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MONITORING OF COMPOSITE MACHINING DEPTH WITH USING ACOUSTIC EMISSION

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***Abstract*—*The outcomes experimental researches of acoustic emission energy parameters at ascending composite material machining depth are reviewed. The regularity ascending of acoustic emission statistical energy parameters are determined. The sensitivity of acoustic emission energy parameters to ascending of composite material machining depth is determined. It is shown, that the percentage increment of acoustic emission signals energy average level dispersion advances a percentage increment of energy average level and its standard deviation. It is shown that the experimental and theoretical results of the acoustic emission signals energy parameters study have a good agreement.*

Index Terms—Acoustic emission; composite material; signal; energy; machining; statistical characteristics.

I. INTRODUCTION

Various methods of research are used to monitor the technological processes of machining composite materials (CM). One of such methods is the method of acoustic emission (AE). The AE investigations results at performing of CM machining various operations show the similarity of acoustic radiation nature. Thus a large number of factors influence on the AE signals. Researches of registered acoustic radiation parameters legitimacies change is directed on mining verification, monitoring and control methods of machining technological processes, including and control of robotic production.

However, the complex nature of the acoustic radiation, which is due to the high sensitivity of the AE method to treated CM surface layers' deformation and the destruction processes, leads to the problem of interpretation the recorded information. Thus for increase reliability the methods for verification and controlling machining technological processes different relative parameters of acoustic radiation is conducted. Such processing is based on common views of acoustic radiation legitimacies change when the contact conditions of pair interacting materials change - processed and the processing material. At the same time, large volumes of received AE information, large number of the influential factors, and composite nature of experimental legitimacies AE parameters change influences on veracity the methods verification, monitoring and control of CM machining technological processes. To increase the reliability of the developed methods, it is required to determine the acoustic radiation parameters sensitivity and informative. Solution of this problem requires determining the influence of all operating factors on AE. One of such factors is the depth of CM machining. Unconditionally, the analysis of its influencing on experimental AE signals amplitude and energy parameters sensitivity introduces doubtless concern.

II. STATEMENT OF THE TASK

The purpose of this article is the experimental researches of AE statistical energy parameters at change of CM machining depth. To achieve these aims next tasks were set: to conduct experimental researches of acoustic radiation energy at change of CM machining depth; to conduct statistical data processing with the mathematical description of AE energy parameters legitimacies change; to determine sensitivity of experimental AE signals energy parameters to change of CM machining depth; to conduct matching experimental and idealized outcomes.

III. REVIEW OF PUBLICATIONS

At mining the methods verification, monitoring and control of CM machining technological processes with usage of AE method is carried out the analysis of influencing technological parameters, and also treating tool wear on acoustic radiation regularity change. Thus, basically, the processing and analysis of registered AE signals amplitude parameters is carried out.

In article [1] the research of root mean square (RMS) value AE registered signals amplitudes is conducted at CM machining speed on the basis of aluminum, tool feed speed and cutting depth. It is determined, that at ascending all investigated machining technological parameters the AE registered signals RMS amplitude relation change have a linear ascending nature. However, relation of RMS amplitude changes at ascending cutting depth has a more composite nature change (on definite cutting depths decreasing AE signal RMS amplitude is watched). At the same time, in article [2] at composite machining is determined, that the ascending of AE signals RMS amplitude at ascending machining speed is not linear. From outcomes of researches also follows, that the machining speed influences on AE signals RMS amplitude spread. The researches, which are conducted in article [3] also have shown, that with ascending of machining speed at shallow cutting depths the linear ascending of registered AE signals RMS amplitude is watched. However, at large cutting depths there is a dip of AE signals RMS amplitude. The outcomes of researches also demonstrate that at ascending a cutting depth on preset machining speeds the ascending of AE signals RMS amplitude is not linear.

The statistical AE signals amplitude parameters are investigated in article [4]. Was determined, that to ascending of machining speed there is not a linear ascending of AE registered signals amplitude average level and AE RMS amplitude. Thus the amplitude distribution skewness decreases with a discontinuous mode, and the kurtosis has composite nature of change. Relations of AE statistical amplitude parameters change at ascending of longitudinal feed rate (amplitude average level, AE registered signals RMS amplitude, amplitude distribution skewness and kurtosis) has composite nature of change. The registered AE signals statistical amplitude parameters at ascending of cutting depth have a composite nature of change. The similar influencing on AE renders a treating tool wear. In article [5] is determined, that ascending of CM machining speed results in decreasing of registered AE signals RMS amplitude. In article [6] is shown, that to ascending of machining time there is ascending of registered AE signals energy average level spread. Thus the skewness of AE signals energy distribution decreases, and the kurtosis changes by a discontinuous mode. Was determined, that the discontinuous AE signals energy distribution kurtosis change to a definite level of treating tool wear. Researches which are conducted in article [7], have shown, that the ascending of machining speed results in dip the AE count, number AE events, AE energy. In article [8] is determined, that to ascending of machining speed there is not a linear ascending of registered AE signals energy average level. At the same time, at increasing of tool longitudinal feed speed and cutting depth the dependence of AE signals energy mean level change have a composite nature of change.

Regularity of AE statistical amplitude parameters change at ascending of CM machining speed is reviewed in articles [9], [10]. Analytical investigations [9] have shown that at increasing of CM machining speed there is a linear increasing of AE signal amplitude average level and its standard deviation. Thus the ascending of AE signal amplitude average level dispersion is well described by the power function. Experimental data, reduced in article [10], have shown good agreement with the results of theoretical studies. The experimental researches of AE amplitude parameters legitimacies change at ascending a CM cutting depth are conducted in article [11]. The outcomes of researches have shown, that at ascending of CM machining depth the ascending of AE statistical amplitude parameters (AE signals amplitude average level, its standard deviation and dispersions) are well described by power functions. Theoretical investigations of the AE statistical energy parameters, carried out in article [12], have shown that at increasing of CM machining depth, a linear increase of AE signals energy average level and its standard deviation should be expected. Thus the AE signals energy average level dispersion is well described by the power function. At the same time, for mining verification, monitoring and control methods of machining technological processes, experimental studies of AE energy parameters change at composite machining depth increasing are of interest.

IV. Results of Experimental Researches

Investigation of the AE signals energy parameters was carried out during machining silumin using the turning operation. Machining operation was carried out, in accordance with the technique that considered in article [11]. The technological parameters of the machining were equal: speed – 200 m min; longitudinal speed of the treating tool – 0.1 mm /rev. The machining depth varied from 0.1 mm to 0.3 mm in increments of 0.05 mm. A CD10 insert with a PCD insert was used for machining. The AE signals were recorded using AE sensor, which was mounted on the tool holder. To analyze the acoustic radiation energy parameters a computer acoustic emission system was used.

The results of the recording AE signals in the form of the acoustic radiation energy dependences change in time for different CM machining depths are shown in Fig. 1. The data of statistical processing the results of experimental studies AE signals energy parameters are given in Table I. In Table I the following designations are accepted: AE signals energy average level ($\overline{E}$); AE signals energy average level standard deviation ($s_{\overline{E}}$); AE signals energy average level dispersion ($s_{\overline{E}}^2$).

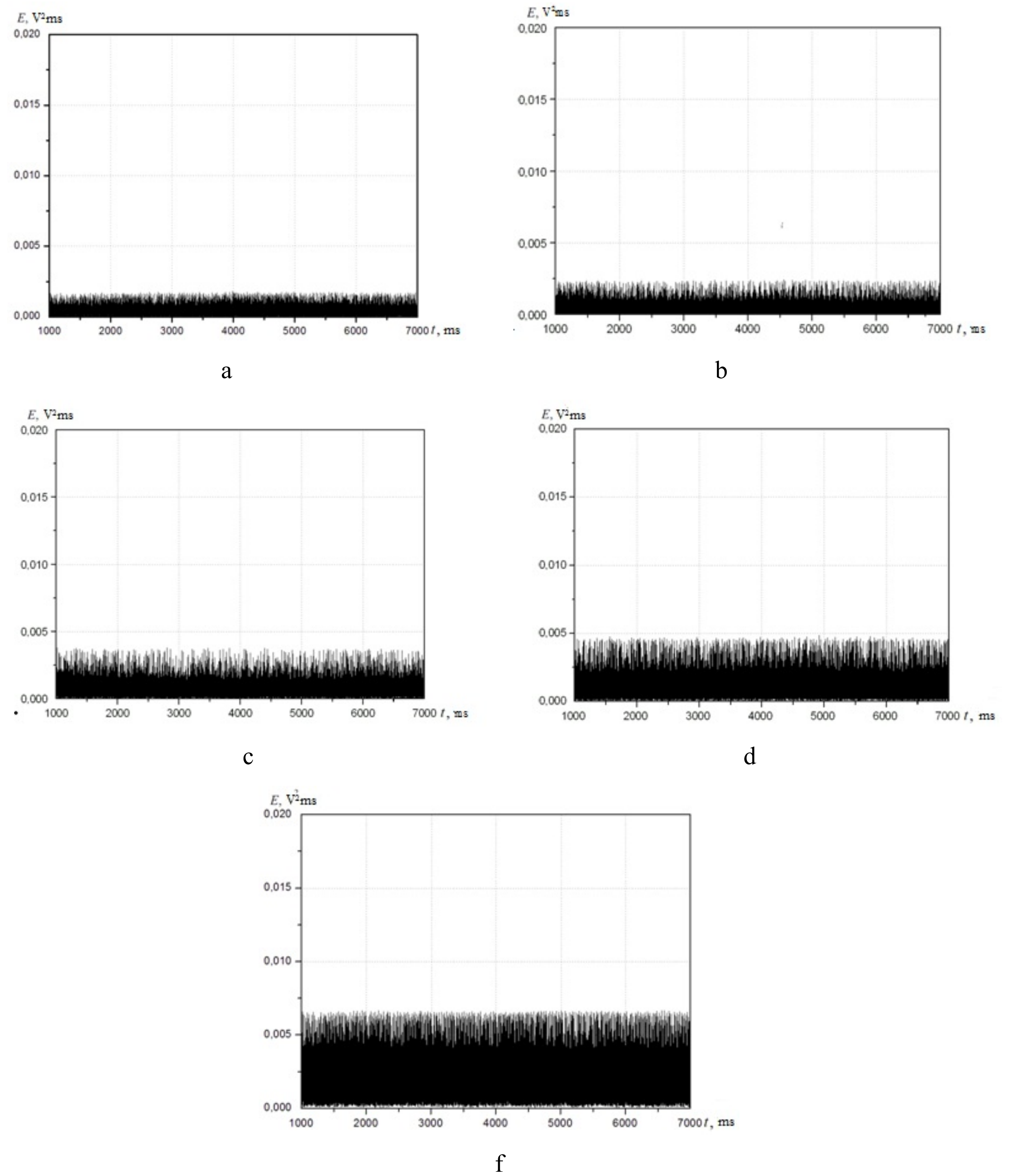


Fig. 1. Relations of AE signals energy changes in time with machining depth change by turning silumin. The values of machining technological parameters: longitudinal speed of treating tool – 0.1 mm/rev, machining speed – 200 mm/min. Machining depth: (a) – 0.1 mm; (b) – 0.15 mm; (c) – 0.2 mm; (d) – 0.25 mm; (f) – 0.3 mm

The obtained results (Fig. 1, Table I) showed that an increase of CM machining depth leads to an increase of all recorded AE signals statistical energy parameters – AE signals energy average level, its standard deviation and dispersion.

According to the obtained data (Table I), on Fig. 2 shown the dependences of AE energy parameters change with increasing of CM machining depth.

From Fig. 2 it can be seen that the dependences of AE energy parameters change have a nonlinear character increase with increasing of CM machining depth. Statistical processing of the dependencies shown in Fig. 2, showed that they are well described by power functions of the form

$$A_z = cz^d, \qquad (1)$$

where A_z are AE signals energy average level or AE signals energy average level standard deviation or AE signals energy average level dispersion; c and d are coefficients of approximating expression; z is the CM machining speed.

The values of approximating expression (1) coefficients c and d are: for the AE signals energy average level – c = 0.01375, d = 1.67045; for the AE signals energy average level standard deviation – c = = 0.00735, d = 1.55765; for the AE signals energy average level dispersion – c = 0.00028, d = 4.37251.

TABLE I EXPERIMENTAL STATISTICAL AE SIGNALS ENERGY PARAMETERS AT INCREASING OF COMPOSITE MACHINING DEPTH

Machining depth z, mm	$\overline{E}$, V^2ms	$s_{\overline{E}}$, V^2ms	$s^2_{\overline{E}}$, V^4ms^2
0.1	$4.629 \cdot 10^{-4}$	$2,926 \cdot 10^{-4}$	$8,564 \cdot 10^{-8}$
0.15	$5.999 \cdot 10^{-4}$	$4,221 \cdot 10^{-4}$	$1,7813 \cdot 10^{-7}$
0.2	$8.817 \cdot 10^{-4}$	$5,419 \cdot 10^{-4}$	$2,937 \cdot 10^{-7}$
0.25	0.00118	$7,412 \cdot 10^{-4}$	$5,494 \cdot 10^{-7}$
0.3	0.00196	0,00121	$1,459 \cdot 10^{-6}$

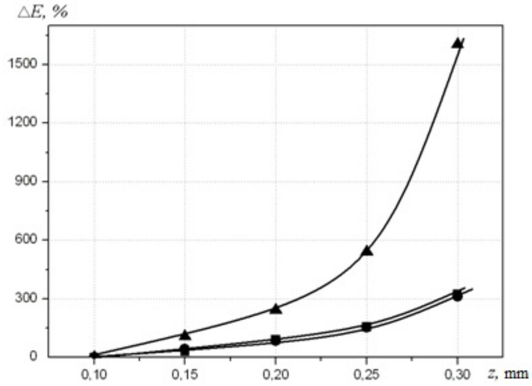
Thus the determination coefficients R^2 in describing the dependencies that shown in Fig. 2, the expression (1), is: for the AE signals energy average level – $R^2 = 0.94566$; for the AE signals energy average level standard deviation – $R^2 = 0.93972$; for the AE signals energy average level dispersion – $R^2 = 0.97595$.

Let us determine the sensitivity of experimental AE signals statistical energy parameters to the CM machining depth. To do this, we calculate the percentage increasing of AE registered signals energy parameters with increasing of CM machining depth, with respect to their initial values at the initial value of the machining depth, which is equal 0.1 mm.

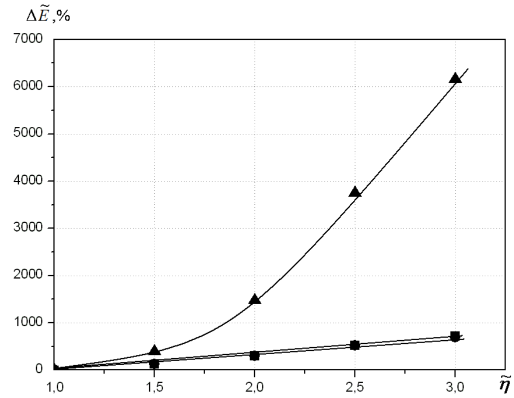
The calculations results are shown in Fig. 3a, where the following notation is adopted: ΔE – the percentage increasing of AE signals energy average level or AE signals energy average level standard deviation or AE signals energy average level dispersion; z – composite machining depth.

The obtained outcomes demonstrate, that ascending of CM machining depth results in increase of all experimental signals statistical energy parameters (Table I, Figs 2 and 3a). At the same time, at CM machining depth ascending the percentage increment of AE signal energy average level dispersion advances a percentage increment of AE signal energy average level and its standard deviation. The statistical data processing has shown, that at ascending of CM machining depth from 0.1 mm till 0.25 mm a percentage increment of AE signal energy average level $\overline{E}$, its standard deviation $s_{\overline{E}}$ and dispersions $s^2_{\overline{E}}$, accordingly, are equal: 934.28 %, 1126.65 % and 14946.72 %. At ascending of CM machining depth from 0.1 mm up to 0.3 mm a percentage increment of AE signal energy average level $\overline{E}$, its standard deviation $s_{\overline{E}}$ and dispersions $s^2_{\overline{E}}$, accordingly, are equal: 1508.02 %, 1889.75 % and 39491.04 %.

From the obtained outcomes it is visible, that the increment of experimental AE signals energy average level dispersion considerably advances an increment of registered AE signals remaining energy parameters at ascending of CM machining depth. In other words, most sensing and informative experimental AE signals energy parameter to ascending of CM machining depth is a AE signal energy average level dispersion.



a



b

Fig. 3. Graphs of the percentage increasing of AE signal energy average level $\overline{E}$ (■), its standard deviation $s_{\overline{E}}$ (●) and dispersion $s^2_{\overline{E}}$ (▲) as a function of composite machining depth: (a) are experimental dependencies; (b) are theoretical dependencies

In Fig. 3b, are shown the theoretical regularity increment of AE statistical energy parameters at ascending of CM machining depth, which are reviewed in article [12]. The obtained relations (Figs 3a and 3b) demonstrate the good coordination of outcomes experimental and analytical investigations. At the same time, the nature experimental and theoretical curves of AE energy average level and its standard deviation change differs among themselves. This, as marked in article [12], is conditioned by that in analytical investigations ascending the area of destruction was esteemed at constant unit thickness of layer being destroyed. In real conditions, at ascending of CM machining depth the ascending of deformable and breakable material volume, probably, does not occur linearly.

VI. Conclusion

The experimental researches of AE energy parameters at ascending of CM machining depth are conducted. The experimental regularity of AE statistical energy parameters change at ascending of CM machining depth is obtained. It is determined, that the regularity ascending of experimental AE signals energy average level, energy average level standard deviation and energy average level dispersions at ascending of CM machining depth are well described by the power functions. The sensitivity of AE signals statistical energy parameters to CM machining depth is determined. It is shown, that the percentage increment of AE signals energy average level dispersion advances a percentage increment of energy average level and its standard deviation. It is shown, that the outcomes experimental and analytical investigations of AE signals energy parameters at ascending of CM machining depth have the good coordination one another.

The outcomes of researches can be used at mining verification, monitoring and control methods of CM machining technological processes, including the control of robotic production. In further research, it is of interest to search of criteria for managing technological processes using neural networks.

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С. Ф. Філоненко, О. В. Заріцький, А. П. Стахова. Моніторинг глибини механічної обробки композита з використанням акустичної емісії

Розглянуто результати експериментальних досліджень енергетичних параметрів акустичної емісії при зростанні глибини механічної обробки композиційного матеріалу. Визначені закономірності зростання статистичних енергетичних параметрів акустичної емісії. Визначена чутливість енергетичних параметрів акустичної емісії до зростання глибини механічної обробки композиційного матеріалу. Показано, що процентний приріст дисперсії середнього рівня енергії сигналів акустичної емісії випереджає процентний приріст середнього рівня енергії и його стандартного відхилення. Показано, що експериментальні і теоретичні результати досліджень енергетичних параметрів сигналів акустичної емісії мають добре узгодження.

Ключові слова: акустична емісія; композиційний матеріал; сигнал; енергія; механічна обробка; статистичні характеристики.

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С. Ф. Филоненко, О.В. Зарицкий, А.П.Стахова. Мониторинг глубины механической обработки композита с использованием акустической эмиссии

Рассмотрены результаты экспериментальных исследований энергетических параметров акустической эмиссии при возрастании глубины механической обработки композиционного материала. Определены закономерности возрастания статистических энергетических параметров акустической эмиссии. Определена чувствительность энергетических параметров акустической эмиссии к возрастанию глубины механической обработки композиционного материала. Показано, что процентный прирост дисперсии среднего уровня энергии сигналов акустической эмиссии опережает процентный прирост среднего уровня энергии и его стандартного отклонения. Показано, что экспериментальные и теоретические результаты исследования энергетических параметров сигналов акустической эмиссии имеют хорошее согласование.

Ключевые слова: акустическая эмиссия; композиционный материал; сигнал; энергия; механическая обработка; статистические характеристики.

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