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Acoustic image-based damage identification of oxide aluminum grinding wheel during the dressing operation

Fábio R. L. Dotto[a], Paulo R. Aguiar[a*], Felipe A. Alexandre[a], Leonardo Simões[a], Wenderson N. Lopes[a], Doriana M. D'Addona[b], Eduardo C. Bianchi[a]

[a]*Universidade Estadual Paulista – Unesp, School of Engineering, Av. Luiz Ed. C. Coube, 14-01, Bauru – SP, 17.033-360, Brazil*
[b]*Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology (Fh-J_LEAPT Naples) Dept. of Chemical, Material and Industrial Production Engineering, University of Naples Federico II, Piazzale Tecchio 80, 80125 Naples, Italy*

* Corresponding author. Tel.:+55 14 3103-6115. *E-mail address:* aguiarpr@feb.unesp.br

Abstract

Grinding is a finish process of parts that require high precision and tight dimensional tolerance, which owe high value-added. As the grinding process takes place, the cutting surface of the grinding wheel undergoes wear and then its cutting capacity is reduced. On the other hand, the dressing operation is responsible for restoring the cutting surface of the grinding wheel and, therefore, plays a key role in the grinding process. This work aims at obtaining acoustic images of the grinding wheel surface to identify its conditions during the dressing operation. Experimental tests were conducted with a single-point diamond dresser in a surface grinding machine, which was equipped with an oxide aluminum grinding wheel in which specific marks were intentionally made on its surface to simulate damages for identification. An acoustic emission sensor was fixed to the dresser holder and the signal were acquired at 5 MHz. The signal spectrum was investigated and a frequency band was carefully selected, which represented the conditions of grinding wheel surface. The root mean square values were then computed from the raw signal with and without filtering for several integration periods, and the acoustic images obtained. The results show that the proposed technique is efficient to identify the damage on the wheel surface during the dressing operation as well as its location.

Keywords: acoustic emission; dressing operation; tool condition monitoring; acoustic image

1. Introduction

A growing search for more efficient techniques to monitor machining processes has been occurring in the last few years, aiming at manufacturing improvement of the precision parts. Grinding, which is usually the last step of the manufacturing chain, is a finish process that is considered one of the most critical and complex operation. That is because the cutting tool is composed by small abrasive grains of irregular geometries, which are placed and oriented randomly and held by a binder [1], [2]. According to [1], grinding represents about 70% of the precision machining processes.

The efficiency of the grinding process is highly dependent of the cutting tool performance, the grinding wheel. Such behavior can change significantly during the operation because the wheel can lose its optimal cutting condition, which compromises the surface quality of the machined workpiece [3]. However, the grinding wheel plays a key role that differs grinding from others machining process. The wheel topography and the conditions in which it is obtained has significant influence on the grinding process performance [4].

When the wheel loses its cutting capacity during the grinding process, it is necessary to stop the process and to perform the dressing operation. Dressing consists of conditioning the grinding wheel surface when it loses its original shape due to wear of the abrasive grains and clogging of the pores [3]–[5].

In this context, tool condition monitoring plays an important role in the grinding process. It is responsible for obtaining higher productivity and better product quality, besides the capability of identifying harsh damages risks in

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the workpieces or machine components [6]. The tool condition monitoring involves acquisition, processing and analysis of data which are related to the tool under several experimental conditions and the results are studied for real applications. Many techniques have been researched to perform each step of the tool condition monitoring. Such stages include the choice of the parameters to collect, as well as extraction, selection and classification of the characteristics [7].

Among the methods of tool condition monitoring, the indirect methods are more appropriate because they do not require to interrupt the machining process. Such methods generally use force signals, acoustic emission (AE) signals, vibration signals, electric current etc. However, the AE signal has greater advantage over the others with regard to harmonic content, because information of interest are in higher frequency ranges than frequencies from machine vibrations and environmental noises [4], [7]–[12]. It is important to mention that, in general, these methods are based on defining thresholds or frontiers, which are responsible to characterize the tool condition. However, according to [13], the use of AE dynamic signal and strategies of monitoring based on thresholds can result in low reliability due to unpredictable behavior of AE signal.

Then, the objective of the present work is to monitor the condition of the oxide aluminum grinding wheel by means of images constructed from AE signal during the dressing operation. The motivation of this study is based on the research of [13], in which a grinding wheel surface map was obtained from the root mean square values (RMS) of AE signals. However, unlike the work that was previously mentioned, the present paper uses variable time-windows and specific frequencies ranges applied to the raw AE signal to construct acoustic images from the resulting RMS signal.

2. Materials and Methods

2.1. Test bench and experimental procedures

Tests were performed by using a surface grinding machine model RAPH 1055, from Sulmecanica manufacturer. An oxide aluminum grinding wheel manufactured by Norton, model 38A150-LVH, with dimensions of 355.6 x 25.4 x 127.0 mm, was used for the tests.

To monitor the signals, an AE sensor from SENSIS manufacturer was used with frequency range up to 500 kHz, which was fixed on the dresser holder. An encoder was mounted on the grinding wheel spindle to collect the synchronism signal to be used in the construction of the acoustic map.

The AE sensor and the encoder were connected to an oscilloscope, model DL850, from Yokogawa. This equipment was set up to collect raw signals at the sampling rate of 5 MS/s. Figure 1 shows the test bench, which was prepared to the dressing process and data acquisition.

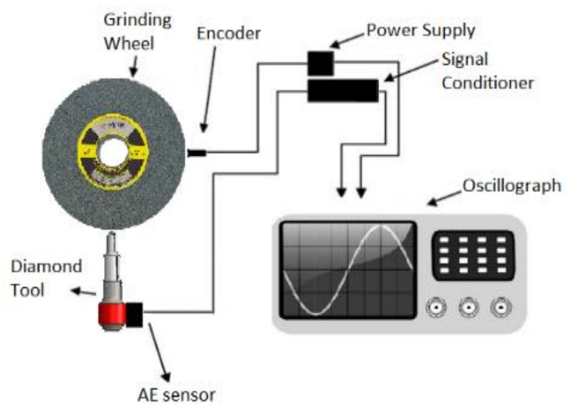

Fig. 1. Test bench

Fig. 2. Damage with shape of "+" inserted on the wheel surface

With the aim of simulating a damage on the grinding wheel surface and, subsequently, obtaining acoustic images from the AE data which were collected during the dressing tests, a plus signal (+) was machined on the wheel surface, as shown in Figure 2. This symbol has horizontal and vertical lengths of 15 mm and depth of 2.5 mm.

The tests consisted of 3 dressing passes with depth of cut of 10 µm. The tests parameters were: dresser width (b_d) of 240 µm, grinding wheel rotation of 1800 rpm (n) and resulting overlap ratio (U_d) of 1. Therefore, the dressing time (t_d) can be calculated by using these parameters, according to Equation (1).

$$t_d = \frac{L_R . U_d . 60}{n . b_d} \quad (1)$$

Where L_R is the width of the wheel, in mm.

The dressing time was set up by means of controlling the transverse movement of the grinding machine table, in which the dresser is placed. The dressing time that was obtained was of about 3.53 seconds. These parameters were kept constant throughout all dressing passes. It is worth to mention that, in this work, the interest was not in obtaining the wheel surface topography, which could be achieved with cut of depth close to zero, as in [13]. Instead, the objective was to obtain the wheel surface condition during a usual dressing operation, verifying, consequently, whether the dressing is running accordingly and/or monitoring the occurrence of damages on the wheel cutting surface.

2.2. Signal processing

The data collected from oscilloscope were analyzed and processed in the MATLAB software. For this purpose, signals were normalized and the mean level was eliminated. Then, a study of the AE signal frequency spectrum was conducted to investigate the frequencies that have a better relationship with the dressing operation.

After the selection of the time-range which is related to the dressing pass (period of contact between the grinding wheel and the dresser tip), a Butterworth bandpass filter, order 5, was used. The cutoff frequencies were determined from the signal spectrum study, as mentioned above. The cutoff frequencies for the digital filter were chosen by identifying the frequency bands that are more related to the grinding wheel surface conditions. After filtering the AE signal in the frequency bands that had been chosen, the RMS value was calculated and then the acoustic map of the grinding wheel was obtained, considering a time-window from 0.1 to 0.3 ms. The construction of the acoustic images was performed for the AE signals without filter and for the AE signals with a filter in a frequency band previously selected. To determine the acoustic image of the grinding wheel, several frequency bands were originally tested and the bands that presented the best results for the image were chosen.

The procedure to obtain the acoustic image is shown in Figure 3, which indicates the geometric characteristics of the wheel surface and relates the surface of the wheel to the two-dimension acoustic image generated. The x-axis represents the position, in millimeters, of the wheel surface and the y-axis represents the length of the wheel, in millimeters. Then, by means of the acoustic image inspection, it is possible to observe the irregularities on the wheel surface and, then, visualize the damage that were deliberately inserted on the surface (“+” symbol). It is worth highlighting that the procedure in which the images were obtained is similar to that adopted in [14].

3. Results

3.1. Signal processing

Figures 4 and 5 show the AE and synchronism signals obtained during the dressing process. It is noted that, in Figure 4, the AE raw signal is complex during all the test, including a noise stretch before and after the dressing pass. Moreover, it is possible to observe that the signal from the dressing operation shows a certain uniformity, which demonstrates that the dressing was performed with constant and adequate depth of cut. However, only based on the analysis of this signal, it is not possible to observe any variation related to the damage (“+” symbol). Thus, a specific digital processing is necessary.

Fig. 3. Relationship between the grinding wheel surface and the acoustic image

On the other hand, the signal from the encoder provides the revolutions that is performed during the test. Figure 5 shows a stretch of the dressing test, where three pulses related to the wheel revolutions can be observed. Each revolution amounts to about 0.033 seconds, which is in accordance with the wheel rotation during the test of 1800 rpm.

Then, the frequency spectrum was obtained from the entire signal of the dressing pass. Figure 6 shows the signal spectrum for the pass number 2. The AE signal has components with frequencies from 20 to 500 kHz, but the frequencies with higher amplitudes are from 20 to 80 kHz. Such frequencies are related to the phenomena that are intrinsic to the dressing process, such as friction of the tool with the abrasive grains, break and/or removal of the grains, vibrations of the system machine-wheel-dresser, cutting fluid, damage (“+” symbol), among others. Thus, it is not possible to affirm which frequencies are related to the wheel surface condition by just analyzing this spectrum as presented. Therefore, a search and investigation of many frequencies ranges throughout the spectrum are necessary, with the aim at finding those that are more related to the tool cutting condition and/or damage. Based on such inference, the AE signal spectra with and without the damage (“+” symbol) were initially observed.

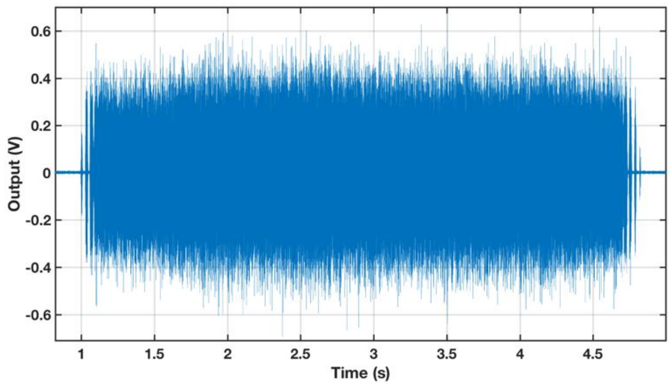

Fig. 4. AE raw signal

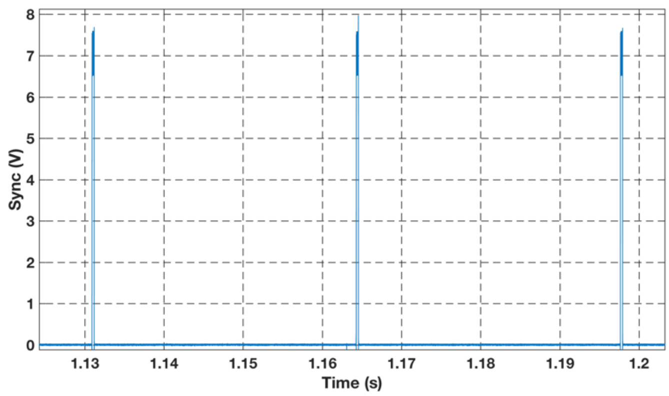

Fig. 5. Synchronism signal from encoder

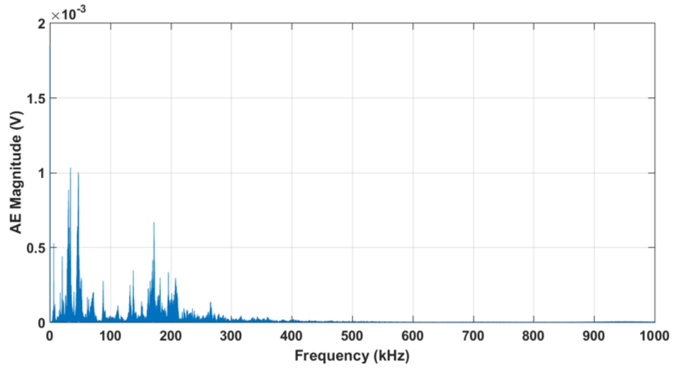

Fig. 6. Frequency spectrum of the AE raw signal

Figure 7 shows two curves that represent the signal spectra for a studied range without damage (blue) and with damage (red). It can be observed significant differences in magnitude between these conditions, that is, in the region without damage a full contact between the dresser and the wheel surface occurs and, consequently, higher acoustic activities take place. On the other hand, the region with the damage presents lower AE magnitudes because a small area of the wheel surface, which corresponds to the induced damage ("+" symbol), generates lower acoustic activity than the other one. However, such feature can be cleared observed for certain frequencies ranges, which produce the best correlation with the irregularities or defects on the wheel surface.

3.2. Acoustic images

The acoustic images were obtained according to the methodology described previously, in which the RMS value, which was calculated from the raw AE signal with filter and without the filter for the chosen frequency bands, was used. In these images, the horizontal and vertical directions are the circumference and the width of the wheel, respectively, while the gray scale represents the magnitude of the RMS value from the interaction between the wheel surface and the dresser. The selection of these bands was conducted by tracking the frequency spectrum regarding frequencies ranges with minimum or without overlap of the spectra, that is, between the condition with damage and the condition without damage. Some of these bands tested include: 20-80 kHz, 100-200 kHz, 200-300 kHz, 300-400 kHz and 400-500 kHz.

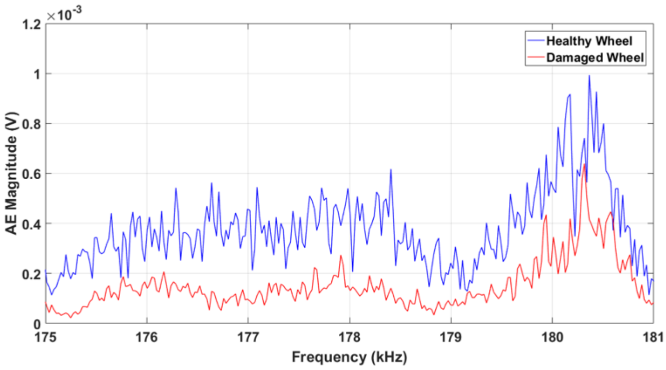

Fig. 7. Spectra of the conditions for the wheel with and without damage

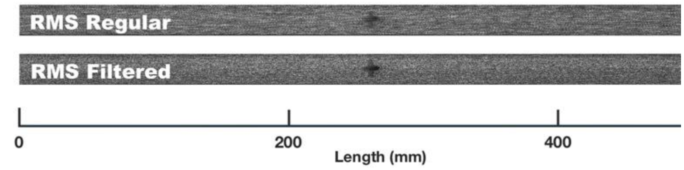

Fig. 8. Acoustic images using RMS statistical parameter without and with filter

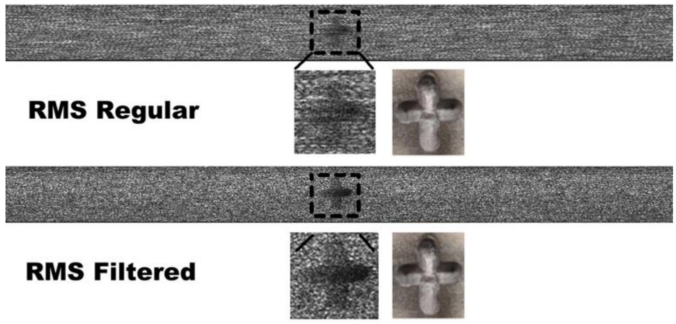

Fig. 9. Magnification of the region with the symbol in the acoustic images

For each frequency range selected, the raw AE signal was filtered and the corresponding RMS value calculated and, finally, the acoustic image generated. Furthermore, several resolutions (samples/mm) were tested to search for the best images. The frequency band of 300-400 kHz and the integration time constant of 0.1 ms are among the best results obtained.

Figure 8 shows two acoustic images obtained. The upper image was constructed by using the AE RMS signal calculated from the raw signal without any digital filter (RMS Regular). The bottom image was generated similarly, but from the raw signal filtered in the chosen frequency band (RMS Filtered). The horizontal line in this figure shows the length of the grinding wheel. It is observed that both images show the "+" symbol, which is located at 280 mm. However, the symbol can be best viewed at the bottom image, which was generated by using the digital filter in the chosen frequency band.

On the other hand, the size of the symbol (induced damage) on the wheel surface is much smaller than its dimensions. Then, for a better comparison and analysis of the quality of the acoustic images, a magnification of the wheel region is shown in Figure 9 in which the symbol "+" is located, as well as a high-resolution photography of the real mark captured before the dressing test. It is noted in the top image (without digital filter in the raw AE signal) that the mark can be identified, but it is quite distorted.

By contrast, in the bottom image (with digital filter in the chosen frequency band), the symbol is sharper, which demonstrates the efficiency of selecting an appropriate frequency band along with the corresponding digital filter.

4. Conclusion

The objective of the present work was to obtain acoustic images from acoustic emission signals to identify the surface condition of the aluminum oxide grinding wheel. Damages on the cutting tool surface were simulated by means of a mark with a specific shape. Dressing tests were conducted by using a single-point dresser, in which raw AE and synchronism signals were collected.

Studies on the frequency spectra of the raw AE signal related to the healthy and damaged wheel surfaces were conducted, and then frequency bands that best represented those tool conditions were selected.

Acoustic images were generated from the RMS values of the AE signal, which were calculated from the raw AE signal with and without digital filter in the chosen bands. From such images, it is possible to verify that the use of digital filter for a frequency range carefully chosen resulted on a sharper acoustic image, and the induced damage could be easier visualized.

It is worth mentioning that this work aimed at monitoring of the grinding wheel surface damage during the dressing operation by acoustic images instead of mapping the grinding wheel topography, promoting a contribution and improvement of the technique reported in the literature and previously mentioned. In addition, other works can be developed based on the method herein proposed, for instance, the influence of different dressing depths on the acoustic images quality and the identification of the grinding wheel balance.

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