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Applicability of Acoustic Emission monitoring to micro polishing

Soufian Ben Achour[1], Giuliano Bissacco[1], Leonardo De Chiffre[1]

[1] Department of Mechanical Engineering, Technical University of Denmark (DTU), Produktionstorvet, 2800 Kgs. Lyngby, Denmark

Email: sbachou@mek.dtu.dk

Abstract

Application of process monitoring solutions to micro polishing is affected by the low intensity of the measured signals, which influences the capability to extract useful information. This work explores the applicability of acoustic emission monitoring for detection of process completion through End Point Detection (EPD) in micro polishing. Several polishing tests have been conducted by gradually reducing the contact area and the acoustic emission signal generated by the process is acquired and analysed. The work shows that the monitoring solutions applied in conventional polishing can potentially be applied to the micro process.

Keywords: Micro-Polishing, End Point Detection (EPD), Monitoring strategies

1. Introduction

Mechanical polishing is an abrasive process, usually identified as the last step in the production process chain of several products as it defines the final surface quality of the parts produced. Micro polishing distinguishes itself from conventional polishing because of smaller tools and parts. In polishing, tool and workpiece slide on each other with a slurry containing abrasive particles interposed between the two. The fundamental mechanism, especially in micro polishing, is still not completely understood. This is due to the large number of uncontrolled variables and their interactions affecting the process [1]. Monitoring the process is key factor for understanding if the process is evolving in the right direction, and ultimately, to stop it when the desired product quality is reached.

Polishing is usually conducted in several steps, often using different tools and abrasive media. Changing to a finer abrasive time-effectively is one of the hardest challenges in mechanical polishing processes. For this reason, monitoring the friction force and the acoustic emission level could give some useful insights [2]. This work studies the applicability of the method based on AE noise and extend it to perform End Point Detection (EPD) in micro polishing using RMS value of AE signals.

This is done by monitoring AE signals by gradually reducing the contact area, while performing mechanical polishing.

2. Experimental tests

In order to demonstrate the applicability of EPD in micro polishing by means of AE signal, a set of experiments were carried out. Moreover, these tests, conducted with different contact areas, aim to show a correlation between the signal intensity and the polishing contact area, and therefore the applicability of the selected AE sensor for micro polishing.

In this investigation, polishing is performed with a cylindrical tool, rotating at high speed, which is brought into contact with the workpiece clamped on a dynamometer (see Figure 1).

Micro polishing tests are conducted on a 3-axis CNC machine equipped with a high speed attached spindle. The polished workpiece is a cylindrical billet of stainless steel (AISI 316) with initial Sa roughness of 1.35 µm. Prior to the test, the workpiece surface in the area of interest was ground with grinding ceramic stones, gradually increasing the grit mesh as following #220, #320, #500, #800. The final Sa surface roughness of all the workpieces was between 300 nm and 350 nm. The workpiece was clamped to a highly sensitive three-component force dynamometer 9347C from Kistler. An acoustic sensor, M304A R-cast with build-in amplifier by Fujy Ceramics Corporation, was fixed to the surface ensuring full contact between the sensor and the workpiece.

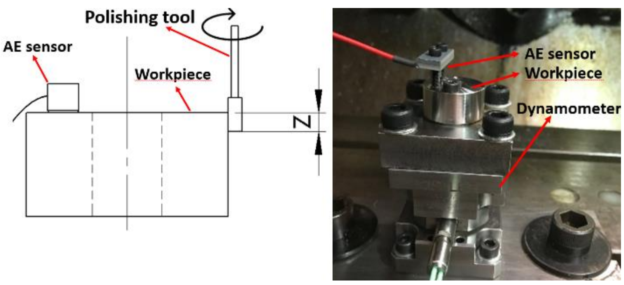

Figure 1. Set-up configuration for micro polishing

2.1. Tests procedure

Polishing tests are conducted with different contact areas. The contact area has been gradually reduced by reducing the height of engagement z (see Figure 1, left). In this way, smaller axial engagement steps correspond to smaller contact areas and the information about the surface roughness can be measured at the end of the process without dismounting the sensor from the workpiece. The heights of engagement Z were 4 mm, 2 mm, 1 mm and 0.5 mm. A constant rotational speed of 20 000 rpm was used in all tests. The monitored polishing steps, object of this investigation, were performed on the pre-polished surface with a tool of mesh #1 200 using two different paste grit size, 10 µm for the first step, and 1 µm for the second step. The contact force is maintained to a constant value of 0.1 N.

3. Results and discussion

Acoustic emission signals contain information about the physical phenomena characterizing the polishing process and other forms of emission noises, which are not directly related to the polishing phenomena. These noises, that can include

Hydraulic noise, spindle bearings, cooling lubricant, environmental conditions etc., have to be filtered out.

In Figure 2, a comparison of the frequency spectra in the designated working environment with and without process activity shows the important frequencies of the AE signal. The polishing process was characterized by frequencies higher than 5 kHz. For this reason, a high pass filter is built into the signal pre-amplifier to reduce noises and to estimate correctly the RMS values of the AE signals. Moreover, before performing the FFT a Hamming window was applied to minimize the effect of spectral leakage. Such a window was chosen in order to eliminate signal discontinuity and preferred to other windows because of its flat spectrum in the high frequency range.

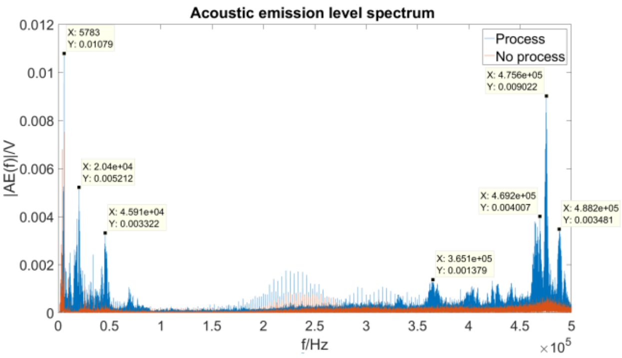

Figure 2. Acoustic emission spectrum showing the important polishing frequencies

Figure 3 shows the results of RMS acoustic emission level for a contact area of $2\,mm^2$ (left) and a contact area of $0.5\,mm^2$ (right). The considered contact areas were measured with an optical CMM. With a contact area of $2\,mm^2$ it is possible to notice a clear exponential decay trend. This trend is typical for polishing processes [2] and it has been found to be repeatable for all polishing steps. For a contact, area of $0.5\,mm^2$ the exponential trend is less noticeable due to the lower polishing total time and because the overall variation of RMS values is smaller than the one with a contact area of $2\,mm^2$. This can be improved by increasing the sampling resolution during the acquisition.

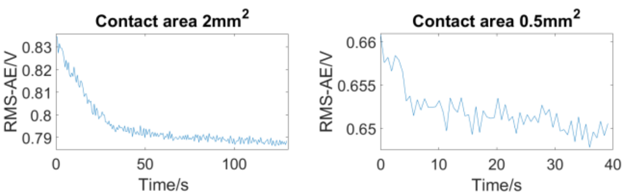

Figure 3. Comparison of different RMS AE level with different contact areas

3.1. End point detection criteria

End point detection has the goal of finding the optimal moment to change to a finer abrasive media between two consecutive steps and if necessary stop the process. To assess an End Point Detection criteria, the AE RMS signal is used as monitoring solution. When the signal reaches a steady state level, while all the boundary conditions are the same, the polishing process can be considered not effective anymore in reducing the surface roughness. Since the AE RMS follows an exponential decay, the data were fitted with an exponential function (see equation 1) and the equation's parameters were estimated.

$$y = y_0 e^{-at} + c = y_0 e^{-\frac{t}{\tau}} + c \qquad 1)$$

Where y_0, a and c are the equation's parameter and τ is the exponential time constant. One interesting property of this function is that it reaches the 95% of its maximum value after $t^* = 3\tau$.

$$y_0\left(1 - e^{-3}\right) = y_0 0.95 \qquad 2)$$

This condition is used as criteria to perform an automatic EPD.

3.2. Results

In figure 4, a fitted RMS curve is shown. The critical end point time t^* and the deviation Δ_{ae} between the maximum and minimum value of the curve approximating the RMS signal, are calculated for every polishing step.

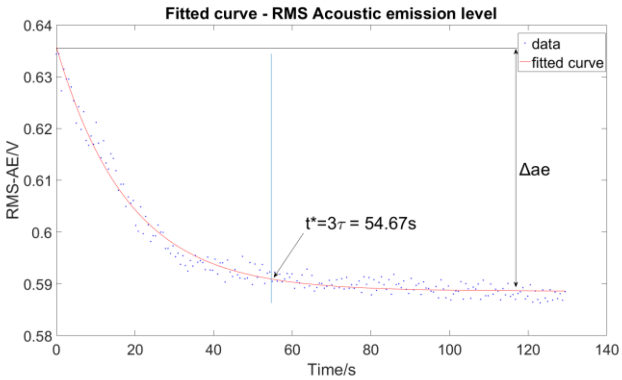

Figure 4. Critical end point $t^*$and the RMS acoustic deviation Δ_{ae}

This deviation Δ has been found to be directly proportional to the contact area, as can be seen in figure 5. The data are well fitted by a linear regression, with a $r^2 = 0.948$ for the first step and $r^2 = 0.999$ for the second polishing step.

Moreover, it is interesting to observe how the Δ_{ae} emission noise is higher for the first step of polishing, since the grit size of the abrasive paste is bigger and therefore more material is removed, resulting in higher emission noises.

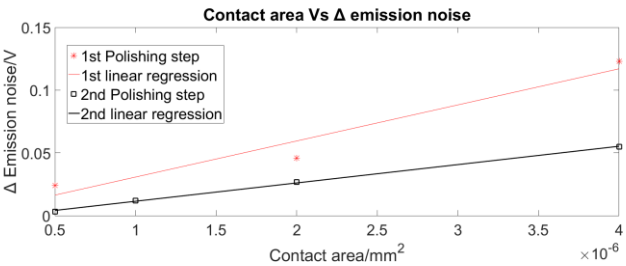

Figure 5. Contact area vs RMS acoustic deviation Δ_{ae}

4. Conclusion and Outlook

A method to perform EPD is presented and its applicability to perform micro polishing is shown. The contact area has been gradually reduced and End Point Detection (EPD) based on acoustic emission monitoring is shown. The proposed monitoring strategy and the criteria used for the automatic EPD can be a robust and efficient way to control the polishing process. The reduced contact area in micro polishing has been seen to reduce the signal intensity. The sensor and the monitoring strategy was successful to monitor contact area down to $0.5\,mm^2$.

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