condition monitoring. The signal accuracy depends on the process, how the signals are collected. The system boundary conditions, using equipments, their placement and orientation have an unavoidable effect on the signals. The AE sensor and other evaluating elements usually deal with the signal ranging from 30 kHz to 2MHz.

Figure 1 shows a typical AE signal acquisition system in metal cutting. During working with any acoustic emission (AE) based tool condition monitoring (TCM) system, three basic elements should be considered, regarding their compatibility: the AE signal itself, a sensor and a pre-amplifier. Reliability of the AE system vigorously depends on how these elements match each other [3].

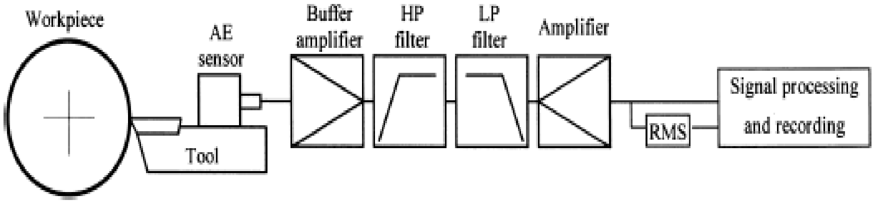


Figure 1: A typical AE signal acquisition system in metal cutting process [3]

As raw AE signal (AE_{raw}) has a very high frequency, its recording and analysis in the original form is quite hard and expensive. Hence, usually root mean square value (AERMS) or some other demodulated form is applied. Signals rectified in this way have much lower frequency, so they are much easier to handle and in most cases being useful enough. If the raw signal has been deformed, this deformation can be completely concealed by demodulation and leads to deceptive conclusions.

In raw AE signal (AE_{raw}) there always have an existence of dominant low frequency component. This is caused by some mechanical disturbances, and consequently should be filtered out as irrelevant to tool wear. Of course in the AERMS signal low and high frequency components cannot be distinguished, making need for the filtering even more imperative [4].

Signal analyzing is crucially inevitable to get information from the AE signals. 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. [5]. Continuous type signals are associated with plastic deformation in ductile materials and the burst type AE signals originate from several sources, such as tool breakage, extension of micro-cracks in tool inserts, chip fracture, collision between the chip and the work-piece, etc. Additionally, chip impacts or chip tangling also generates burst-type AE signals [6].The magnitude of burst AE signals is often much larger than that of continuous AE signals [7, 8].

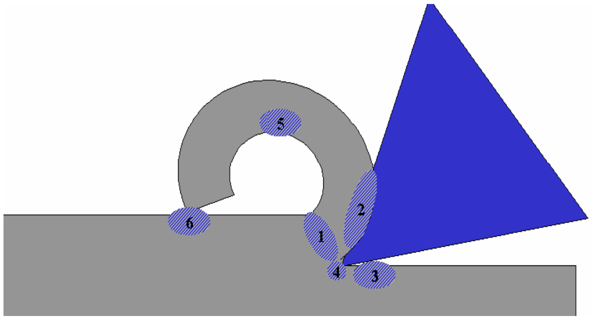


Figure 2: Main sources of AE stress waves associated with chip formation: 1) primary shear zone, 2) secondary shear zone and craterization by friction, 3) tertiary shear zone and flank wear by friction, 4) crack growth by tool tip-workpiece contact, 5) chip plastic deformation, and 6) chip-tool collision [9]

Figure 2 shows the main sources of AE during cutting processes [9].The signals originating from the cutting zone can be very strong. Because of the characteristics of pre-processing units, such high amplitude signals sometimes cause overloading of the preamplifier and distortion of the signal. This can often result in a misleading evaluation of the signals [6].

The major concern of AE signal processing is detecting and characterizing the bursts that evidence the abrupt emissions of elastic energy produced inside the material, estimating their time localizations, oscillation frequencies, amplitudes and phases and, possibly, describing appropriately their overlapping structure. Various methods are involved for signal processing/analyzing to make the signal apprehensible. These methods play the master role to know about the tool conditions. Three major methods are involved: Continuous Transformation, Discrete Transformation and Statistical analysis. The continuous transformation is good in describing the tool wear, where-as the discrete transformation has significance in tool breakdown and chipping. On the other hand the statistical distribution is obtained by making a plot of the frequency where the different amplitudes of the signal are given. This is an amplitude distribution method. The most comprehensive methods for signal analyzing are Fourier Transformation, Wavelet Transformation, and Statistical analysis.

Fourier transformation: A physical signal is usually represented by a time function *f (t)* or, alternatively, in the frequency domain by its Fourier Transform (FT), *F (ω)*. Assuming an energy-limited and non-periodic signal *f (t)*, this can be decomposed by its Fourier Transform *F (ω)*, namely:

(1)

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)e^{i\omega t}d\omega \qquad (1)$$

and

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t}dt \qquad (2)$$

where t is time and ω is angular frequency. Both functions, known as Fourier Transform (FT) pair, contain exactly the same information about the signal, but from different and complementary focuses.

But the problem is that this type of functions is adequate to represent stationary and $e^{i\omega t}$ harmonic waves. Then, taking into account that AE signals are essentially non-stationary, it is possible to affirm that, in general, the FT pair does not represent this kind of signals correctly. However, some studies have been carried out successfully using FT for the processing of AE signals from cutting tools with different wear levels [9].

Wavelet transformation: By analyzing 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. By using the wavelet function the localization complexity of the Fourier Transform can be driven out. 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. The modulated window functions with variable dimension are adjusted to the oscillation frequency, in particular windows with the same number of oscillations in its domain.

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 [7]. This is achieved by generating a complete family of elementary functions by dilations or contractions and shifts in time, from a unique modulated window:

$$\psi(t) \Rightarrow \psi_{a,b} = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right) \qquad (3)$$

The wavelet functions are characterized into two. Some are attributed for the continuous signal where-as others are for discrete [7]. Continuous Wavelet Transform can be defined by:

$$W_{\psi}s(a,b) = \int_{-\infty}^{\infty} s(t)\psi_{a,b}(t)dt \qquad (4)$$

Assuming a real mother wavelet and a limited energy signals (t), the Wavelet Discrete Transform is defined by:

$$DW_{\psi}s(j,k) =< s,\psi_{jk} >= \int_{-\infty}^{\infty} s(t)\psi_{jk}(t)dt \qquad j,k \in Z \qquad (5)$$

Statistical analysis: The amplitude distribution method is one statistical analysis based technique. It tries to recognize differences among signals through the study of the distribution of amplitudes. The most comprehensive classification of the distribution shape can be achieved by means of the central moments of the distribution function. In particular, by the third and fourth central moments called skew and kurtosis respectively and given by:

— (6)

and

— (7)

where *f* is the function of the probability density of variable *x* and σ the standard deviation.
The skew measures the symmetry of the distribution about its mean value while the kurtosis represents a measure of the sharpness of the peaks. A positive value of the skew generally indicates a shift of the bulk of the distribution to the right of the mean, and a negative one, a shift to the left. A high kurtosis value implies a sharp distribution peak, i.e. a concentration in a small area, while a low *kurtosis* value indicates essentially flat characteristics [10].

In this study, an AE monitoring system is developed to sense tool condition in turning. The objectives of this work are twofold. Firstly, to develop a real-time AE monitoring system for machining-induced the signal analysis; secondly, to establish a correlation between AE feature signals and tool wear. The findings will provide fundamental information to develop practical AE monitoring system for tool condition in turning.

MATERIALS AND METHOD

A piezoelectric AE sensor Type: KISTLER 8152B for sensing the change corresponding to the condition of the tool insert has been used. The sensor has a frequency range from 50 to 400kHz.This has been placed as close as possible to the cutting zone, e.g. on the tool shank. Because of high impedance of the sensor it must be directly connected to a coupler which contains a buffer amplifier. The coupler type which we have used in experiment is KISTLER5125B. The coupler allows the signal to next for band-pass HP: 50 kHz and for band-pass LP: 1000 kHz. The necessary modification of the raw signal is undertaken over here. Low frequency noise components, which are inevitably present in AE signal, are considered to be not correlated with tool's condition and hence useless. Besides, they can be of high amplitude forcing usage of lower signal amplification. This results in lower amplification of useful band of the signal. Therefore, those components should be eliminated (high-pass filtered) at the earliest possible stage of signal processing to enable usage of full amplitude range of the equipment. Usually the signal we have got from the coupler output is in RMS form. Sometimes, the AE signal is then fed through a low-pass filter to get rid of the high frequency noise components due to electric sparks, etc. or to avoid aliasing. The filtered AE signal is a subject to further processing and/or recording. The raw AE signal can be demodulated in the form of the mean value or RMS to obtain a low frequency variable, so it can be recorded or processed with the conventional, less expensive signal processing equipment. Finally the signal come out from the coupler is further fed to DEWE-43 preprocessor. Inside this the input signal are re-filtered, alias filtered with 250 kHz band-pass filter, amplified and then digitized before storing for analyzing.

The process of signal transmission from source to storage

The AE signal initiated when the tool-insert is subjected to force. Due to this force deformation of adjacent layer is takes place inside the tool-insert material. These deformations act as source of AE and relies energy in elastic wave form. The process of AE signal transmission is shown below:

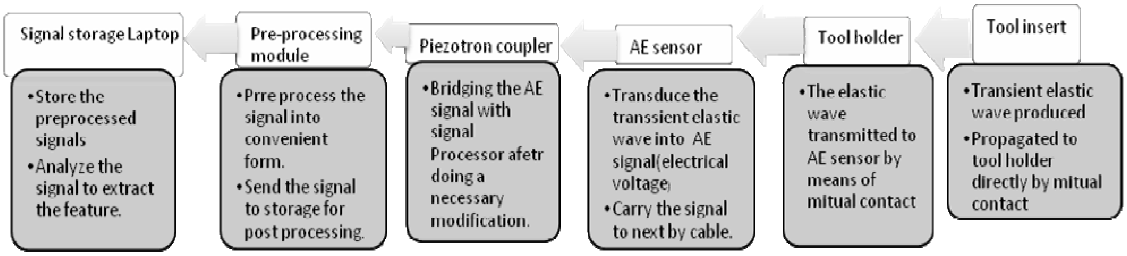


Figure 3: The AE signal transmission system

Experimental details: The turning operation has been performed on a COLCHESTER VS MASTER3250 6.1/2"×50"(165mm×1270mm) Gap bed Center Lathe. The work-piece that used was a round bar (92.22mm) of

ASSAB-705 is a medium carbon steel (hardnessHB270-310).The SANDVIK gold coated carbide, type: TNMG 16 04 08-PM tool insert was used for the experiment. No coolant was used during the process. The cutting conditions are crucially emphasis on tool and work-piece health. The conditions under which the experiment was conducted are tabulated below in the table: 1

Table 1: Cutting conditions

Cutting speed (m/min)	Cutting feed (mm/rev)	Depth of cut (mm)
170	0.28	2

RESULT AND DISCUSSION

The raw signal is very rough squiggle and stochastic. It contained a lot of message within this. Just seeing the signal it is quite difficult to presume the tool status and about the entire occurrence those are taking places. The very raw signal consists of a wide range of frequency, which is inconvenient to manipulate and the equipments for this are not available. This is expensive also. So the raw signals are modulated into root mean square (RMS) form for the next processing.

The raw signal in figure 4 showing the over-all status of the system, but do not represent the tool condition exclusively. The signals emitted from all sources are exist in the same signal. Seeing this signal one can't distinguish which pattern of signal belongs to which occurrence. After have a look on the signal it can say that the low and continuous frequencies belong to tool wear whereas the burst and discrete are from chipping. For tool breakage the burst signals amplitude will be higher and immediately there have no existence of signal for a short interval. The signal may generate from chipping, wearing, tool-breakage and also from any other abnormal happening. But of course their amplitude and frequency will be different whereas all are incorporated in one raw signal. So to make the signal apprehensible it need to break into different frequency and spectrum according to their sources. Using FFT and CPB (narrow band Fourier Transform) it is possible to breakdown the raw signals into different frequency band. From different frequency band it is easy to trace the dominating frequency and its intensity in the raw signal as well as to correlate the signal with the tool condition.

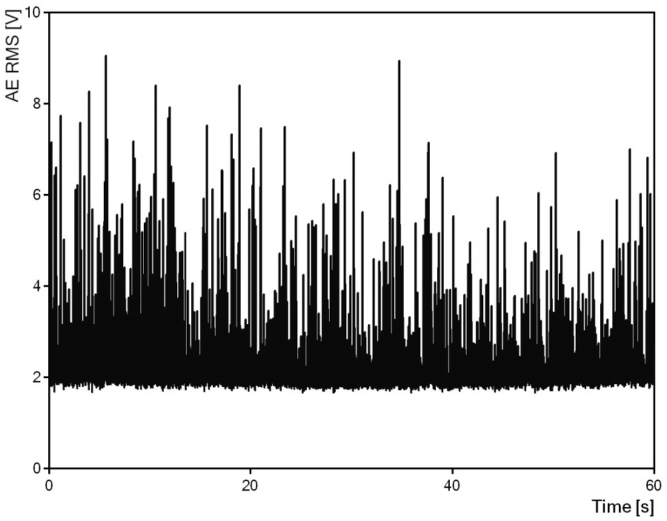
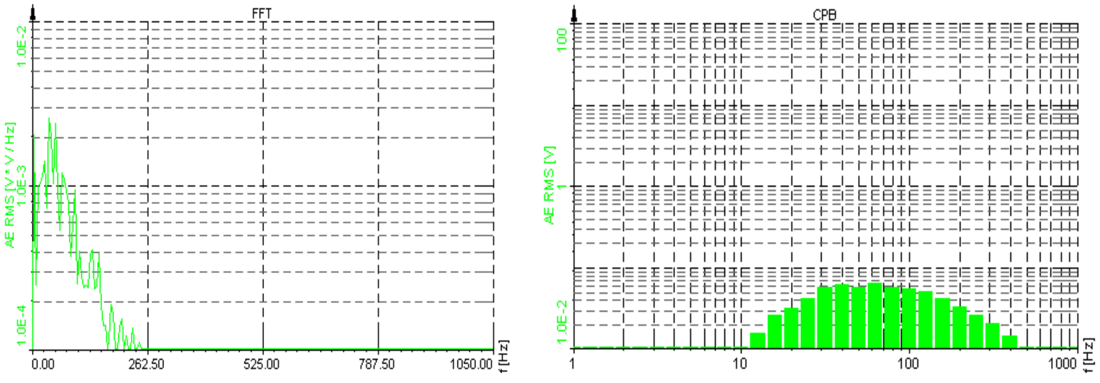


Figure 4: The AERMS signal got from the experiment

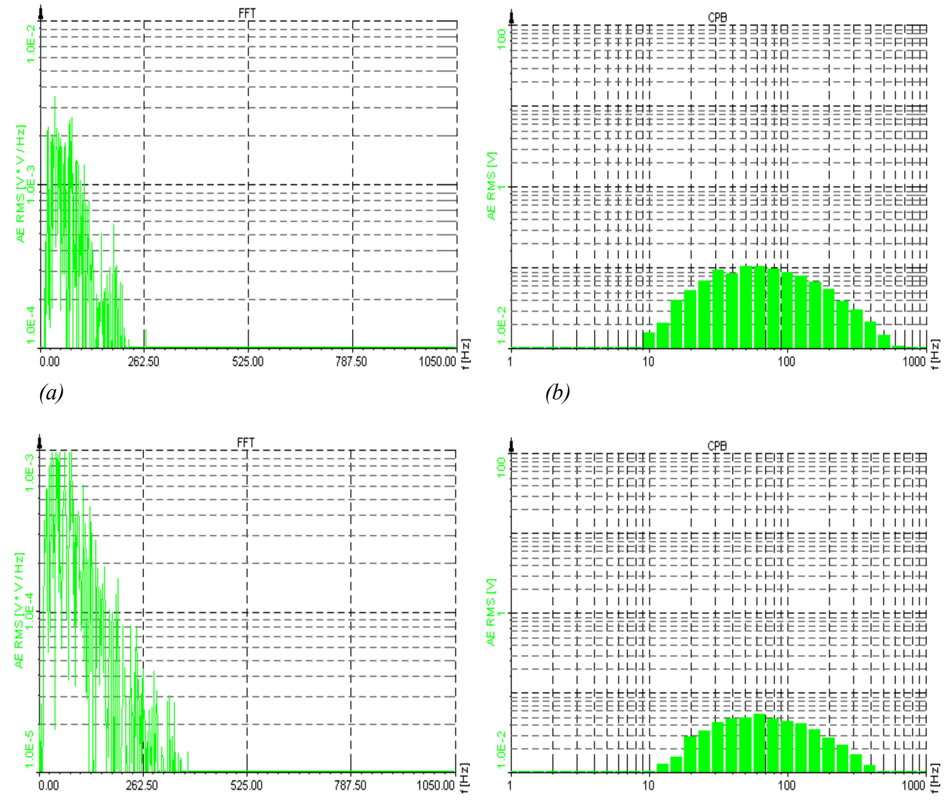
From figure 5 (a) and (b) it is seen that the low frequencies is about 20 Hz to 260 Hz have a high intensity. That means the low frequencies are dominating more than the high frequencies in the process whereas the low frequencies are usually originated from tool wear. The chipping emits a little bit higher amplitude of signal which is also included in this signal.



(a) *(b)*

Figure 5: (a) and (b) represent the FFT and CPB of raw signal at 1st second respectively

From the figure 6 (a) and (b), it is seen that at 300th second the low frequencies intensity has slightly decreased, that means the tool wear and chipping have uniformly progressed but rather slowly than that at the initial stage. But from figure (c) and (d), the 2500th second signal show a more high intensity of low frequencies which indicate more wear progression in this stage. After measuring the tool wear at every stage and then plotting all corresponding to different tool wear the graph below is found which represents the status of the tool wear. From the flank wear versus cutting time graph shown in figure 7, it is noticed that the tool wear at initial stage is rapid whereas at the middle stage it becomes steady. At the last stage the wear is rapid again.



(a) *(b)*

(c) *(d)*

Figure 6: (a), (b) are for 300th sec and (c), (d) are for 2500th sec FFT and CPB representation respectively

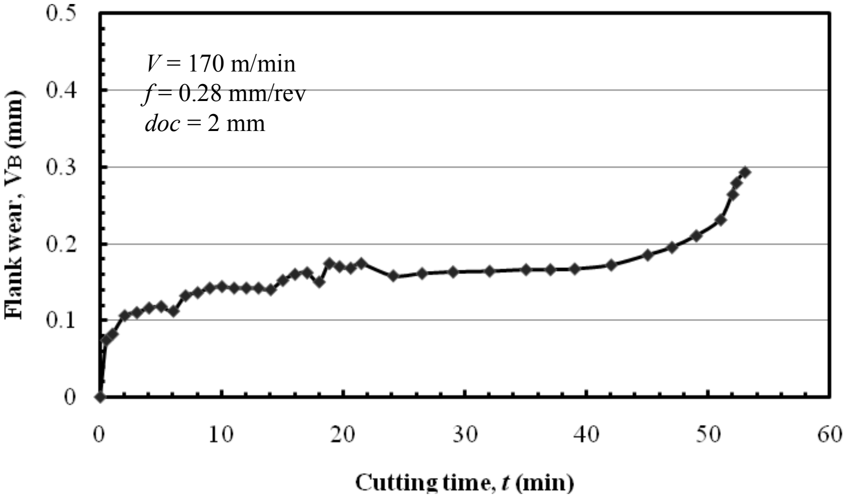


Figure 1: The flank wear vs cutting time graph

CONCLUSION

The excellence of the AE in tool condition monitoring is uncontroversial. From this study it is found that it is possible to obtain information on tool conditions after analyzing the raw signals using AERMS and FFT, both capable of showing some discriminating feature. But for knowing the complete status of the tool need to localize the signal. If it possible to identify the compositions of frequency that, which signal belongs to which occurrence, then monitoring will become more informative and reliable also. This particular investigation shows that in the dominating frequency band of 20 – 260 Hz, wear progression is steady and for a sudden fracture, the signal is lost momentarily and then frequency was observed to jump.

ACKNOWLEDGEMENT

The authors would like to thank UMRG, University of Malaya for providing the funds to carry out this study.

REFERENCE

[1]. Ravindra, H.V, Srinivasa, V.G, and Krishnamurthy, R (1997) Acoustic emission for tool condition monitoring in metal cutting, Wear 212 (1997) 78-84, Elsevier Science S.A.

[2]. Li, X (2002) A brief review: acoustic emission method for tool wear monitoring during turning, International Journal of Machine Tools & Manufacture, International Journal of Machine Tools & Manufacture 42 (2002) 157–165.

[3]. Jemielniak, K (2001) Some aspects of acoustic emission signal pre-processing, Journal of Materials Processing Technology 109 (2001) 242±247

[4]. Jemielniak, K (2000) Some aspects of AE application in tool condition monitoring, Ultrasonics 38 (2000) 604–608

[5]. Pontuale, G, Farrelly, F.A, Petri, A, Pitolli, L and Krogh, F Properties of Acoustic Emission Signals for Tool Condition Monitoring (TCM) Applications.

[6]. Inasaki, I (1998) Application of acoustic emission sensor for monitoring machining process, Ultrasonics 36 (1998) 273-281.

[7]. Xavier, J.F, and Sampathkuma , S (2005) Condition Monitoring Of Turning Process Using AE Sensor, Proceedings of the International Conference on Mechanical Engineering 2005 (ICME2005) 28- 30 December 2005, Dhaka, Bangladesh.

[8]. Haili, W, Hua, S, Ming, C and Dejin, H (2003) On-line tool breakage monitoring in turning, Journal of Materials Processing Technology, Journal of Materials Processing Technology 139 (2003) 237–242.

[9]. Rubio, E.M, Tetib, R and Baciu , I.L Advanced signal processing in acoustic emission monitoring systems for machining technology.

[10]. Kamarthi , S, Kumara, S, and Cohen, P (1995) Wavelet representation of acoustic emission in turning process. Intelligent Engineering Systems of Artificial Neural Networks.

NOMENCLATURE

$F(\omega)$	Fourier Transform function
$W\psi s(a, b)$	Continuous Wavelet Transform function
$DW\psi s(a, b)$	Discrete Wavelet Transform function
S	Skew
K	Kurtosis
FFT	Fast Fourier Transform
CPB	Constant Percentage Bandwidth