INFLUENCE OF THE SENSOR POSITION IN THE SIGNAL OF ACOUSTIC EMISSION WHEN MONITORING MILLING OPERATION

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Abstract. *The monitoring of a machining processes is an important tool to improve the quality and to increase the productivity. Acoustic emission (AE) signal has proved to be suitable for a wide range of applications, like the monitoring of tool wear, detection of contact bewteen workpiece and tool and grinding wheel dressing. However, to monitor tool wear it is necessary to evaluate the behaviour of the acoustic emission signal for the specific application. The aim of this work consists in the analysis of the effect of the position of the sensor relative to the source of acoustic emission, which means the cutting zone. This work was carryed out in a face milling operation of 400 mm x 50 mm workpiece of low alloy high strengh carbon steel. It was used only one insert in the tool hold to facilitate the analysis of the signal. The acoustic emission signal was adquired at a rate of one million points per second for several cutting conditions and also for different stages of tool wear. The AE sensor was positioned in the central part of the workpiece and the signals for three different position of the cutting region were compared: in the beginning of operation, at the middle section and at the end of the workpiece. Statistic parameters were estimated from the signal for each position and a hypothesis test was applied to verify if they belong to similar statistic groups. The results indicate that the position of the sensor in relation to the sources of acoustic emission may affect the signal.*

Keywords*: Machining process monitoring, milling, acoustic emission.*

1. INTRODUCTION

The automation and optimization of manufacturing processes have an increasing importance in the productivity improvement, as a result monitoring and control systems have become fundamental for production. Also, systems for process monitoring are an important requirement in the automation of manufacturing processes (Dolinsk and Kopac, 1999).

Among the main functions of a monitoring and control system of machining processes, are: to establish the cutting speed and feed rate, tool movements, and control of the cutting tool path. Most of these functions mentioned are possible to be done with the current stage of technological development of the CNC machines. However, several functions such as the inspection of the state of the tool and workpiece and also the determination of the exact moment to change the tool still remain a decision of the operator and depend on the practical experience. Besides this, when implementing a monitoring system to a certain process it is important to verify how this system shall react to several variations that may occur during the operation. This can be variation of dimension and geometry of the workpiece, changes in the material of the workpiece and tool, sensors position, cutting conditions and many others. In the case of acoustic emission, it must also be evaluated if the variation of the source distance from and to the sensor perform any influence over this signal.

Acoustic emission, according to Ravindra, Srinivasa and Krishnamurthy (1993), may be addressed as being waves of elastic tension resulting from the short discharge of energy of one or more sources inside of a material submitted to an external stimulus. These vibration waves are due to an internal rearrangement of the crystal structure of metals, and the frequency of propagation is normally over 20 kHz (Dolinsk and Kopac, 1999). These waves of tension produce displacement in the surface of the material that can be detected by piezoelectric sensors that transform this displacement in electric signals.

The acoustic emission signals are classified in two types (Figure. 1): the peak signal (transient) and the continuous signal (Blum and Inasaki, 1990; Matsumoto and Diniz, 1997). In metal cutting operations, the continuous signal is normally associated to plastic deformations in the ductile materials and the peak signal of short duration are normally originated from crack formation and chips impacts.

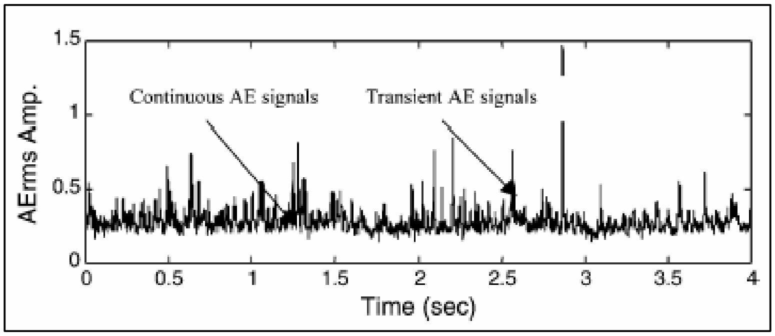

Figure 1. Characterization of an acoustic emission signal (Li, 2002).

Figure 2 shows the main sources of acoustic emission for an orthogonal metal cutting operation. As a consequence of the bands of AE frequency in machining (Liang and Dornfeld, 1987), between 50 and 1000 kHz, the signal may be separated from noises with certain facility by using high band pass filters. On the other side, the high frequencies make it difficult the sampling, the storage, and processing of the digitalized signal during the process.

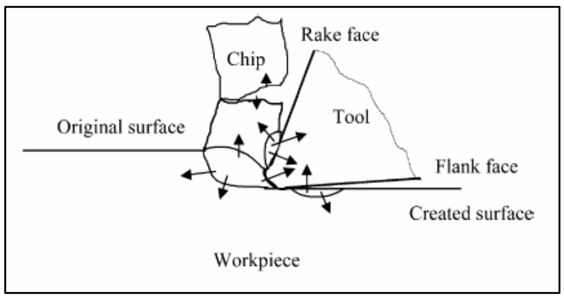

Figure 2. Main sources of acoustic emission in machining (Li, 2002).

Among the currently existing conventional processes of machining, milling shows itself as one of the most important. Its importance is mainly due to the good versatility in manufacturing, high rate of material removal and also by the characteristic of the chip produced, which is relatively short, what does not compromises the quality of the surface generated. Its versatility is possibly mainly due to the great variety of geometries that its tools may present, making it possible, by consequence, the generation of an equally vast number of surfaces.

The main goal of this work is the study of the effect of sensor position in the AE signal. The signal acquisitions were done in three distinct regions of the workpiece during the cutting operation. During the operation, the relative position of sensor and source of acoustic emission changes, and this result in some influence over the signal.

2. EXPERIMENTAL PROCEDURE

It was used a face milling operation of high strength low alloy pearlitic steel (DIN 38MnS6), with mean hardness of 258 HV and chemical composition shown in Table.1.

Table 1. Chemical composition the high strength low alloy steel DIN 38MnS6, % weight.

C	Mn	P	S	Si	Ni	Cr	Mo	V	Al	Cu	Pb	Ti	Nb	B	Sn	Ca	H_2	N_2	Te
0,38	1,50	0,024	0,061	0,54	0,06	0,18	0,03	0,004	0,006	0,15	0,002	0,0017	0,0050	0,0007	0,007	0,0005	0,0002	0,0159	0,0027

The dimensions of the workpiece were 400 mm x 50 mm x 100 mm. A scheme of the milling process is shown in Figure 3.

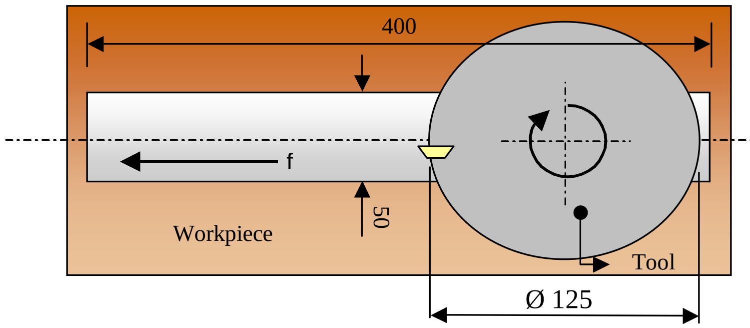

Figure 3. Scheme of the face milling operation used in the work.

Three cutting conditions were used, as shown in Table. 2. Condition 1, was the most sever condition for the insert, and was established according to the recommendation of the tool manufacturer. Condition 2 is an intermediate situation in terms of cutting speed, feed rate and depth of cut, and finally Condition 3 a finishing cutting operation.

Table 2. Cutting conditions used in the tests.

Cutting conditions	v_c (m/min)	a_p (mm)	f_z (mm/rev)
1 (rough)	205	1,5	0,24
2 (intermediate)	250	1,0	0,20
3 (finish)	300	0,5	0,16

There were also established three distinct stages of maximum flank wear ($VB_{Bmáx}$). Table 3 presents the three adopted stages. The aim of creating cutting conditions and different tool wear stages was to amplify the band of situations to the observation of results after the application of the hypothesis test. In order to increase the reliability of the results, sixteen repetitions were made for each of the possible combinations of the tests.

Table 3. Values of maximum flank wear in which the AE signal was acquired.

Tool wear	Values of $VB_{Bmáx}$
New tool	0
Intermediate wear	Between 0,20 and 0,40 mm
Severe tool wear	Over 0,40 mm

The milling operations were carried out in a CNC machining center Romi Discovery 760, with maximum power of 11 kW, continuous variation of spindle rotation and feed rate, maximum spindle rotation of 10.000 rpm and feed speed of up to 25.000 mm/min. The toolholder had a diameter of 125 mm for up to eight inserts, it has a specification R245 125Q40-12M. The inserts of cemented carbide had specification SEMN 12 04 AZ, class M, coated with titanium nitride (TiN).

The AE signal was acquired using a sensor connected to the workpiece and to a signal conditioner DM 42. The conditioner has four input channels an two output channel, one for the RMS value and the other for the raw signal. The signal conditioner was connected to a block of connectors BNC-2110 which was connected to an acquisition card NI-DAQmx PCI-6251M. The signal was acquired at a rate of 1,25 MS/s, which is indicated for acquisition of the raw signal of AE.

The signal acquisition was made during two seconds. This short time was employed due to the acquisition rate (1 MHz) used and the number of maximum data that could be stored in the computer file. It was possible to generate files with two million points for each acquisition. In experiment that is necessary a longer acquisition time, for example the monitoring of tool wear, only two seconds would not be enough to represent a pass of the mill over the workpiece. The cutting lasted for about three minutes for each pass. Due to this limitation, the acquisition was made during three tool wear stages for each pass (using each combinations of cutting conditions and tool wear stage established). The region of acquisition in the workpiece was divided in three parts, according to figure 4. The first part (1) at the entrance of the mill in the beginning of the cut, the second part (2) where the mill passes approximately by the middle of the workpiece and the last part (3) and the third part (3) close to the end of the cut. One simple acquisition was made in each of these parts. It was employed a high band pass filter of 50 kHz and, therefore, the signal was analysed inside a band of frequencies from 50 to 500 kHz. This experimental procedure was used to monitor tool wear and the results can be found in Souto et al (2006) and Souto (2007).

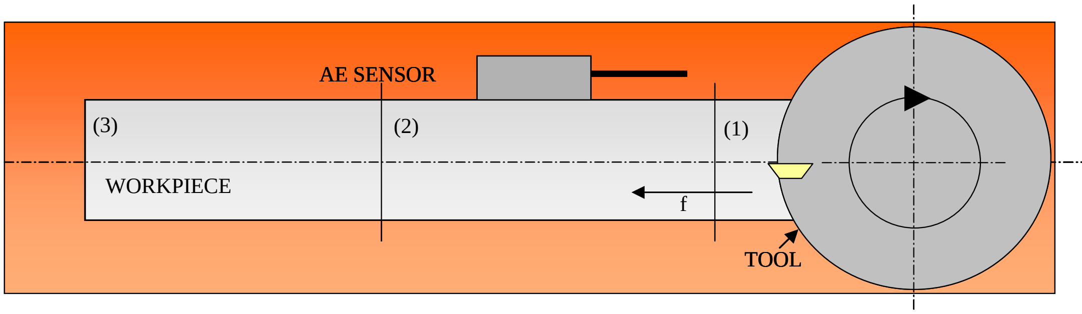

Figure 4. Scheme of the stages in which the AE signal was acquired.

In order to evaluate the raw signal of acoustic emission and analysis of the effect of the sensor position, it was estimated nine statistic parameters from the signal:

. Kurtosis;
. Skewness;
. Global RMS;
. Peak;
. Crest factor;
. Band 1 (RMS of the signal in the band from 120 to 170 kHz);
. Band 2 (RMS of the signal in the band from 190 to 240 kHz);
. Band 3 (RMS of the signal in the band from 260 to 300 kHz);
. Band 4 (RMS of the signal in the band from 120 to 300 kHz).

The last four parameters were taken after the verification of the power spectrum of signal, from where one can observe bands which presented higher levels of energy that would better represent the process. The parameter, namely Band 4, represents all other bands (from 120 to 300 kHz).

The hypothesis test was used as a tool to verify if the averages of the parameters that represent the acquisition in each region of the workpiece are similar. In other words, it was used to verify if the results belong to the same statistic group. Therefore, the input data of the test were the nine statistic parameters (and its sixteen repetitions) calculated from the signal of each of the stages of acquisition previously mentioned.

For calculation of the hypothesis test, it is necessary to compute the value of t_0, given by Equation 1, which is a *t-distribution* with the number of degree of freedom calculated by Equation 2.

$$t_0 = \frac{\left|\bar{x} - \bar{y}\right|}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{1}$$

$$\upsilon = \frac{\left[\left(\frac{s_1^2}{n_1}\right) + \left(\frac{s_2^2}{n_2}\right)\right]^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 + 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 + 1}} - 2 \tag{2}$$

where:

. $\bar{x}$ and $\bar{y}$ are the estimative of the averages of groups 1 and 2, respectively;

. s_1^2 and s_2^2 are the estimatives of the variances of groups 1 and 2, respectively;

. n_1 and n_2 are the numbers of data of the groups 1 and 2, respectively.

It was considered as null hypothesis that the averages of both groups are equal and an alternative hypothesis that the averages of the groups are different. For a high level of significance α_t of 95% for the hypothesis test, if the value calculated of t_0 is higher than that for t_α, then $t_0/t_\alpha > 1$, the null hypothesis is rejected and one concludes that both averages belong to distinct statistic groups. Otherwise, if t_0 is less than t_α, so $t_0/t_\alpha < 1$, the null hypothesis is accepted and one concludes that both averages belong to the same statistic group

In the case of influence in the signal of the procedure of dividing the acquisition in three parts, it is expected that the test shows that the statistic groups representing each part did not suffer any influence of the position if the result of the test is less than 1.

The comparisons for this test were done two by two. Therefore, group 1, that represents the statistic parameters taken from the acquisition in part 1, was compared to group 2, taken from part 2. Following, the group 1 was compared to group 3, and finally, group 2 was compared to group 3, completing every possible combination.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Table 4 presents the results of the hypothesis test for the tool with no wear. Inside each cutting condition used, the parts are compared with each other. The parameters estimated are the references to the test. The averages of the sixteen repetitions of the acquisitions were used in each part.

Table 4. Hypothesis test for verification of parts 1, 2 and 3 for a tool with no wear.

	Cutting condition 1			Cutting condition 2			Cutting condition 3		
	1 e 2	1 e 3	2 e 3	1 e 2	1 e 3	2 e 3	1 e 2	1 e 3	2 e 3
Kurtosis	0,17	1,31	1,14	0,26	8,81	8,21	0,95	4,76	2,26
Peak	0,28	0,24	0,10	0,24	0,09	0,16	0,17	0,52	0,32
Global RMS	0,05	0,26	0,29	0,12	1,39	1,42	1,56	1,38	0,93
Crest factor	0,05	0,38	0,34	0,09	1,62	1,68	1,81	1,44	0,97
Crest factor	0,04	0,39	0,32	0,07	0,67	0,58	0,41	3,78	2,68
Band 1	0,01	0,28	0,28	0,16	1,38	1,36	0,02	0,65	0,64
Band 2	0,01	0,27	0,26	0,06	1,35	1,34	0,25	0,55	0,37
Band 3	0,02	0,12	0,14	0,03	1,18	1,20	0,17	0,25	0,13
Band 4	0,00	0,27	0,26	0,13	1,31	1,30	0,07	0,63	0,59

The hypothesis test for a new tool indicates that, mainly for cutting condition 1 which is the most severe condition, there is no effect of the variation of the relative position of sensor. All results of the tests for cutting condition 1 belong to similar statistic groups, indicating that they are possibly similar data. However, for the two other cutting conditions, the results indicate that part 3 is different from the others. In most of the results the values are greater than 1 when part 3 is compared to the others.

Table 5 presents the results of the hypothesis test for a tool in the intermediate stage of wear for all cutting conditions used in this work.

Table 5. Hypothesis test to verify parts 1, 2 and 3 for a tool with intermediate wear.

	Cutting condition 1			Cutting condition 2			Cutting condition 3		
	1 e 2	1 e 3	2 e 3	1 e 2	1 e 3	2 e 3	1 e 2	1 e 3	2 e 3
Kurtosis	0,09	1,65	3,15	0,05	2,99	3,46	0,49	5,79	3,42
Peak	0,20	0,17	0,02	0,17	0,40	0,24	0,27	0,25	0,07
Global RMS	0,04	0,50	0,50	0,09	0,48	0,60	0,41	8,45	4,02
Crest factor	0,10	0,64	0,65	0,07	0,72	0,87	0,46	7,78	3,95
Crest factor	0,02	0,54	0,53	0,47	0,41	1,02	0,14	3,10	2,39
Band 1	0,10	0,63	0,55	0,10	0,47	0,64	0,17	3,93	3,41
Band 2	0,08	0,23	0,32	0,05	0,25	0,30	0,27	1,27	0,92
Band 3	0,17	0,42	0,59	0,10	0,02	0,07	0,19	3,22	2,61
Band 4	0,04	0,51	0,50	0,09	0,41	0,55	0,34	6,28	4,38

Most of the results of the hypothesis test for a tool with intermediate stage of flank wear indicate also that part 3, when compared to the other parts, do not belong to the same statistic group. However, for cut condition 1, only the kurtosis parameter has indicated values greater than 1 when comparing the results for part 3 and the others.

Table 6 presents the results of the hypothesis test for the tool in high stage of wear to all cutting conditions used in this work.

Table 6. Hypothesis test to verify parts 1, 2 and 3 for the tool with severe wear.

	Cutting condition 1			Cutting condition 2			Cutting condition 3		
	1 e 2	1 e 3	2 e 3	1 e 2	1 e 3	2 e 3	1 e 2	1 e 3	2 e 3
Kurtosis	1,21	3,00	3,39	0,54	4,88	8,19	0,28	6,32	5,34
Peak	0,08	0,38	0,44	0,26	0,27	0,45	0,21	0,30	0,07
Global RMS	0,27	0,02	0,24	0,44	1,64	1,49	0,56	7,40	7,58
Crest factor	0,57	0,45	1,04	0,46	1,98	2,01	0,38	8,03	7,47
Crest factor	0,13	0,97	1,29	1,20	1,66	0,28	1,82	3,46	1,87
Band 1	0,15	0,11	0,25	1,67	3,46	2,52	0,15	2,99	3,54
Band 2	0,06	0,04	0,02	0,40	1,43	1,17	0,19	3,25	2,16
Band 3	0,17	0,17	0,02	0,33	0,86	0,59	0,88	4,07	4,61
Band 4	0,14	0,08	0,21	1,14	2,47	1,83	0,15	3,45	3,78

The result also indicates that the AE signal in part 3 is different from the other, they do not belong to the same statistic group. As usual, in cutting condition 1, most of the results were less than 1, indicating that for this situation the groups are similar. Parts 1 and 2, when tested with each other, indicate that both belong to the same group, with few exceptions.

The cutting condition 1, the most severe condition, is the one that has the greater intensity of power generation. It is possible that this makes that there is no considerable difference among the signals of each of the regions were the acquisitions were made. Most of the parameters used were not able to identify differences among the parts. The only parameter that could indicate this difference was the kurtosis. This parameter measures the dispersion of the function density of probability (fdp). This may be indicating that, in the most severe cutting condition, the dispersion of the functions of the groups may be sufficiently distinct, in order to the hypothesis test be able to show differences among them.

The results of most of the hypothesis tests indicate that part 3 of the acquisition do not belong to the same statistic group of parts 1 and 2. This means that it would not be appropriated to use part 3 in the analysis of the AE signal using the same cutting situations, workpiece geometry and acquisition conditions of acoustic emission. The use of data from this region together with the data from other regions should affect the results and prevent from a correct interpretation of the phenomena that might come to be studied.

Figure 5 shows how the feed velocity and the sources of acoustic emission generated by machining changes the relative position to the sensor installed in the central part of the workpiece. It is observed that, in the final region of the workpiece (parte 3), both cutting tool and the elastic waves that characterize the acoustic emission are moving away from the sensor, unlike to what happens in the entry and in the middle of the workpiece (partes 1 and 2, respectively). Therefore, it may be possible that this variation in the direction of the elastic waves that are captured by the AE sensor are affecting in the characteristics of the acquired signal.

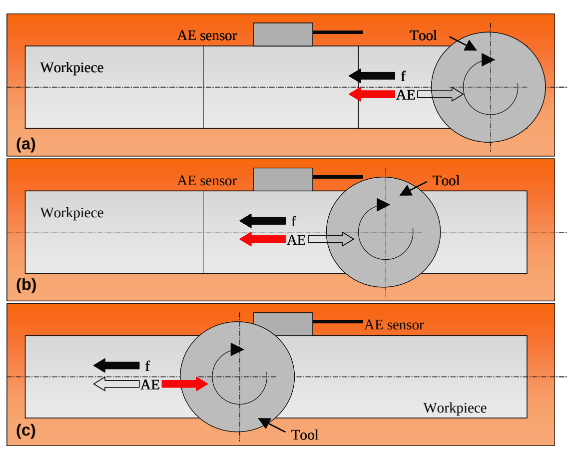

Figure 5. Position of the cutting tool and AE source relative to the sensor. a) e b) in parts 1 and 2 of the acquisitions, cutting tool and the elastic waves are moving towards the sensor; c) in part 3, cutting tool and the AE waves move away from the sensor.

4. CONCLUSIONS

The results obtained allow the following conclusions to be withdrawn for the cutting conditions and materials adopted in this work:

1. The hypothesis test with the signal of acoustic emission acquired in part 3 (final part of the workpiece) has shown that its estimated parameters do not belong to the same statistic group of parts 1 and 2, according to the methodology adopted in this work.
2. The most severe cutting condition (condition 1) used in this work could not identify, with exception of the kurtosis parameter, difference among the parts of acquisition like the other conditions.
3. Most of the results shown that the final part of acquisition has suffered some influence of the position.

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6. RESPONSIBILITY NOTICE