# Tool Condition Monitoring using Acoustic Emission and Vibration Signature in Turning

M. S. H. Bhuiyan, I. A. Choudhury, and Y. Nukman

***Abstract*** **- The various sensors used to monitor tool condition usually sense the cutting tool state in terms of electric/magnetic/optical signal by responding to the change of process dynamics during machining. The redistribution of energy that is released from the localized sources, i.e. stress and strain developed in machining, generates the transient elastic wave inside the workmaterial and cutting tool known as, the acoustic emission (*AE*). The changes in cutting condition produce vibration in the system and thus affect the cutting tool state. Therefore, investigating the tool condition using the acoustic emission and vibration signature would be an effective approach. In this study, an acoustic emission sensor and a tri-axial accelerometer have been placed on the shank of the cutting tool holder to monitor the cutting tool condition in machining. The acoustic emission sensor assesses the internal change whereas the vibration sensor demonstrates the external effect on tool state. The RMS signals and Fast Fourier transform (FFT) are used to illustrate the output of sensors. For this particular investigation, the experiment shows that the AE and vibration components can effectively respond to the tool state and the different occurrences in turning. The $AE_{RMS}$ represents the rate of tool wear progression whereas the feed directional vibration component ($V_X$) corresponds to the surface roughness in turning. The vibration components, $V_x$, $V_y$ and $V_z$ change with feed rate, depth of cut and cutting speed respectively. The amplitude of vibration components decreases with the increase of cutting speed, and increases with the increase of feed rate and depth of cut; which support the nature of tool wear in turning. Even though the maximum intensity of signal frequency fluctuates at the different state of tool wear and at different cutting conditions, the frequency of vibration components always lies within a band of 0 Hz - 41 kHz, and the AE varies between 56 kHz and 581 kHz.**

***Key words*** **- Acoustic emission, Vibration, Tool condition monitoring, Tool wear, Surface roughness.**

## I. INTRODUCTION

THE cutting process dynamics is very transient and unpredictable whereas the cutting conditions have strong influence on the process stability.

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The change in cutting condition alters the process dynamics and thus affects the cutting tool condition and process stability. Although the primary effect appears as vibration, the ultimate effect comes up as cutting tool wear, impairs the machine tools, and in extreme cases, the tool essentially fails. In machining operations, the machine tool, cutting tool, workpiece and cutting conditions establish a vibratory system having a complex dynamic behavior [1]. Monitoring the abnormalities in machining could be categorized into two types, i.e. abnormal state occurring during cutting and the trouble of the machine tools itself [2]. However, both of them disturb the machining process stability and the cutting tool condition. As the material mechanics would change by the direct interaction between workmaterial and the cutting tool during operation, the effect therefore could be investigated using the acoustic emission (*AE*) sensor. Dornfeld (1989) pointed out the possible AE sources referring to stress waves generated by the sudden release of energy in deforming material during metal cutting are: (*a*) plastic deformation of the workpiece during cutting process, (*b*) sharing of the chip, (*c*) frictional contact between the tool flank face and the workpiece resulting in flank wear, (*d*) frictional contact between the tool rake face and the chip resulting in crater wear, (*e*) collisions between chip and tool, (*f*) chip breakage, and (*g*) tool fracture [3]. The AE sources given in (*a*) to (*d*) generate continuous AE signals, while sources from (*e*) to (*g*) generate transient AE signals [4]. It is generally agreed that the continuous-type AE signals are associated with plastic deformations of workmaterial and tool wear during metal cutting, while the burst- type signals are observed during crack growth inside the material. Additionally, tool fracture, chip breaking, chip impacts or chip tangling generate a burst-type AE signals [5-7]. Despite, the AE signal being complex and stochastic in nature, it is more reliable and accurate because of its high-frequency content, and being unaffected by the surrounding noise. Besides the vibration signals are considerably less complex in nature, more comprehensive, and convenient to analyze. Vibrations are produced by cyclic variations in the dynamic components of the cutting forces. Usually, these vibratory motions start as small chatter responsible for the serrations on the finished surface and chip thickness irregularities; progress to what affects the stability of the process. 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 [8]. Mechanical vibrations result from the tool wear and the cutting conditions are generally periodic in nature; the tool breakage, process interruptions and other events involved with the machining are the ultimate causes of random vibratory motion in turning. The AE sensors are used to capture higher-frequency signals resulting from material deformation, fracture, and chip breakage [9], whereas the accelerometer (vibration measuring sensor) is used to pick up comparatively the low frequency producing occurrences in machining. Therefore, the combined application of AE and accelerometer could sense the occurrences in machining even more completely, both from the internal and external sources.

This works has been carried out to develop a more promising tool condition monitoring system using the acoustic emission and vibration phenomena. An acoustic emission and a tri-axial accelerometer have been used to measure the acoustic emission, and the vibration generated from the metal cutting. The measured AE and vibration signal are time domain signal; FFT is used to convert the captured time domain signal into the frequency domain. The raw signals and their frequency analysis has been used to correlate the sensor's output with entire occurrences and with the tool condition.

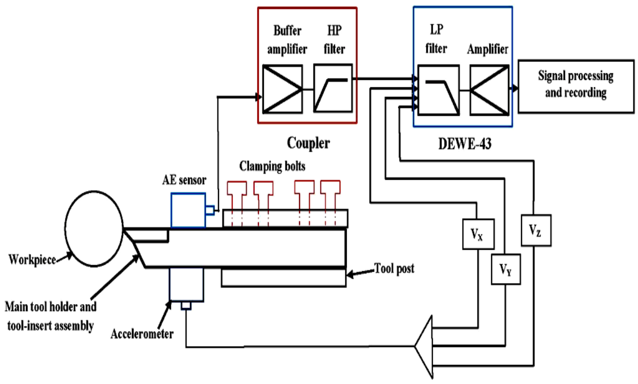


Fig 1: Experimental setup to capture the acoustic emission and vibration signal from the cutting tool in turning.

## II. MATERIALS AND METHOD

The turning operation is performed on a COLCHESTER VS MASTER3250, 165 mm × 1270 mm Gap bed Center Lathe. The work-piece is a round bar (92 mm diameter and 760 mm long) of ASSAB-705, medium carbon steel (hardness HB270-310). The TiN coated carbide, type: TNMG160408N-GU tool insert and PTGNR 2020K-16 tool holder assembly are used as cutting tool arrangement. The experiment has been conducted in dry cutting mode for this investigation. The AE and vibration signals have been recorded at various stages of cutting until failure of the tool. The procedure of AE and vibration signal acquisition from the tool holder during metal cutting follows the pattern schematically illustrated in Fig 1.

A KISTLER 8152B AE-piezoelectric sensor and a KISTLER 8762A50 tri-axial accelerometer have been mounted on top and bottom of the tool holder shank, and are placed as close as possible to the tool-insert. The AE sensor has a frequency range from 50 kHz to 1 MHz whereas the frequency range of accelerometer is 1 Hz to 50 kHz. A KISTLER-5125B type coupler and a DEWE-43 module are used to pass the signal through. The coupler and DEWE-43 module jointly acted as a band-pass filter which has a low cutoff frequency of 50 kHz and a high cutoff frequency of 1000 kHz. The AE signals pass through both the modules: the Coupler and DEWE-43 in series whereas, the vibration signals pass only into the DEWE-43 module before storage. The necessary modification of the raw signal is undertaken inside these modules. The filtered AE and vibration signals are then amplified and digitized before storing for further processing.

## III. RESULT AND DISCUSSION

The AE and RMS vibration signals of Fig 2 have been captured at cutting speed of 215 m/min, feed rate of 0.20 mm/rev and depth of cut of 0.5 mm. From Fig 2a, two types of signal patterns are obvious: the continuous type low amplitude pattern and discrete type burst pattern. The continuous type low amplitude patterns are from the plastic deformation of workmaterial and tool wear whereas the burst patters represent the chip formation, chip breakage, tool fracture and so on. From Fig 2b, the vibration components, $V_x$ represents the vibration along the feed; $V_y$ shows the radial vibration, and $V_z$ represents the tangential (along main cutting force) vibration of cutting tool in turning. The low amplitude signals of Fig 2b are most possibly generated from components of machine tool and the vibration of machine itself; whereas, the different occurrences in turning are the sources of high-amplitude signals. The change in surface roughness, the variation in cutting conditions, change in the level of tool wear, types of chip formation, tool-chip collision during removal and the disturbance in smooth progression of the process, etc. are the major causes of high-amplitude frequencies of AE signal produced in turning.

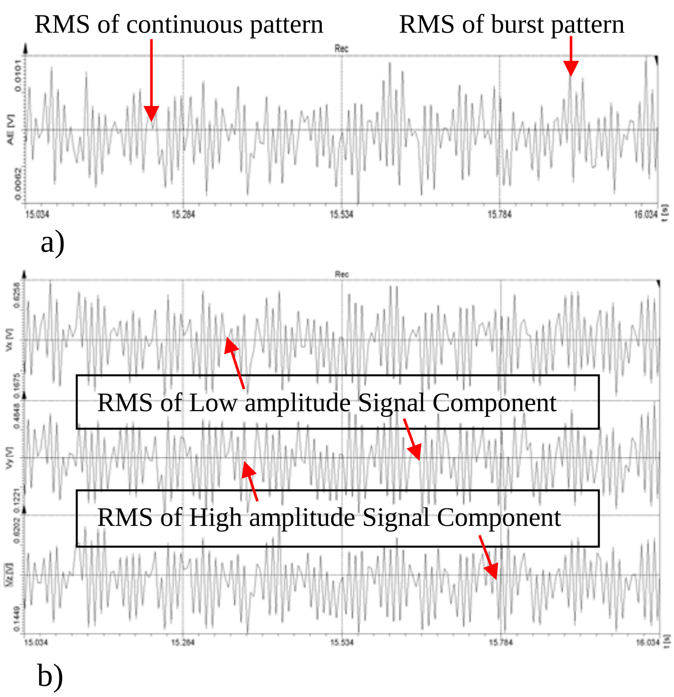


Fig 2: a) RMS AE signal captured in turning and b) RMS Vibration signal (three-dimensional) signal at the same instance of time.

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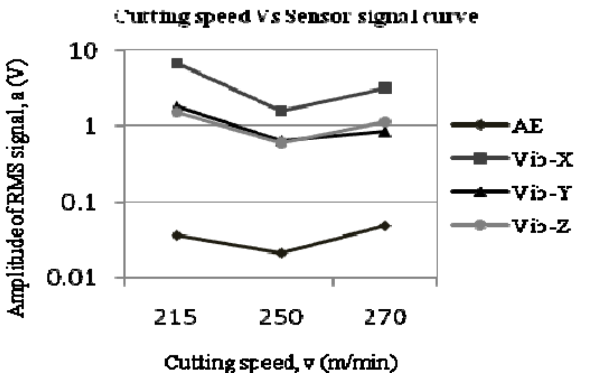
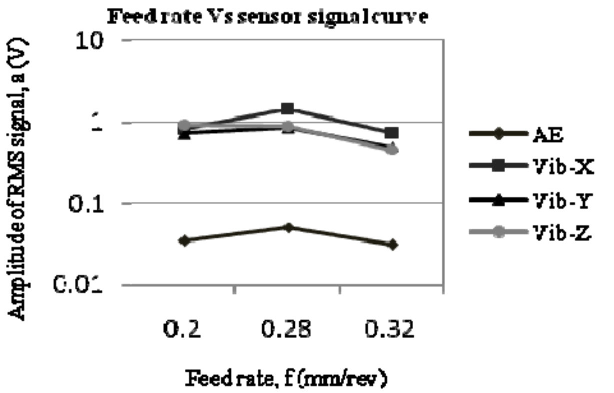



a)

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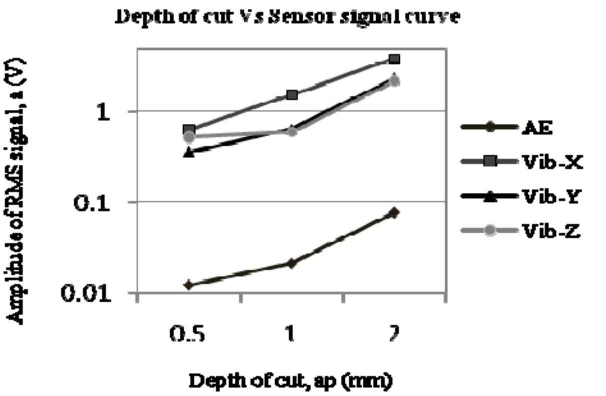
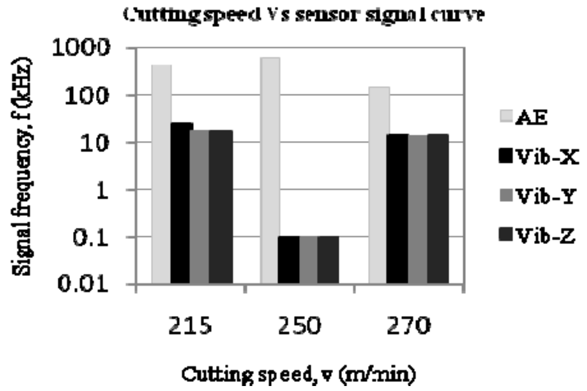
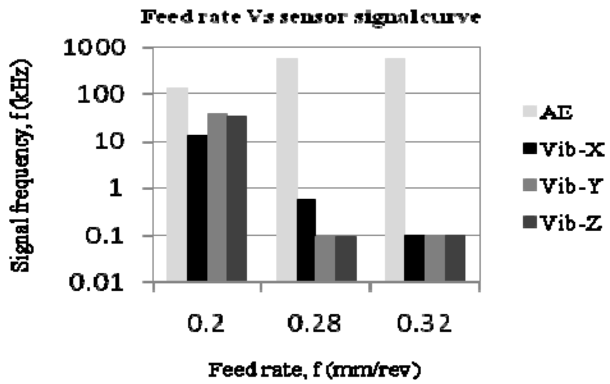



c)

Fig 3: Variation of signal's RMS values at different cutting speeds, feeds and depths of cut.




a)

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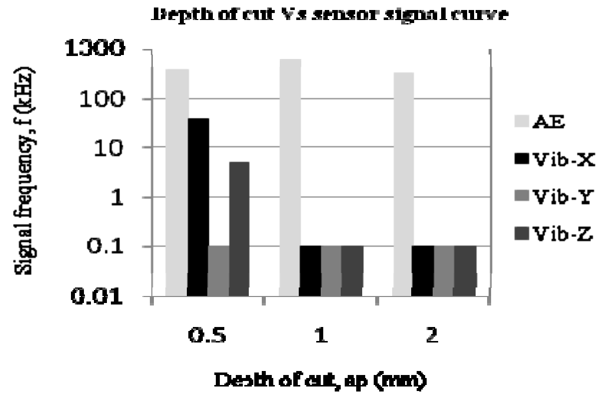


c)

Fig 4: The maximum intensity of frequency of Fig. 3 signal components

Fig. 3a.1) represents the nature of AE and vibration signal at constant feed rate of 0.32 mm/rev, depth of cut of 1 mm and with three different cutting speeds of 215 m/min, 250 m/min and 270 m/min. Fig. 3b.1) represents the behavior of AE and Vibration signal at cutting speed of 250 m/min, depth of cut of 1mm and with three different feed rates of 0.20 mm/rev, 0.28 mm/rev and 0.32 mm/rev. Fig. 3c.1) represents the nature of AE and Vibration signal at constant cutting speed of 250 m/min and feed rate of 0.32 mm/rev with three different depths of cut of 0.5 mm, 1 mm and 2 mm in turning. All the signals presented here have been captured at 2 minutes of cutting when flank wear measured was 0.129 mm. From the above figures, the AE signal decreases with the increase of cutting speed and increases with the increase of feed rate and depth of cut. The observation shows the tangential vibration component ($V_z$), the feed directional vibration component ($V_x$) and radial vibration component ($V_y$) have an identical response to the AE signal during the change of cutting speed, feed rate and depth of cut respectively. Even though, the exact values of vibration components fluctuate with the changing cutting parameters, the trend of all components remains unchanged. Fig. 3a.2) to c.2) represents the fluctuation of maximum intensity of frequency for the same AE and vibration signals. From frequency analysis, the frequency of AE signal fluctuates between 56 kHz and 581 kHz whereas the frequency of vibration signal lies in the band of 0 Hz - 41 kHz. The peak values (frequency of maximum intensity) fluctuate at different cutting conditions although the entire bands of signal remain within a fixed limit. For a specific cutting condition (cutting speed of 250 m/min, feed rate of

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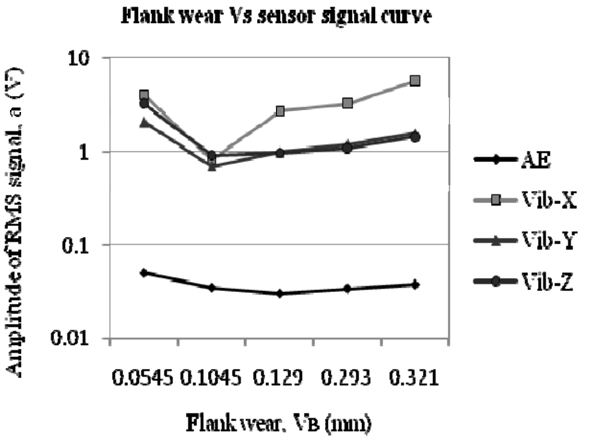
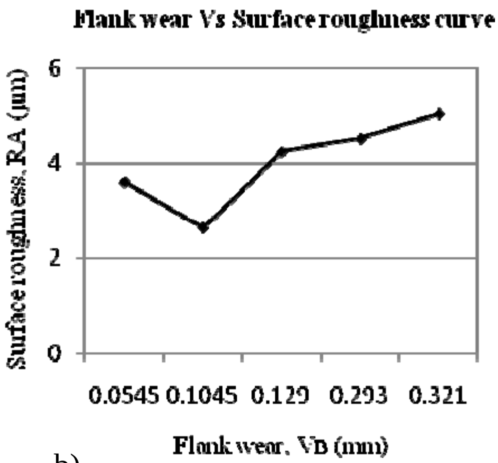
0.32 mm/rev and depth of cut of 1 mm), the AE and vibration signal components at different stages of tool life have been captured to observe their response to the flank wear progression.




a)




b)

Fig 5: a) Amplitude of RMS signal at different level of flank wear and b) surface roughness of workpiece corresponding to different flank wear.

From Fig 5a), the RMS vibration components, $V_{x(RMS)}$, $V_{y(RMS)}$ and $V_{z(RMS)}$ show corresponding change at the different level of flank wear. Though, all the RMS signals components ($AE_{RMS}$, $V_{x(RMS)}$, $V_{y(RMS)}$ and $V_{z(RMS)}$) are found to fluctuate at different stages of flank wear, the $V_{x(RMS)}$ plot is observed to resemble with the surface roughness curve of Fig 5b). The $AE_{RMS}$ shows an identical and very significant change to the rate of tool wear progression. From the analysis, the $AE_{RMS}$ represents the rate of progressive tool wear whereas the $V_{x(RMS)}$ corresponds to the surface roughness in turning.

Fig 6 represents the fluctuation of maximum intensity of frequency for the same AE and vibration signals. From the frequency analysis, the AE signal frequency fluctuates between 56 kHz and 581 kHz whereas the frequency of vibration components lies in the band of 0 Hz – 41 kHz all along the tool life. However, the maximum intensity of AE and vibration frequency varies at different flank wear depending on the cutting conditions.

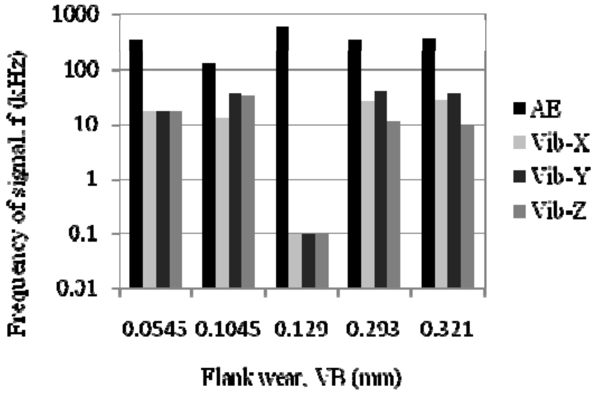



Fig 6: Frequency of sensor's signal at different level of tool wear.

## IV. CONCLUSIONS

The RMS AE and vibration signals and their frequency analysis are capable of attributing a particular incidence in turning without any ambiguity. The major findings from this experiment are:

- The trend of the vibration components $V_x$, $V_y$ and $V_z$ increase with the increase of feed rate and depth of cut, whereas they show a decreasing trend with the increase of cutting speed.
- Even though, all the vibration components have a minimum response to the change of cutting conditions; the change of feed rate is mostly influenced by the feed directional vibration components ($V_x$), $V_y$ corresponds to the change of depth of cut effectively whereas $V_z$ shows the most significant response to the change of cutting speed.
- For a specific tool-workpiece combination, although the maximum intensity of signal frequency fluctuates with the change of cutting speed, feed rate and depth of cut in turning; the range of frequency always remains within a certain band. The frequency of *AE* signal varies between 56 kHz and 581 kHz whereas the frequency of vibration components: $V_x$, $V_y$ and $V_z$ fluctuates between 0 Hz and 41 kHz for a set of cutting conditions.
- Despite, the maximum intensity of signal frequency of different vibration components $V_x$, $V_y$ and $V_z$ fluctuates, for a particular cutting condition, the entire frequency of all vibration components remains within the same band.
- The *AE* represents the rate of tool wear progression whereas the feed directional vibration component ($V_x$) corresponds to the surface roughness which is found to increase with the increase of depth of cut and feed rate in turning.

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## REFERENCES

[1] G. H. Lim, “Tool-wear monitoring in machine turning,” *Journal of Materials Processing Technology*, vol. 51, no. 1-4, pp. 25-36, April 1995.

[2] D.Y. Song, N. Otani, T. Aoki, Y. Kamakoshi, Y. Ohara and H. Tamaki, “A new approach to cutting state monitoring in end-mill machining,” *International Journal of Machine Tools and Manufacture*, vol. 45, no. 7-8, pp. 909-921, June 2005.

[3] S. Liang and D. Dornfeld, “Tool wear detection using time series analysis of acoustic emission,” *Journal of engineering for industry, Trans. ASME*, vol. 111, no. 3, pp. 199–205, August 1989.

[4] X. Li, “A brief review: acoustic emission method for tool wear monitoring during turning,” *International Journal of Machine Tools and Manufacture*, vol. 42, no. 2, pp. 157-165, January 2002.

[5] I. Inasaki, “Application of acoustic emission sensor for monitoring machining processes,” *Ultrasonics*, vol. 36, no. 1-5, pp. 273-281, February 1998.

[6] R. Y. Chiou and S. Y. Liang, “Analysis of acoustic emission in chatter vibration with tool wear effect in turning,” *International Journal of Machine Tools and Manufacture*, vol. 40, no. 7, pp. 927-941, May 2000.

[7] T. Moriwaki and K. Okushima, “Detection for Cutting Tool Fracture by Acoustic Emission Measurement,” *CIRP Annals - Manufacturing Technology*, vol. 29, no. 1, pp. 35-40, 1980.

[8] D. E. Dimla, “Sensor signals for tool-wear monitoring in metal cutting operations-a review of methods,” *International Journal of Machine Tools and Manufacture*, vol. 40, no. 8, pp. 1073-1098, June 2000.

[9] I. Abu-Mahfouz, “Drilling wear detection and classification using vibration signals and artificial neural network,” *International Journal of Machine Tools and Manufacture*, vol. 43, no. 7, pp. 707-720, May 2003.

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