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Tool wear evaluation in drilling by acoustic emission

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Abstract

A drilling process with different degrees of wear in the drill bit was studied to find relationships between acoustic emission (AE) and torque measured during the drilling process, and also with the degree of wear of the tool.
SAE 1040 steel samples were drilled, making holes with 5 mm diameter twist drill bits in continuous feed. The drill bits were modified with "artificial" (produced by spark-erosion) and "real" (obtained by regular mechanical use) failures such as different degrees of wear in the cutting edge and the outer corner. For every drilled hole, torque and AE were simultaneously measured and acquired.
In the first part of this work, the correlation between the AE parameters and torque measured during the drilling process is studied. Torque was measured as a control parameter to follow the dynamic behaviour of the drill bit. An alternative AE feature, called Mean Power (MP) showed a good correlation with torque when the moving average (MA) was computed.
In the second part, the AE mean power (MP) was related to different degrees of wear in drill bits. Clusters for the different levels of wear in a 2-D plot were obtained. In that plot the moving variance of the MP vs. the moving average of the MP, for each case of wear, were represented.
This application aims at repetitive manufacturing operations, where many signals per second may be obtained with fixed parameters as shape, drill bit diameter, spindle speed, feed, and a good statistical study can be done.

Keywords: acoustic emission; tool wear; torque; drilling; mean power

1. Introduction

Tool condition monitoring is an important point in manufacturing industry, because it allows: an increase in the quality of the products, an optimization of the cost and a good control of the process [1]. Drilling is one of the most commonly used machining processes in the manufacturing industry, and many tool condition monitoring methods are applied to drilling [2]. Tool wear in a machining process can be assessed by direct and indirect methods such as:

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measurement of tool wear, vibrations, power consumption, torque and load (thrust) and acoustic emission (AE).

These methods can be applied to study tool wear in turning, milling, drilling, etc. [3]-[5]

AE is the spontaneous release of localized strain energy in stressed material. The elastic waves are recorded by piezoelectric sensors on the material surface. The obtained electrical signal is parameterized and/or stored and analyzed with an AE system. AE signals can be burst or continuous type. AE feature parameters are typically defined for burst signals (but some of them can be extended for continuous signals). In machining, AE is produced by many sources such as: plastic deformation during cutting (in the workpiece and chip), friction (tool rake and chip, tool flank and workpiece), work material and chip breaking, tool fracture, and collisions between chip and tool. Both continuous and burst emissions are produced depending on the sources. [3],[6]-[8] Beyond the definition in the wide sense of the word wear by Kannatey-Asibu and Dornfeld [8], in this work the term is particularly referred to cases associated only to the flank or edge wear.

In the literature, waveform and features of AE signals are studied to extract information about drill bit wear in drilling [10]-[13].

Many AE parameters are defined for burst type signals and do not make sense for continuous signals, except RMS, average frequency and amplitude. In this work other basic and representative AE parameters were tested, to extract the essential information of the development of the cutting process. That is the AE parameter named mean power (MP), defined as the ratio between AE Energy and hit duration, can be applied to burst and continuous signals. MP was evaluated as a complementary parameter added to the more commonly used parameters.

Other way to study AE in drilling is analyzing the waveform by mathematical tools such as power spectra, wavelets, auto-similarity, etc. At present, these complementary studies of this work are under elaboration. Some preliminary results for turning were presented by the authors in a previous work [12].

In this work the suitability of AE features as indicators of the evolution of a drilling process is evaluated. In the first part, all the computed AE parameters were correlated with the torque signal. Torque has been widely studied in literature as an important parameter to evaluate the dynamics of the cutting process. The idea of this work is to find the AE parameters more correlated with the torque, in order to assess the tool condition.

2. Experimental Method

2.1. Material and machining

2.1.1. Workpiece samples

Thirty SAE 1040 steel specimens, 95 mm length, 14mm width, were used as workpieces. Homogeneity of the material, grain size and low quantity of inclusions was verified by metallographic studies, to ensure repeatability of measurements. In all samples a 1.5 mm pilot hole 10mm deep was prepared.

2.1.2. Drill bits

Six high speed steel (HSS) 5 mm diameter twist drills were used. “Healthy” drills were modified, adding artificial and real defects in flank and outer corner. The type and degree of drill bit damage was examined and measured by

SEM. The condition of the drill bits is represented in Table 1. WS1 and WS2 (cases 1 and 2 of spark-eroded edges) refer to different wear angles.

Table 1. Kinds of Drill bit wear

Drill bit	Condition	Label
1	New. Regular edge.	NRE
2	New. Irregular edge. (defective manufacture)	NIE
3	Worn cutting edge by spark-erosion (case 1).	WS1
4	Worn cutting edge. by spark-erosion (case 2)	WS2
5	Worn outer corner by mechanical wear	WOC
6	Crater wear in edges by mechanical wear.	CWE

2.1.3. Drilling machine

The specifications of the drilling machine were: LC-50RS vertical machine, continuous feed, spindle speed: 470 RPM, feed rate: 0.25 mm/seg, average final length of drilled holes: 15 mm, continuous lubrication with soluble oil.

2.1.4. Drilling procedure

Every specimen sample was drilled, one at a time with different drill bits. At least, three tests were made for each wear condition in order to obtain statistically representative results.

The test was performed in four stages:

First stage: drill bit approach to the sample, contact between the drill bit and the sample and start of drilling.
Second stage: stationary performance of the drilling process aided by the pilot hole.
Third stage: end of the pilot hole and start of cutting beyond the pilot hole.
Fourth stage: steady state drilling in the zone beyond the pilot hole.

2.2. Torque and AE measurements

For all the drilling tests, the AE was measured with an 18-bits resolution PAC PCI-2 system. The elastic waves produced in the cutting process were converted to electrical signals by a PAC differential wideband piezoelectric sensor and conditioned with a 40 dB preamplifier. The torque was measured with an Instron torque cell, and the electrical signal obtained was conditioned and registered as an external parameter of the AE system. The AE was A/D converted, acquired with a sampling rate of 5 Msamples/sec and parameterized. The measured parameters were: energy, counts, duration, amplitude and RMS. In view of the fact that the drilling AE signals are continuous, for the three first mentioned parameters, the mean power and the average frequency were computed.

AE parameters, waveforms and torque obtained for each drilled bar with each drill bit with different condition of wear were saved in a PC computer to be further processed with mathematical and statistical analysis.

For the torque analysis, linear correlation was applied to amplitude, RMS, average frequency (Avg freq) and MAMP. The moving average of the MP was calculated in order to smooth the scattered MP, as a low pass filter. The results were plotted and analyzed.

For the wear degree evaluation of the drill bit by means of the AE parameters, the MAMP and the moving variance of the MP were the appropriate parameters.

3. Results

3.1. Part I. Torque vs. AE

The correlation between torque and AE parameters is displayed in Fig.1 for all the measured cases with different worn drill bits: new (NIE and NRE), worn edge with spark-erosion (WS1 and WS2), worn outer corner (WOC) and craterized edge (CWE). The red squares represent the torque-MAMP correlation, the brown circles the torque-RMS correlation, the green triangles the torque-Avgfreq correlation and the blue diamonds the torque-amplitude correlation. The best correlation was for MAMP, better than the RMS, the most commonly used parameter to study the AE in machining. Although the mathematical procedure to obtain both parameters is comparable, the MP analysis showed better results than RMS.

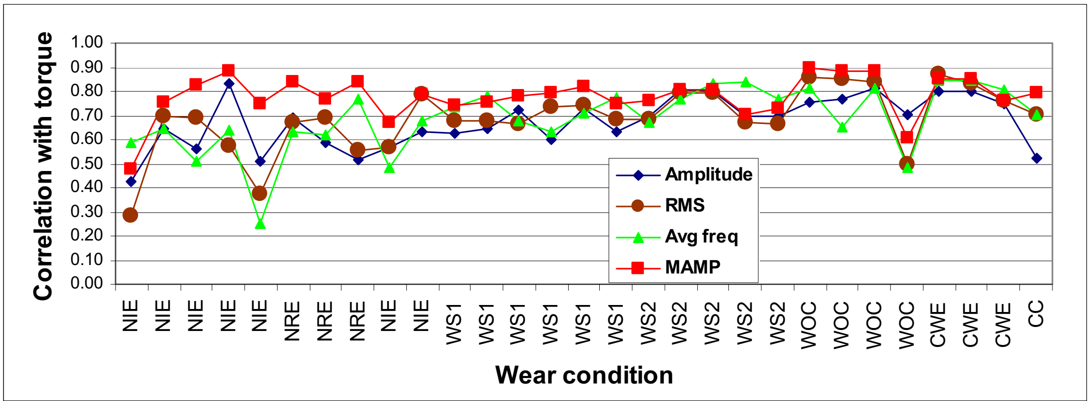
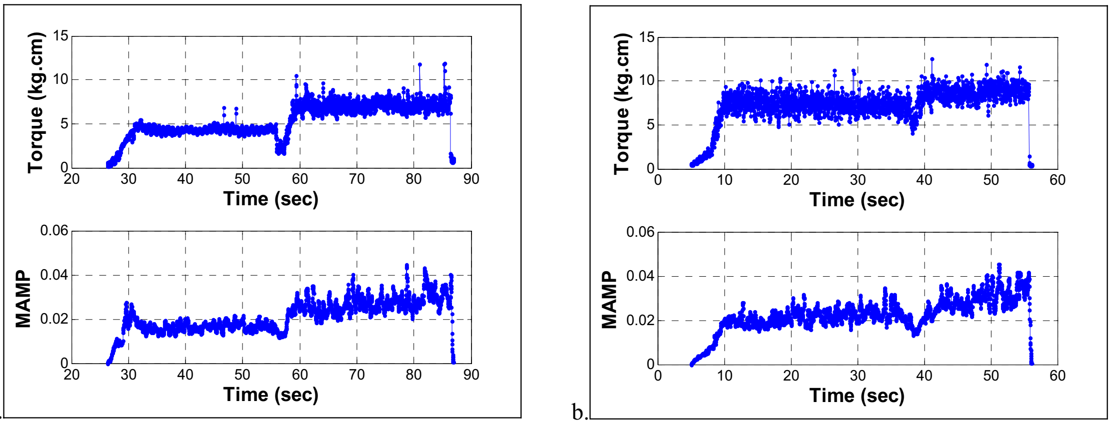


Fig.1 Linear correlation between torque and AE typical parameters (features) amplitude, RMS, average frequency (avg freq), moving average of mean power (MAMP). MAMP shows a better matching with the torque than RMS in a wide range of the MA. CC refers to an extra case for a drill bit with craterized chisel.

In Fig.2 the torque and the MAMP versus time were shown for two cases, as examples. The similarity between torque and MAMP behaviour over the test is evident. This is obviously related to the results in Fig.1. Both graphs in Fig.2 show the different stages of the cutting process detailed above, by means of both indirect methods. For example watching the AE signal the drilling machine operator can infer if the tool is entering the material (first stage), reaching the end of the pilot hole (second stage), leaving the pilot hole (third stage) or finishing the cut (fourth stage).

In the stationary regimen, second stage (in this case the main part of the duration of the machining process) irregularities could be observed in the signal related with anomalies of the cutting process.

The energy of the rotating drill is transmitted to the sample through the friction of the chisel, the friction of the flute with the wall, and in proper cutting of the material (plastic deformation). This is actually measured by the torque. It is outstanding how accurately the AE follows these mechanical changes giving place to an important correlation.



a. b.

Fig.2 a) Torque and MAMP vs. time for a drilling process for NIE lubricated, 470 rpm, b) Torque and MAMP vs time for a drilling process for WS1 lubricated, 470 rpm.

3.2. Part II. AE MP vs. wear

This part of the analysis was made for 25 drilling tests for the same conditions of feed rate, lubrication, spindle speed, and with different states of the drill bit as described in Table 1.

To avoid the wide spreading of this feature, the MP was filtered by means of moving average, as in the previous part, obtaining the MAMP (Moving Averaged Mean Power). The degree of variation of the signal was measured by the Moving Variance of Mean Power (MVMP). The MVMP were represented as a function of MAMP. The obtained results are displayed in Fig.3. The blue up triangles corresponds to NIE and NRE cases of new drills, the red diamonds to WS1, the green circles to WS2, the cyan squares to WOC and the violet down triangles to CWE. Each point in this graph was obtained using a sliding window including 10 AE hits. The dependence with the quantity of averaged points was evaluated, and the procedure works correctly in a wide range. In the processing of each drilling test data, only 20 seconds of the stationary part (second stage) of the AE signal were considered. This method may be useful for repetitive processes, for example in manufacturing the same workpiece, with the same material, at constant conditions of speed, lubrication, size of tool, etc. AE from drilling is a stochastic process and the results for each test appear as clusters in a 2D plot, and the points corresponding to a definite state of the tool are located around the center of mass of the cluster.

In this work it was established that the behavior of the MVMP can be related to the fracture of chip, the most scattered the results the highest the chip breakage. A similar result is shown in literature for the RMS parameter. The regular edges made a regular cut while the damaged edges as WS, WOC and CWE produced irregular, small chip pieces.

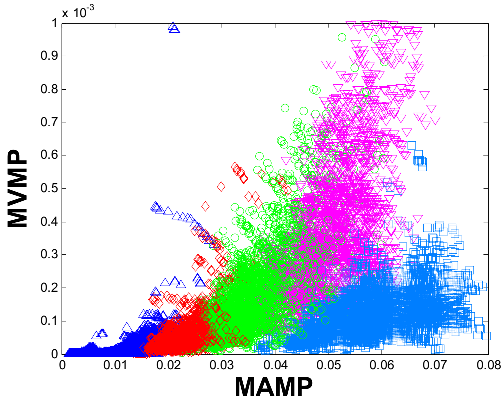


Fig.3 AE MVMP vs. MAMP measured and computed for different tool wear condition in 25 drilling tests at the same cutting parameters. The color of the marker represents the wear case of the drill bit. The blue up triangles corresponds to NIE and NRE cases of new drills, the red diamonds to WS1, the green circles to WS2, the cyan squares to WOC and the violet down triangles to CWE. The average was performed with the 10 nearest points of each calculated point for highest number of nearest points the clustering is better.

4. Conclusion

An analysis of the relationship between torque and AE parameters shows the best correlation for MAMP. Although the mathematical procedure to obtain both parameters is similar, the MP analysis showed better results than the most commonly used parameter in continuous AE signals, the RMS.

AE from drilling is a stochastic process and the results for each test appear as clusters of points in a MVMP-MAMP 2D-plot. The points corresponding to signals obtained from a definite state of the tool are located around the center of mass of the related cluster. This method may be useful for repetitive manufacturing processes. The behaviour of the MVMP vs. MVMP can be related to the fracture of chip, the most scattered the results the highest the chip breakage. A similar result is shown in literature for the RMS parameter variation. The dependence with the numbers of averaged points was evaluated, and the procedure works correctly in a wide range. The next steps of this work are to add new measurements in different conditions to corroborate the validity of the method, and to include the results obtained from the waveforms study.

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