XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

TOOL BREAKAGE MONITORING IN A MULTI-SPINDLE DRILLING OPERATION

Jouko Kiviö, Paul H. Andersson

Tampere University of Technology, Institute of Production Engineering (IPE), Tampere, Finland

Abstract – This paper describes tool breakage monitoring in a multi-spindle drilling using acoustic emission (AE) signals. Measurements have been carried out in a real industry environment with a tailor-made multi-spindle gun drilling machine. The drilling machine comprises some 300 spindles in one line and it is used to drill holes in paper machine parts. Measured AE-signals have been analysed both in time and frequency domain and especially high frequency content of AE-signals (over 150 kHz) have been examined. Breakage can be detected distinctly over the frequency content of AE-signals born in a normal undisturbed drilling. The location of sensors play very crucial role because the high frequency content of AE-signals attenuates very rapidly with increasing distance between the sensor and cutting process.

Keywords: Tool condition monitoring, drilling, acoustic emission.

1. INTRODUCTION

On-line tool breakage monitoring is very vital especially in the multi-spindle drilling operations where it is impossible for the machine operator to detect a drill breakage and where the drilling has to be stopped in order to make off-line inspection of the drills either manually or automatically. In both cases the effective cutting time is decreased due to the periodical process halts and undrilled holes caused by undetected drill breakages. These holes have to be drilled afterwards.

Plenty of research has been made in the field of tool condition monitoring [1,2,3,5,6,9,10,11]. Also great effort has been invested in different kinds of signal analysing methods [3,4,6,7,12]. However, the experiments have usually been done in a laboratory environment [2,3,4,5,7,8,12]. In most research reports the cutting method is turning or single spindle drilling [3,4,6,7,8,9,10,11,12]. There are also very few published research or reports of breakage monitoring in multi spindle operations.

In this work tool breakage monitoring is investigated in multi-spindle drilling operations in a real industry environment. The special design multi-spindle gun drilling machine (fig. 1.) is used to drill special rolls for a paper machine. There are 296 spindles in one line, which is the maximum number of holes that can be drilled simultaneously. Diameter of drilled holes varies typically from 3,5 mm to 5,0 mm.

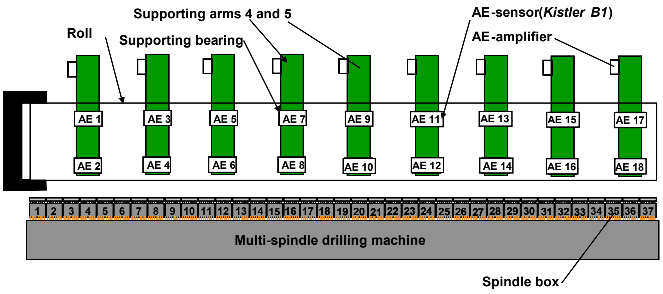


Fig. 1. A schematic illustration of a multi-spindle drilling machine.

The measured AE-signals were analysed both in time and frequency domain. In time domain normal statistical analyses were made and in the frequency domain the examined frequency band was 50 kHz to 1 MHz. It is very crucial to separate the frequency content of an AE-signal caused by normal undisturbed cutting from frequency content born in a drill breakage.

To perform frequency analysis to AE-signals it requires high-speed data acquisition (sampling rate over 2 MHz), which settles high demands to both the hardware and the software; especially when amount of data acquisition channels have to be high. However, the high-speed data acquisition is only needed in a research phase, when a frequency content of signal is examined. Frequency analysis helps to apply normal statistical calculations, which do not need as heavy calculations as frequency domain analyse. This is very important in on-line monitoring of multi-spindle operations where also many sensors are needed.

2. RESEARCH ENVIRONMENT

2.1. Research equipments

AE-signals were measured with 18 piezoelectric AE-sensors (*Kistler 8152B121*) mounted on the end face of the axle of the supporting bearing of a roll (there are two supporting bearings and two sensors located on each supporting arm, fig. 1.). The measured signals were amplified with a *Kistler 5125 B*. There are two signal outputs in the amplifier: filtered raw signal and Root Mean Square (RMS) signal outputs. Both signals were digitised and analysed. RMS-signal is sampled and analysed with a multi-channel data acquisition board (*Innovative Integration ADC-64*) and raw signal is sampled and saved with a high-speed data acquisition board (*ADLink PCI-9812*). Both signal are analysed partly online and partly offline using *Matlab*® or *DasyLab*® data-analysing programs.

2.2. Analysing methods

The measured signals were analysed both in time and frequency domain. Most of the calculations were performed online on the data acquisition board. In time domain maximum values, sum of squares and standard deviation were calculated. In frequency domain power spectral density (PSD) analysed was made.

AE-RMS output signals of the amplifiers were digitised with a sampling frequency of 11000 kHz and the case of raw signal acquisition a sampling frequency of 2 MHz was used. Further signal analysing was made to data blocks which lengths were 512 or 1024 samples.

3. RESULTS

3.1. Normal undisturbed drilling

In fig. 2. the standard deviation curve of an AE-signal measured with two sensors mounted in the same supporting arm but on the different axles of the supporting bearings is presented. In the beginning of the drilling cycle AE level raises quite rapidly and after a short period of time it decreases and becomes more stable. It is also noteworthy, that signal levels vary depending on the location of the sensor. The major reason for this is that the contact pressure between workpiece and the supporting bearings varies.

The frequency content in a normal undisturbed drilling (no breakage) is below 150 kHz (fig. 4., before and after breakage) and major part of the signal power is centred between 100 … 150 kHz.

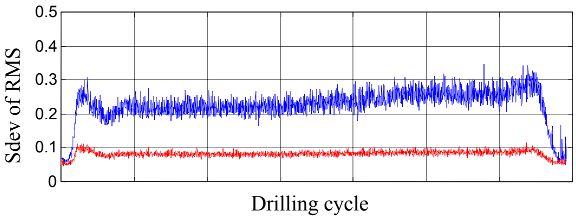


Fig. 2. Standard deviation curve of an AE-RMS-signal in a normal undisturbed drilling.

3.2. Drill Breakage

When a drill breakage occurs there are typically one or more spikes in the maximum value (fig. 3. a), standard deviation (fig 3. b) or sum of squares curves (fig. 3 c) depending on the breakage type and the amount of broken drills. A drill might break in the beginning, in the middle or just in the end of a drilling cycle. There might be fine cracks or breaks in the cemented carbide tip of the gun drill or the whole tip might break off from its shank. Also the shank can twist and break. In addition a breakage is usually a combination off all the mentioned breakage types. Nevertheless, a breakage is most clearly seen in the sum of squares curve (fig. 3 c).

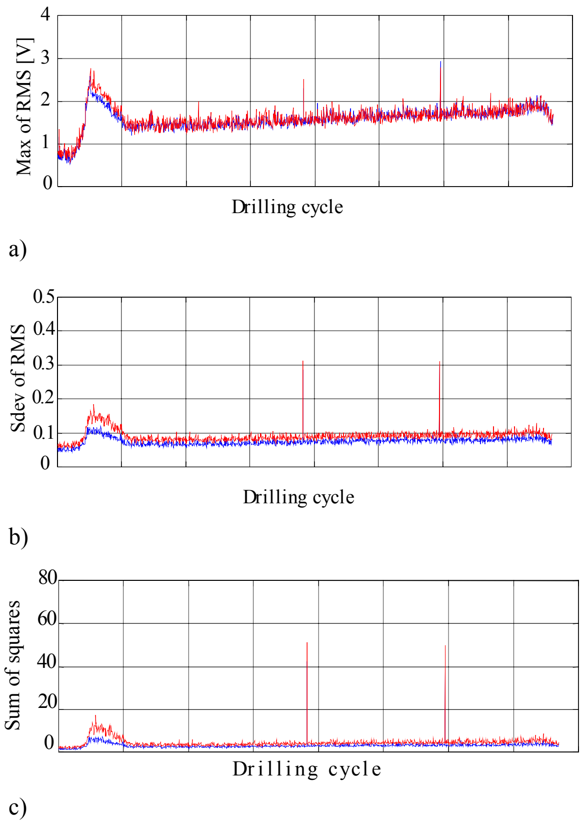


Fig. 3. Drill breakage: a) maximum curve of an AE-RMS-signal, b) standard deviation curve of an AE-RMS-signal, c) sum of squares signal of an AE-RMS-signal.

In fig. 4. it is clearly seen that when a breakage occurs there is a great increase in a spectral power in the frequency band 150 … 275 kHz. Spectral power increases clearly also in the frequency band 100 … 150kHz, but more secure detection of a drill breakage can be achieved, if the frequencies caused by normal cutting is high-pass filtered. However, AE-sensors have to be installed so near the cutting process as possible, because especially the high frequency content of an AE-signal attenuates quite rapidly. In addition there have to be as few contact surfaces as possible between the cutting process and sensors

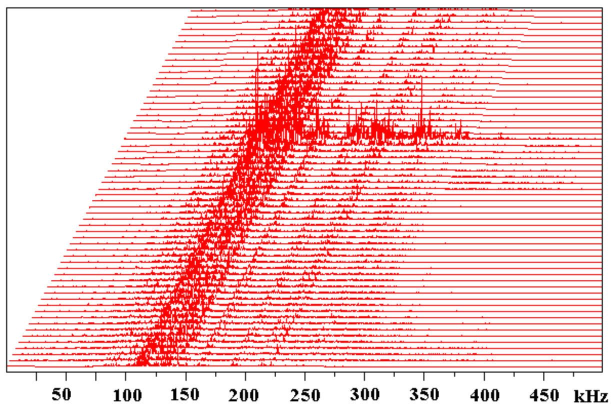


Fig. 4. AE-PSD curve in a drill breakage.

In a real tool condition monitoring system it is quite vital that measuring and analysing do not need too much processing power. Especially in the case of multi-spindle applications the amount of sensors and data acquisition channels easily make the whole system too expensive and complicated if high sampling rates and thus fast and heavy calculations are needed. Because of this, it is impossible to base the monitoring system on frequency analysis of AE-signals in industrial applications. That is why the time domain analysis of AE-RMS-signal is used in this research. If the signal is appropriately high pass filtered before the RMS-converter of the amplifier the drill breakage can be detected more reliably. In fig. 5 is shown two standard deviation curves of AE-RMS-signals measured from the same supporting arm. Upper curve is an unfiltered signal (HP=50kHz) and the lower one is a high-pass filtered signal (HP=200kHz). It is clearly seen that most of the noise from the normal cutting process is removed and the detection accuracy of the breakage is increased.

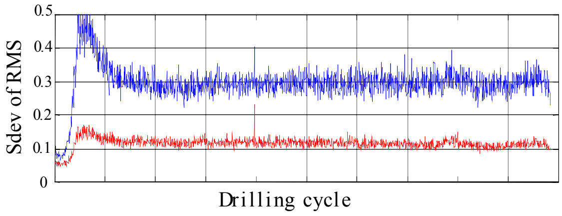
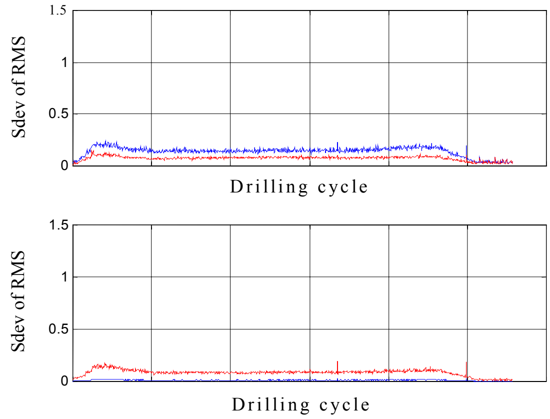


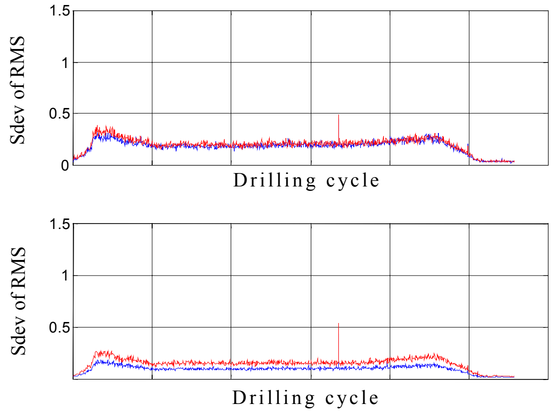
Fig. 5. Drill breakage: upper curve unfiltered signal (HP=50kHz), lower curve high-pass filtered signal (HP=200kHz).

A breakage of a drill typically consists of one or more individual cracks, which cause very short pulses to AE raw signal. The duration of a crack propagation is typically app. 8 ms (time period of adjacent curves in fig. 4 is app. 4 ms), so the integration time constant of the RMS-converter and the length of the data block for statistical calculation have to be short enough to ensure a high detection sensitivity of a drill breakage.

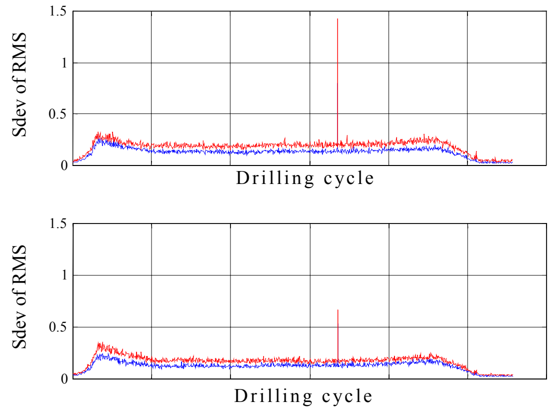
The results show that the location of the broken drill can be traced according to height of the signal spikes of different sensors (fig. 6). Diagrams in fig. 6 consist of signals of 16 sensors. In each subfigure (a, b, c, d) there are signals from two supporting arms, each individual chart shows signals from two sensors which are mounted on the axle of the supporting bearings. In this case a drill breakage has occurred in the 18th spindle box (sixth drill), which means that the breakage has taken place between fourth and fifth supporting arms, a little closer to fifth arm (fig. 1.). As the subfigure c shows, the highest spikes are detected with sensors (supporting arm 5), which are in the closest vicinity to the drill breakage. As the distance between the sensor and the breakage increases (supporting beams 6,4,3,7,8,2 and 1), the height of the spikes gradually decreases. In practise this means that it is easier to an operator to locate the broken drill, especially if there is only fine cracks in the hard tip of the drill.



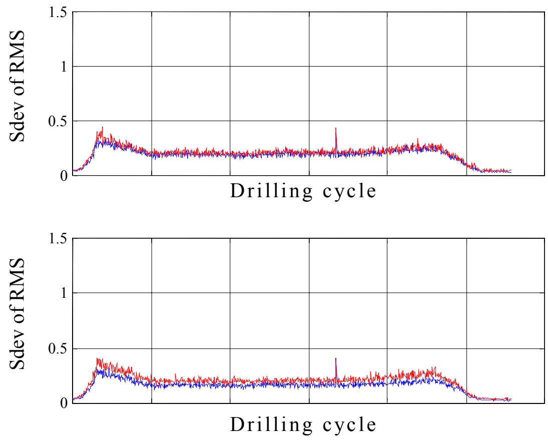
a) Upper chart: supporting arm 1, lower chart: supporting arm 2.



b) Upper chart: supporting arm 3, lower chart: supporting arm 4.



c) Upper chart: supporting arm 5, lower chart: supporting arm 6.



d) Upper chart: supporting arm 7, lower chart: supporting arm 8.

Fig. 6. Standard deviation curves of AE-RMS-signals from different sensors during drill breakage in the 18th spindle box.

4. CONCLUSIONS

Tool breakages cause great increase in spectral power in the frequency band 175…250kHz. There is also evident increase in AE-level in lower frequency bands (app. 100 kHz … 150 kHz). The normal undisturbed drilling increases AE-level in the same frequency band as well. If this band can be separated, drill breakage is detected more accurate.

The high frequency content of an AE-signal caused by a drill breakage attenuates quite rapidly. To utilize this frequency band, sensors have to be installed as near the cutting process (AE-signal source) as possible.

It is quite evident that the method described in this paper can be used also in different cutting operations e.g. in milling or in turning, because the nature of tool breakage is quite same.

In this research AE has been measured through the workpiece, but it is possible to apply same kind of measurement strategy to measure AE-signal through a tool. In machining centre applications it is often much easier to measure AE via a tool and a spindle installing the sensor on the face surface of the spindle. Mechanical vibrations caused by e.g. a spindle, a gearbox and a driving motor are not a problem, because they appear at much lower frequencies as high frequency content of an AE-signal.

REFERENCES

[1] Byrne, G., Dornfeld, D., Inasaki, I., Ketteler, G., König, W. & Teti, R. 1995. Tool Condition Monitoring (TCM) – The Status of Research and Industrial Application. Annals of the CIRP, vol. 44/2/1995, pp. 541 – 567

[2] Dornfeld, D. A. 1990. Neural Network Sensor Fusion for Tool Condition Monitoring. Annals of the CIRP, vol. 39/1/1990, pp. 101 – 105

[3] El-Wardany, T. I., Gao, D., & Elbestawi, M., A. 1996. Tool Condition Monitoring in Drilling Using Vibration Signature Analysis. International Journal of Machine Tools Manufacturing, No. 6. Vol. 36, pp. 687-711

[4] Govekar, E., Grabec, I. 1994. Self-Organizing Neural Network Application to Drill Wear Classification. ASME, Journal of Engineering for Industry, May 1994 Vol. 116, pp. 233 – 238.

[5] Inasaki, I., Aida, S. & Fukuoka, S. 1987. Monitoring System for Cutting Tool Failure Using an Acoustic Emission Sensor. JSME, International Journal, No. 261, Vol. 30, pp. 523 – 528

[6] Jemielniak, K. & Otman, O. 1998. Catastrophic Tool Failure Detection Based on Acoustic Emission Signal Analysis. Annals of the CIRP, vol. 47/1/1998, pp. 31 – 34

[7] Leem, Seong Choon, Dornfeld, D. A., Dreyfus, S. E. 1995. A Customized Neural Network for Sensor Fusion in On-Line monitoring of Cutting Tool Wear. ASME, Journal of Engineering for Industry, May 1995 Vol. 117, pp. 152 – 159.

[8] Li, G. S., Lau, W. S., Zhang Y. Z. 1992. In-Process Drill Wear and Breakage Monitoring for a Machine Centre Based on Cutting Force Parameters. International Journal of Machine Tools Manufacturing, Vol. 32, No. 6, pp. 855-867.

[9] Liang S. Y. & Dornfeld, D. A. 1989. Tool Wear Detection Using Time Series Analysis of Acoustic Emission. ASME, Journal of Engineering for Industry, Aug 1989 Vol. 111, pp. 199 – 205

[10] Rice, J. A. & Wu, S. M. 1993. On the Feasibility of Catastrophic Cutting Tool Prediction via Acoustic Emission Analysis. ASME, Journal of Engineering for Industry, Nov. 1993 vol. 115, pp. 390 – 398.

[11] Teti, R. 1989. Tool Wear Monitoring through Acoustic Emission. Annals of the CIRP, vol. 38/1/1989, pp. 99 - 102

[12] Yao, Y., Fang, X. D., Arndt, G. 1991. On-Line Estimation of Groove Wear in the minor Cutting Edge for Finish Machining. Annals of the CIRP, vol. 40/1/1991, pp. 41 – 44.

AUTHORS: Jouko Kiviö, Tampere University of Technology, Institute of Production Engineering, BOX 589, FIN-33101 Tampere, Finland, phone: +358 3 3115 3913, fax: +358 3 3115 2753 E-mail: Jouko.Kivio@tut.fi.

Paul H. Andersson, Tampere University of Technology, Institute of Production Engineering, BOX 589, FIN-33101 Tampere, Finland, phone: +358 3 3115 2750, fax: +358 3 3115 2753 E-mail: Paul.Andersson@tut.fi.