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WHEEL / WORKPIECE CONTACT DETECTION DURING GRINDING PROCESS BY AE SIGNAL

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Abstract. *This paper describes research in the application of acoustic emission (AE) to wheel/workpiece contact detection. This paper differentiates itself by focusing on analyzing the raw signal instead of the RMS signal and by exploring the "grit contact" instead of "wheel contact". The possibility and sensitivity of detection of contact with the help of AE are demonstrated. Results of experimental evaluation are presented. Methods studied include Kurtosis, Skew, MVD statistics, ROP, zero-crossing and Page's test.*

Keywords: *Contact, Grinding, Acoustic emission, Signal processing*

1. INTRODUCTION

Grinding is a major manufacturing process, which accounts for about 25 percents of the total expenditure on machining operations in industrialized countries (Malkin,1989). Moreover, the grinding process is virtually the only machining operation which can be applied to advanced ceramic materials. This industrial importance and the fact that the grinding process is considered a very expensive and time consuming task makes it appropriate to study its optimization. Contact detection helps to maintain position accuracy of the wheel relative to workpiece, to reduce air grinding time, to prevent workpiece damage through crashing and to prevent related problems of lobing etc.(Dong *et al*, 1997).

The use of AE, basically a technique to detect pulses of released elastic strain energy caused by deformation, crack growth and phase changes in a solid (Aburatani, 1996), for contact detection, has been investigated by Dornfeld (1984), Inasaki *et al.*(1985), and has showed promise as a more suitable and sensitive method than those based on force or power (Dong *et al*, 1995, Inasaki *et al.*, 1985, Kakino, 1982). However, a close look at the previous research reveals that AE_{rms} (root mean square) was predominantly studied; the raw AE signal has not received the much attention. Due to AE_{rms}'s statistical-average nature, some important instantaneous features, such as the initial contact of the grits with the workpiece, may not be revealed through it. Therefore extracting characteristics of the raw AE signal is an open and necessary step to use efficiently AE for fast and reliable contact detection.

We are interested in "grit contact", the initial stage of contact. This work deals with methods for analyzing the AE signal. These methods and different AE features in the transition of wheel/workpiece contact are specifically discussed, and the results are compared.

2. Experiments

The experiment was carried out on Edgetek Superabrasive machine, involving the material, inconel 718. Figure 1 shows the instrument setup. The AE signal was received by an AE sensor (PAC U80D-87) whose frequency characteristics are known and mounted directly on the workstation. The system consists of the sensor, a preamplifier, a post amplifier and a data acquisition system which is a HP E1430A running in continuous-sampling mode at 2.56 MHz.

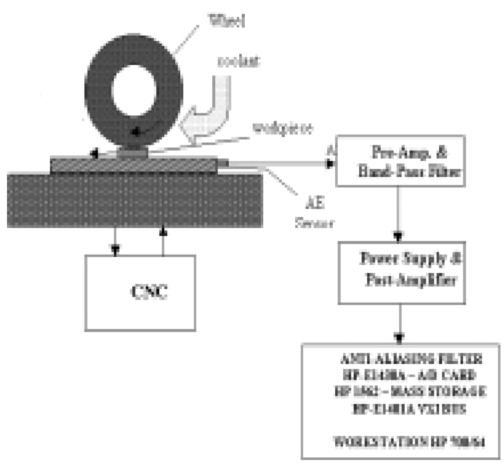

Fig 1: Setup of AE test

Grinding parameters are as following:

- Wheel peripheral speed: 7500 rpm
- Workpiece feed rate: 30 in/min.
- Wheel diameter: 7.5 in
- Coolant type: Master Chemical VHP 200
- Coolant flow rate: 29 gallon/min.
- Grinding wheel type: WOLFCO,CBN 1012,100/120-CBN, M.O.S.6115

Wheel/workpiece contact includes two stages: one can be defined as "grit contact" in which the higher grits contact with workpiece first and generates burst type AE; the other is "wheel contact" in which the wheel is continuously in contact with the workpiece and thus generates continuous type AE. Practical contact detection is usually implemented in "wheel contact" stage. We believe in that it is more useful to detect contact in the "grit contact" stage, which is milliseconds ahead of full contact of the wheel and workpiece and the possible concomitant damage.

3. The signal Processing

Two criteria, the amplitude issue and the time duration issue, can be established to detect contact (Webster *et al.*, 1996). If the two criteria were met, it would be reasonable to declare the contact. For this purpose, a number of signal processing tools were applied. Some statistical methods, such as Nuttall statistic, show no promise here, so we don't explore them further.

3.1. Kurtosis and Skew

The Kurtosis and Skew statistics have attracted much interest (Jemielniak & Otman, 1998). It is supposed that among the parameters of the AE signal, the Skew and Kurtosis of an AE signal distribution are sensitive to the process change. They can be given as:

$$K(r,s) = \frac{6((r-s)^2(r+s+1) - rs(r+s+2))}{rs(r+s+2)(r+s+3)} \tag{1}$$

$$S(r,s) = \frac{2(s-r)}{(r+s+2)}\frac{(r+s+1)^{\frac{1}{2}}}{(rs)^{\frac{1}{2}}} \tag{2}$$

where r and s are

$$r = \frac{\hat{\mathrm{AE}}_{rms}}{\sigma^2}(\hat{\mathrm{AE}}_{rms} - \hat{\mathrm{AE}}^2_{rms} - \sigma^2) \tag{3}$$

$$s = \frac{1-\hat{\mathrm{AE}}_{rms}}{\sigma^2}(\hat{\mathrm{AE}}_{rms} - \hat{\mathrm{AE}}^2_{rms} - \sigma^2) \tag{4}$$

where $\hat{\mathrm{AE}}_{rms}$ is the empirical AE_{rms} and σ^2 is the empirical variance of AE_{rms}.

3.2. Zero-crossing rate

Attention was paid to zero-crossing rate from the very beginning of the use of AE (Baron & Ying, 1987). As the name implies, this method counts the number of zero-crossing events during each block of raw signal x(n). Here we choose T = .1 ms, meaning that we count the number of zero-crossings in each block of 256 samples.

3.3. ROP (Ratio of Power)

The ratio of power is calculated from the power spectrum (PS). The power in some frequency range in the PS is divided by the total. The formula is

$$ROP = \sum_{k=n_1}^{n_2} |X_k|^2 / \sum_{k=0}^{N-1} |X_k|^2 \tag{5}$$

N is the chosen FFT length (here it is 256), X_k is the k^{th} FFT output, and summation is over any specified range of frequency, presented by n_1 and n_2. In our case, use the range 300-400 kHz. Actually, the ranges 500-600 and 600-700 kHz appear to be useful as well.

3.4. MVD(mean value dispersion)

The form of the statistic (Chen, 1998) is

$$MVD(X) = \sum_{k=0}^{N-1} log(\frac{\frac{1}{N}\sum_{l=0}^{N-1} X_l}{X_k}) \tag{6}$$

in which X denotes the FFT vector of a block of x(n), the collected raw signal. N is the block length, X_k is the k^{th} FFT output. Since this statistic requires x(n) to be whitening first, we use the band-limited MVD instead. Thus the form is adapted to

$$MVD(X) = \sum_{k=n_1}^{n_2} log\left(\frac{\frac{1}{n_2-n_1+1}\sum_{l=n_1}^{n_2} X_l}{X_k}\right) \tag{7}$$

The preferred frequency band is determined by n_1 and n_2. It is found that only the 0-100 kHz band proves to be useful to contact detection.

3.5. Page's Test

To some extent, wheel/workpiece contact triggers a switch from one statistical state (coolant process) to another (grinding process). We assume that there exists an independent observations segment x_n and an unknown switching time n_0 for which

$$x_n \text{ has density} \begin{cases} f_0(x_n), & \text{if } n < n_0 \\ f_1(x_n), & \text{if } n > n_0 \end{cases}$$

Page's test (Page, 1954) is the generally-accepted technique for such a "quickest" detection problem. Each time the cusum statistic

$$\begin{aligned} Z_0 &= 0 \\ Z_n &= max(0, Z_{n-1} + g(x_n)) \end{aligned} \tag{8}$$

passes a threshold h, detection is declared. In our case, we choose

$$g(x_n) = x_n^2 - .5max(x^2) \tag{9}$$

x is the raw signal obtained during the period when the contact absolutely doesn't occur.

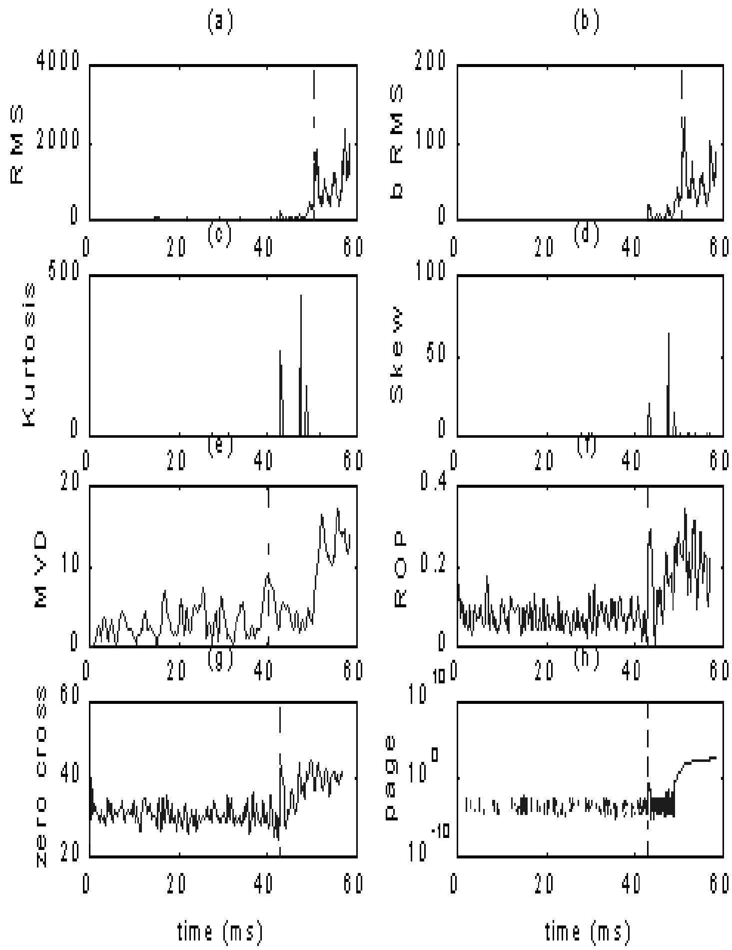

Figure 2: Results from inconel test 2. (a) AE RMS. (b) band-limited AE RMS ($300 < f < 400$ kHz). (c) Kurtosis statistic. (d) Skew statistic. (e) band-limited MVD statistic. (f) band-limited ROP ($300 < f < 400$ kHz). (g) zero-crossing rate. (h) Page's test. The vertical dashed lines represent time of contact detection.

4. Results and discussions

Figure 2 shows the results obtained for inconel test 2 using the above statistics. Note that a prompt contact detection can be observed from this figure. They are compared with the traditional RMS method, both broadband RMS and band-limited RMS (through a band pass filter first). It is clear that band-limited RMS reveals the same result as broadband RMS does, meaning band-limited RMS tells us nothing more than traditional RMS, at least in the case of contact detection, hence we study RMS only. Since high amplitudes imply abrupt change, absolute values of Kurtosis and Skew were showed. In the MVD statistic and zero-crossing rate methods, a low pass filter was used as the last step.

In each statistic, a threshold is adaptively set, referred to the value before the contact happens. When the amplitude reaches the threshold, the contact detection is declared. The contact time (t) will be compared with that of the RMS method using 10E(v_b) threshold and used to assess the efficiency of different methods, given in Table 1.

As expected, Kurtosis value is assessed an impulse at the moment of contact occurs. It is worth mentioning that, in Figure 2 (c) and (d) (Kurtosis and Skew statistics), we conjecture that the first spike is related to "grit contact" and the second spike to "wheel

method	threshold h	t(ms)	$t_{RMS} - t$ (ms)
RMS	10E(v_b)=850	50.6	-
Kurtosis	100E(v_b)=35	42.9	7.7
Skew	100E(v_b)=37	42.9	7.7
MVD	1.3E(v_b)=460	40.5	10.1
ROP	5E(v_b)=.45	43.0	7.6
zero rate	1.4E(v_b)=42	43.0	7.6
page	0.01-0.1	42.9	7.7

Tabela 1: Contact detection using different methods. In this table, t means the time of contact, t_{RMS} represents the contact time detected by the RMS method. v_b are values set obtained using each statistic during the time interval when wheel/workpiece is impossible in contact.

contact".

The above statistics and the threshold setting rules are applied to the other 5 Inconel tests, and t_{RMS}-t is recorded as contact delay T. It shows that the difference of the threshold value for different tests is within 10 percent in the MVD, ROP, zero-crossing and Page's test methods. The analyzed results are showed in Table 2.

method	E(T)(ms)	σ^2(T)	min(T)	max(T)
Kurtosis	3.26	5.65	1.2	7.7
Skew	3.26	5.65	1.2	7.7
MVD	7.30	48.58	-0.4	18.2
ROP	4.36	7.77	1.3	7.6
zero rate	3.64	5.14	1.3	7.6
page	4.38	8.10	1.2	7.7

Tabela 2: Contact detection for different tests. In this table, E(T) means the empirical T and σ^2 is the empirical variance of T.

It is noted that the RMS method has the largest contact detection time t, which means RMS method is the least sensitive to the change factor - the beginning of contact. All other statistics can detect the contact several milliseconds earlier than the RMS. They all prove to contribute to fast and reliable contact detection. Based on Table 2, it is safe to say that the statistics, including Kurtosis, Skew, MVD, ROP, rate-crossing and Page's test, are all more efficient in contact detection that RMS method.

We believe that the contact delay T is related to the difference between "grit contact" and "wheel contact". The RMS's average nature makes it fail to detect "grit contact" and only can respond to the later "wheel contact" where stationary and large enough RMS values are revealed, while other statistics succeed to detect the "grit contact" due to their special features which make them sensitive to the transient events.

5. Conclusions

Motivated to find an effective method to detect wheel/ workpiece contact, different statistics are employed using a high sampling rate AE signal. Based on the work presented above, it can be concluded that: AE technology is a powerful tool for contact detection; since the AE raw signal does tell something that the RMS signal just misses, some statistic tools catching features of the raw signal have proved useful and reliable to contact detection, especially Kurtosis, Skew, the MVD statistic and Page's test; the discussed statistics are sensitive to the "grit contact", thus can detect contact several milliseconds before the traditional "wheel contact". Future research will be focused on finding suitable statistic tool to catch features of raw AE signal for different applications, such as grinding cycle, burn and crack detection.

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