

The possibility of applying acoustic emission method to optimize determination of milling parameters

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Abstract: - Nowadays acoustic emission (AE) method is used in many fields of science, including in the diagnosis and monitoring of machining processes such as turning, grinding, milling, etc. Monitoring of milling process allows to ensure stable conditions of treatment. Stable conditions of milling process have a great impact on the quality of the surface. There are different methods used for monitoring machining processes, i.e. dynamometer methods, thermography, vibrations measurement, acoustic emission, etc. The research was carried out on a universal FUW3157 III milling machine using end mills made of HSS. Tools were in different stages of wear. The research was carried out at constant rotational speed and variable other cutting parameters, i.e. feed, depth of cut. Milling process was performed on a sheet made of EN AW-7020 aluminium alloy. The milling process was monitored by an acoustic emission set made by Physical Acoustics Corporation (PAC). The PAC system consists of: preamplifier USB AE Node, type 1283 with bandpass 20 kHz – 1 MHz, AE signal measurement sensor type VS 150M, with a frequency range 100 – 450 kHz, computer with AE Win for USB Version E5.30 software for recording and analysing AE data. During the study, the acoustic emission signals generated during milling process were recorded and then chosen parameters were analyzed e. g.: amplitude, number of events - hits, the effective value of the signal (RMS). The study can be the basis for the use of acoustic emission method for monitoring milling process and determining the parameters to ensure stable conditions of that process and the same to obtain a high quality surface.

Key-Words: - acoustic emission (AE), diagnostic, monitoring, milling, cutting parameters, optimization

Received: April 9, 2020, Revised: July 20, 2020. Accepted: August 3, 2020. Published: August 6, 2020.

1 Introduction

Machining is still the most common method ensuring shape and dimensional requirements for forming of different materials, usually metals. Milling is one of them. Conventional machining accuracy is usually considered as a function of the characteristics of all the components of object, tool, fixture and machine. There are: accuracy performance, the accuracy of static and dynamic determining and cutting parameters, which are associated with strength, temperature and wear of the cutting edge [1, 2].

To obtain a high surface quality should be optimized determination of cutting parameters. Manufacturers of tools give ranges of recommended parameters, but in order to achieve the best possible surface area is necessary to define the exact parameters [3]. One of the criteria for ensuring high surface quality is reducing the tool vibration [4]. This is particularly important for finishing treatment. Additional advantage is longer tool operational time. Monitoring the tool wear allows obtaining high quality of machined surface and

avoiding unplanned breaks in production caused by its catastrophic failure [5, 6, 7, 8]. On the other hand, there is requirement of possible the best machining efficiency which results in reducing production costs [9, 10].

There are many methods for monitoring and optimization of the machining process for selection of cutting parameters. One of them is the acoustic emission (AE) method [11]. According to the definition acoustic emission is an evanescent elastic wave, which is the result of rapid release of the energy accumulated in the material by propagating a micro-damage (increase in micro-cracks, the movement of groups of dislocations) in the material or by a process (friction, leakage, etc.) [12, 13, 14]. The frequency range of typical acoustic emission signal is usually determined in 20 kHz – 2 MHz [15].

Acoustic Emission is considered as a passive non-destructive method. One of the advantages of using this method is the possibility of conducting continuous research without having to shut down equipment out of service. The sensitivity of AE is

one of the highest of all methods. Lee et al. [16] reported that the AE technique has a higher sensitivity compared to other sensing systems due to its wide detection range. And last but not least is the possibility of locating the source of the AE signals generated by internal and external factors e.g.: cracks, leaks, etc.

The stimulus causing the release of energy and the formation of elastic waves can be: temperature change, environment, load operation, and the processes which are accompanied by acoustic emission changes both at the micro and the macro scale, such as: friction, cracks, plastic deformation, leaks, corrosion, chemical reactions, structural and phase changes, delamination, cracking of the fibers and matrix in composites, etc. [12, 17].

The acoustic waves propagate in all directions from the source, can thus be detected by one or more sensors mounted on an object or component. Due to the phenomenon of wave attenuation during their propagation, the distance from which they are detectable is limited. This distance depends on many factors, including mainly material properties, object geometry and the level of interference from background noise [13, 17]. Examples of AE signals are shown in Fig. 1 and Fig. 2.

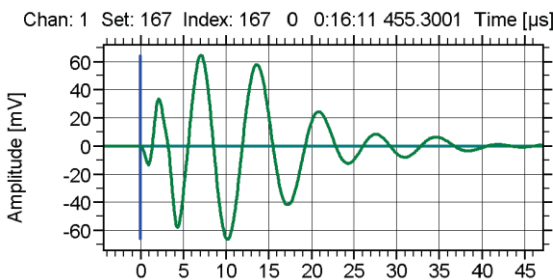


Fig. 1. Example of typical acoustic emission burst signal [15].

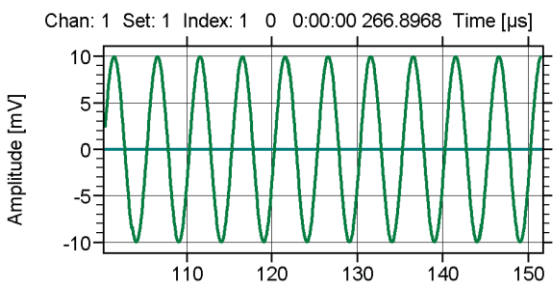


Fig. 2. Example of typical acoustic emission continuous signal [15].

AE signal can be characterized by parameters such as: number of exceedances of the threshold of discrimination – counts, hits, amplitude, duration, rise time, RMS and energy of the signal, etc. Schematic definition of the features of an AE signal are presented in Fig. 3.

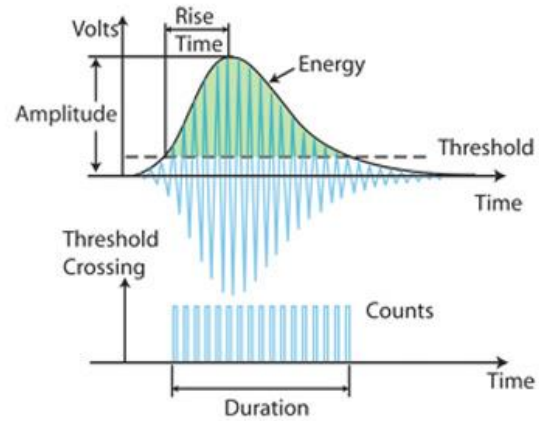


Fig. 3. The definitions for AE parameters [18].

This article presents the possibility of using acoustic emission method for optimizing the selection of cutting parameters during milling.

2 Research methodology

The research was carried out on a universal FUW3157 III milling machine using end mills made of HSS. Milling process was conducted without any cooling.

As a workpiece was used sheet made of AW-7020 aluminium alloy. Sheet thickness was 20 mm. The chemical composition of chosen alloy is presented in table 1.

Table 1. Chemical composition of AW-7020 alloy

Chemical composition (%)									
Zn	Mg	Fe	Si	Mn	Cr	Cu	Zr	Ti	Al
4.70	1.30	0.35	0.30	0.24	0.14	0.10	0.07	0.08	bal.

The basis of cutting parameters selection was the recommendations of the tool manufacturer. The research was carried out at constant rotational speed n and changing feed and depth of cut. The cutting parameters are presented in table 2.

Table 2. The cutting parameters of milling process

	Cutting parameters	
n [rpm]	400	
ap [mm]	3.0	5.0
f [mm/min]	25; 30; 35	25; 30; 35

Used four fleets end mills (3428 type) with a diameter of 20 mm in various degrees of wear: new, blunt, slightly blunt with broken one of blades. Selected tools are shown in Fig. 4 and the view of cutting edges in Fig. 5.

For monitoring the milling process acoustic emission method was used. Research of acoustic emission (AE) accompanying the milling process was performed using a kit from Physical Acoustics Corporation. The kit includes: AE-Sensor VS 150M (with a frequency range of 100 - 450 kHz), preamplifier with bandpass 75 kHz – 1.1 MHz, USB AE Node recorder, type 1283 with bandpass 20 kHz – 1 MHz and computer. For recording and analysing AE data was used software AE Win for USB Version E5.30 designed for mentioned PAC system. The software enables recording of a raw signal and performing analyzes. Information is available on changes in individual parameters: amplitude, RMS, energy, hits and counts over time. It is possible to perform FFT (Fast Fourier Transform) analysis to find characteristic signal frequencies for individual phenomena. Analysis of rise time and signals duration allows to determine their character, e.g. whether it is a continuous or burst signal. Selecting available filters and changing the threshold settings makes it easier to separate the signal from the background noise.

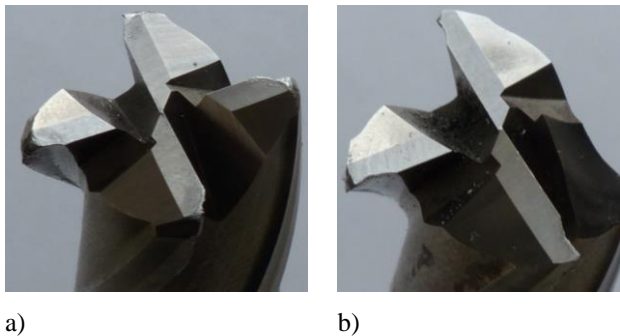


Fig. 4. The view of the tools:
a) blunt, b) with broken one of blades.

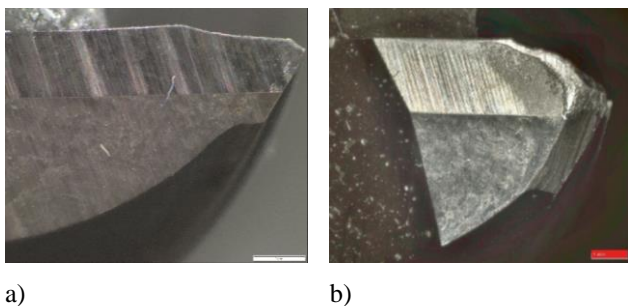


Fig. 5. The view of cutting edges:
a) new tool, b) blunt tool.

The sensor was fixed to the surface of the vice, used as a workpiece holder, by dedicated magnetic holder. Between the sensor and the surface, the silicone grease was used as a coupling fluid.

A view of the laboratory stand is shown in Fig. 6.

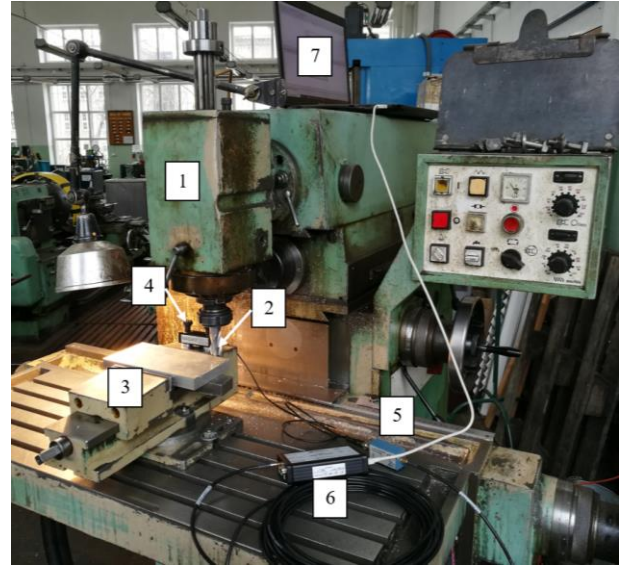


Fig. 6. The view of laboratory stand: 1 – milling machine, 2 – tool, 3 – vice with workpiece, 4 – AE sensor with magnetic holder, 5 – preamplifier, 6 – AE recorder, 7 – computer.

3 Research results

During the study, the acoustic emission (AE) generated in the milling process carried out on a test, recorded a number of parameters which were analyzed. These parameters were e.g.: number of hits, amplitude, RMS, energy, etc. The analysis of that parameters was performed using AE Win for USB Version E5.30 software. The tests were repeated three times for all chosen parameters.

An example of graph presenting raw AE signal recorded in the tests - changing voltage as a function of time, is shown in Fig. 7.

The recorded signals were analyzed. Fig. 8 and Fig. 9 present selected charts: amplitude and RMS changes over time for the new tool. There is a significant decrease in RMS value after the initial running-in process of cutting edges in the tool. Signal was recorded during milling by new tool with parameters: $a_p = 3 \text{ mm}$, $f = 25 \text{ mm/min}$.

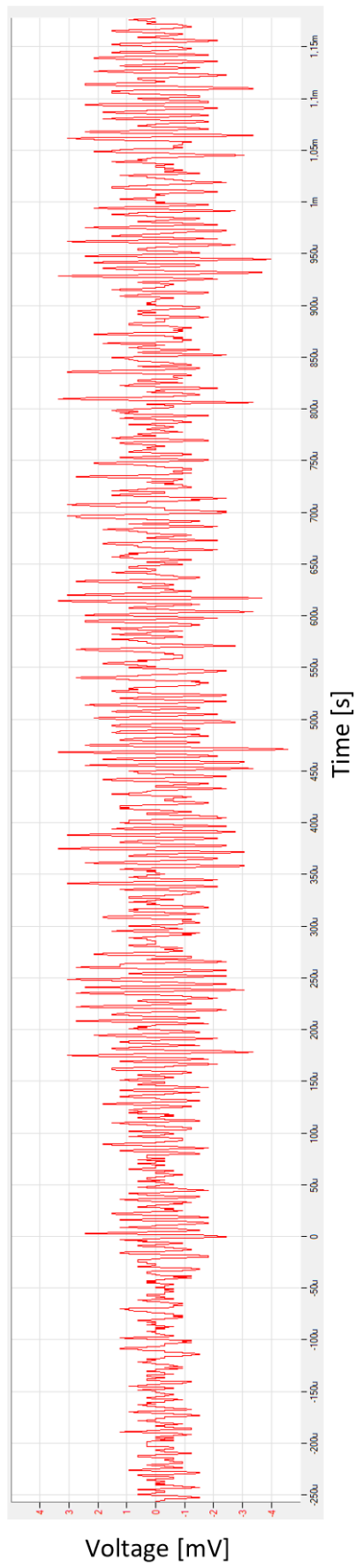


Fig. 7. An example of raw AE signal.

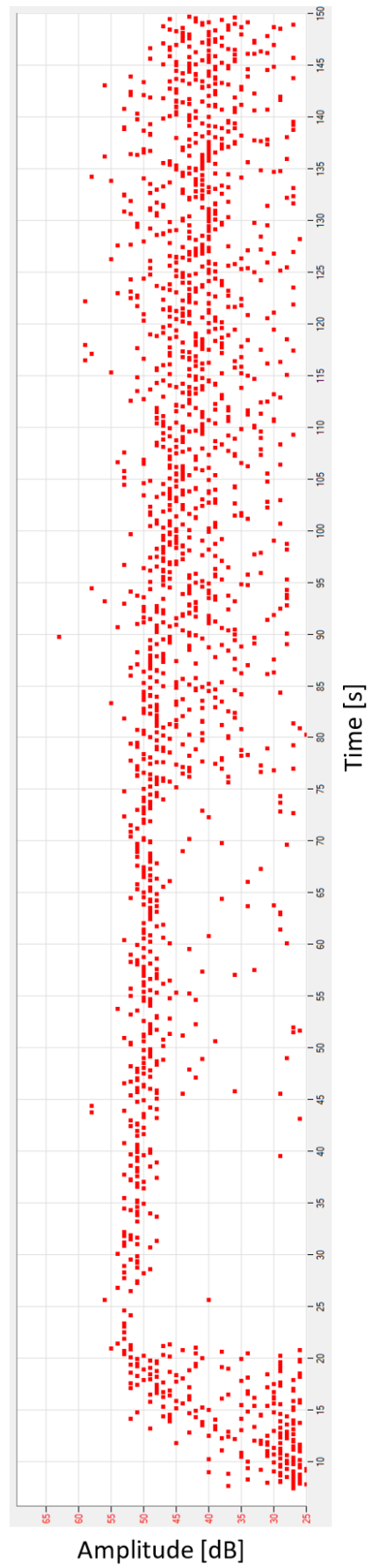


Fig. 8. Amplitude over time of AE signal for the new tool and parameters, $a_p=3$ mm, $f=25$ mm/min.

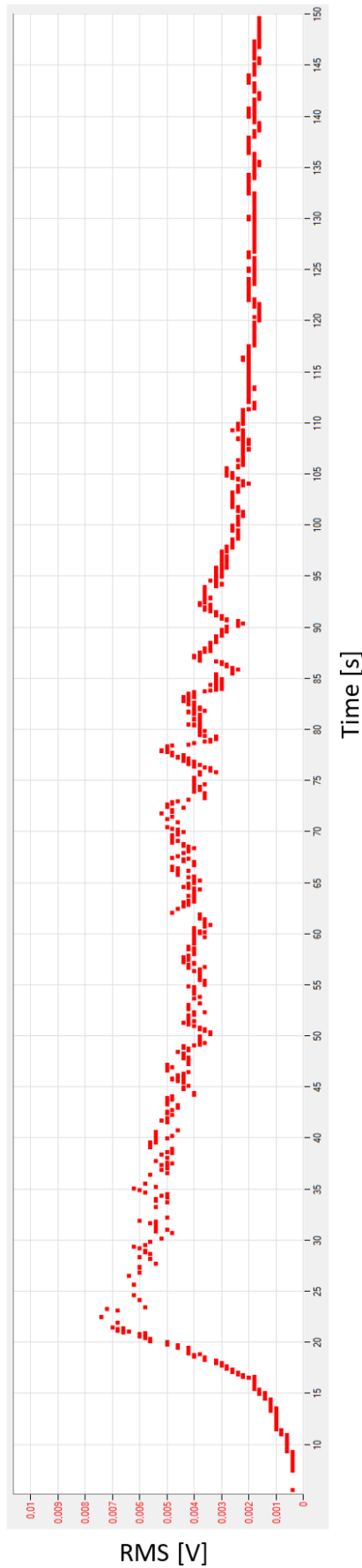


Fig. 9. RMS over time of AE signal for the new tool and parameters, $a_p=3$ mm, $f=25$ mm/min.

Fig. 10 shows the change in signal amplitude as a function of time and their frequency.

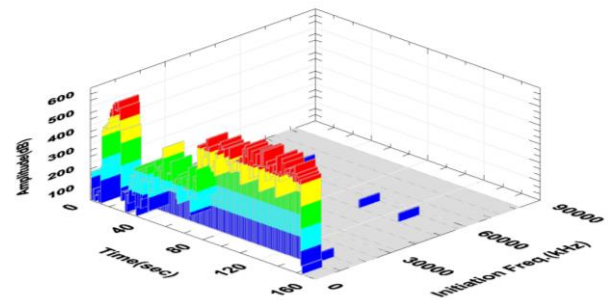


Fig. 10. AE signal for the new tool and parameters, $a_p=3$ mm, $f=25$ mm/min – amplitude over time and frequency.

The low frequency character of recorded signal is characteristic for continuous signals, e.g. friction [2]. An increase of signal amplitude is visible along tool break-in time. High values of signal amplitude with simultaneous decrease in RMS indicate of low energy of events generating acoustic emission. It allows to conclude that the machining conditions have stabilized after the initial tool break-in process. Fig. 11 presents a chart of the number of AE hits over time. Here too, the break-in period is visible, followed by a stable milling process. The steady increase in the number of hits during milling, after about 75 s, indicates machining stability.

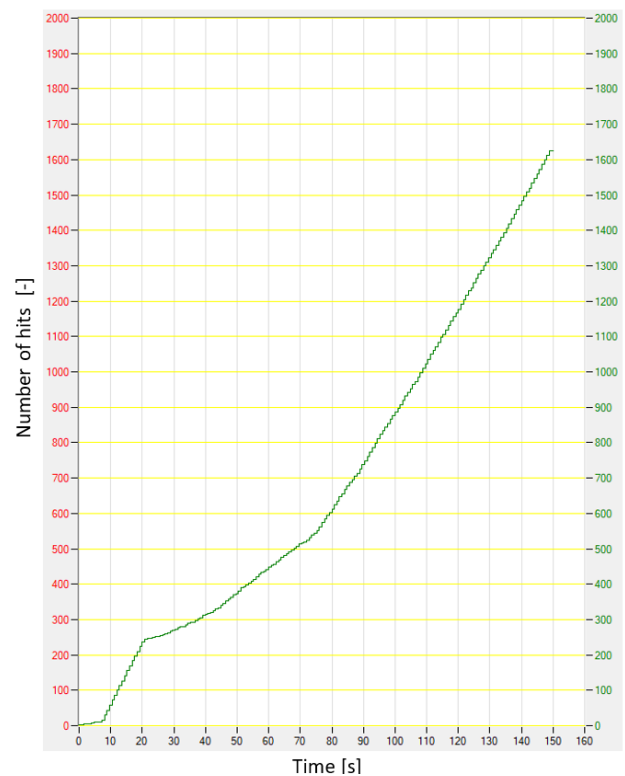


Fig. 11. AE signal for the new tool and parameters, $a_p=3$ mm, $f=25$ mm/min – number of hits over time.

The research results were shown in tables 3, 4 and 5. Those are average values of chosen parameters: amplitude, RMS and AE hits of the signals and their standard deviation, for various wear stages of the tool.

Table 3. Research results for new tool

Cutting parameters		AE parameters					
f [mm/min]	ap [mm]	A [dB]		RMS [mV]		hits [-]	
		mean	std dev.	mean	std dev.	mean	std dev.
25	3	41.84	6.41	2.20	0.56	531	751
30		31.32	4.86	1.04	0.14	52	112
35		38.55	7.01	1.72	0.25	446	656
25	5	38.85	6.89	3.49	0.72	197	309
30		38.31	5.45	1.62	0.22	487	736
35		41.85	9.21	2.91	0.37	624	819

Table 4. Research results for blunt tool

Cutting parameters		AE parameters					
f [mm/min]	ap [mm]	A [dB]		RMS [mV]		hits [-]	
		mean	std dev.	mean	std dev.	mean	std dev.
25	3	30.55	5.03	1.03	0.12	41	103
30		29.64	4.44	0.92	0.11	32	140
35		30.54	4.82	0.98	0.14	40	98
25	5	29.91	4.08	0.86	0.11	30	86
30		30.23	4.61	0.87	0.11	29	87
35		32.85	6.08	1.16	0.25	94	229

Table 5. Research results for the tool with broken one of blades

Cutting parameters		AE parameters					
f [mm/min]	ap [mm]	A [dB]		RMS [mV]		hits [-]	
		mean	std dev.	mean	std dev.	mean	std dev.
25	3	31.63	5.92	1.51	0.64	45	116
30		28.83	4.11	0.84	0.11	13	34
35		29.90	4.11	0.88	0.14	33	41
25	5	32.05	5.54	1.02	0.12	86	171
30		29.61	4.71	0.83	0.11	18	53
35		29.95	4.53	0.94	0.27	22	68

Analysis of test results showed, that the lowest values of amplitude, RMS and number of hits were obtained during milling with the parameters: ap = 3 mm and f = 30 mm/min. The application of these cutting parameters resulted in the generating of a signal with the lowest values of analyzed parameters, in all considered states of tool wear.

Examples of charts recorded during milling with selected optimal cutting parameters are shown in Fig. 12 – 14.

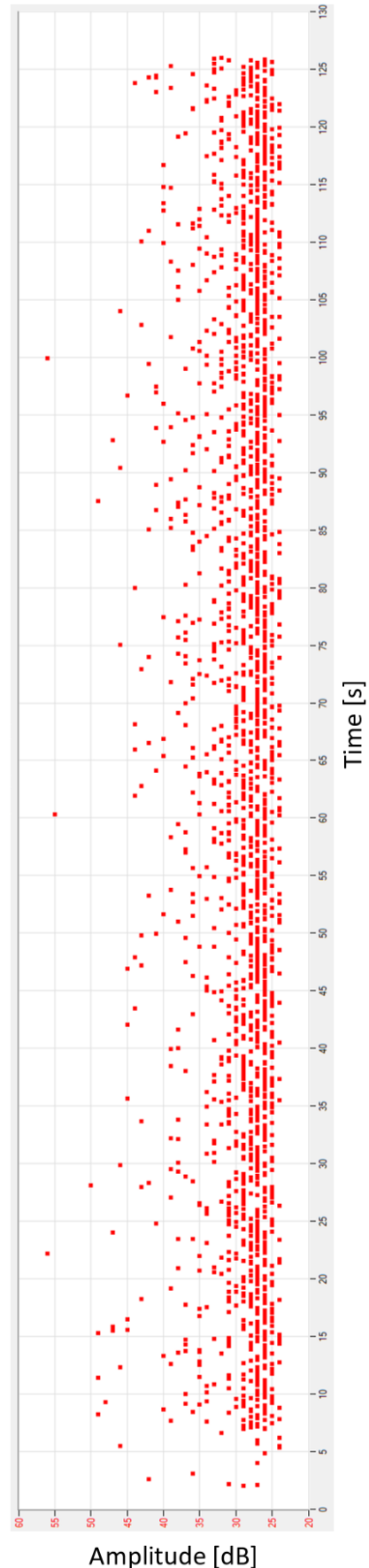


Fig. 12. Amplitude over time of AE signal for the broken tool and optimized parameters, ap=3 mm, f=30 mm/min.

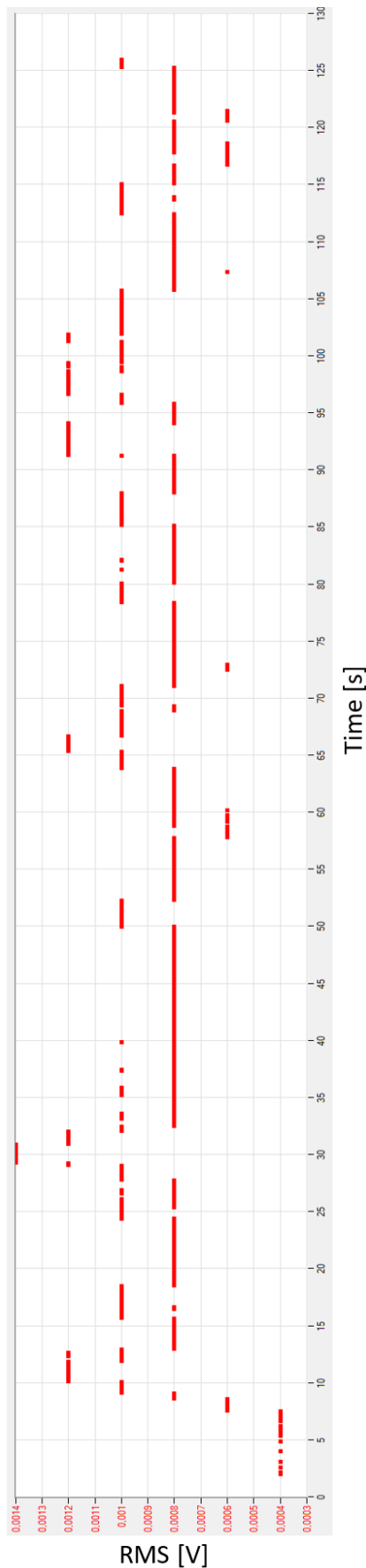


Fig. 13. RMS over time of AE signal for the broken tool and optimized parameters, $a_p=3$ mm, $f=30$ mm/min.

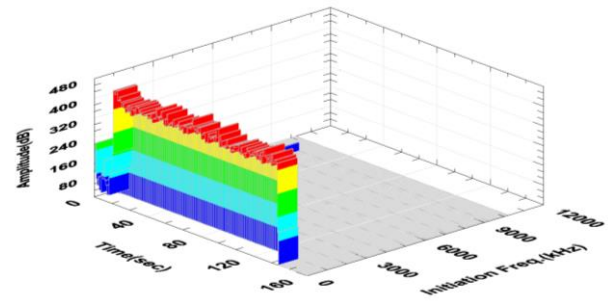


Fig. 12. AE signal for the broken tool and optimized parameters, $a_p=3$ mm, $f=30$ mm/min – amplitude over time and frequency.

Constant, relatively low values of the analyzed AE parameters, especially low frequency of the signal, indicate stable machining conditions throughout the entire milling process.

The low RMS value and the number of hits of the AE signals generated during machining processes may indicate stable machining conditions. The rule here is: the less, the better. Deterioration of machining conditions results in increased levels of vibration in the system, which ultimately affects the quality of the treated surface. Increasing the level of these phenomena is accompanied by the generation of AE signal with higher energy. Test results showed that blunting of cutting edges of tools was more important for machining conditions than breaking one of the blades while maintaining the remaining edges in good condition.

4 Conclusion

Correct machining parameters have a significant impact on machining stability and thus on the quality of the processed surface [3]. In addition, tool life is extended, which directly reduces machining costs [19].

The research was carried out at a constant rotational speed $n = 400$ rpm. End mills with a diameter of 20 mm were used in three levels of wear: new, blunt and slightly blunt with broken one of four blades. During the study, it was observed that in the first phase of milling with the new tool, the generated acoustic emission signal was clearly higher compared to the later phase of normal work. In that time the signal RMS has been reduced by more than 50%. This was probably due to the break-in process of the tool [19]. It was observed that blunt tools worked more stable than the new one. The parameters of the signal recorded during milling both, with a blunt tool and without one of the blades were at a lower level compared to the new one. The analysis of the obtained test results

showed that missing one cutting edge in the tool has no effect on the machining stability. The remaining 3 cutting edges were sufficient, with selected machining parameters, to ensure the correctness of the milling process.

Changes of selected cutting parameters caused changes in the acoustic emission signal generated during machining. The lowest values of amplitude, RMS and number of AE hits were recorded with the parameters: depth of cut $a_p = 3$ mm and feed $f = 30$ mm / min. In the case of a blunt tool, changing the cutting parameters did not matter so much. In all considered tool states, the use of these parameters generated lower energy signals. In the case of a new tool and with one blade broken off, the appropriate selection of parameters resulted in a reduction of the signal RMS by about two times. A 25% decrease in RMS was observed for the blunt tool.

The specific values of the selected parameters describing the AE signal generated during milling are new in this article. The parameter with the highest diagnostic capabilities is the RMS. Based on this, operators can monitor the state of tool wear, but above all choose the machining parameters under conditions similar to those described in the test methodology. Selection of machining parameters on the basis of AE tests allows to ensure better machining conditions than just their selection according to the recommendations of the tool manufacturer.

The tests showed that the acoustic emission method can be used to optimize the selection of cutting parameters during milling. In further work it is planned to compare the results obtained with the AE method with other methods, e.g. measurement of forces during machining and temperature measurement.

Acknowledgment

This research was supported by National Science Center of Poland under the grant DEC-2019/03/X/ST8/00372.

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