MATHEMATICAL MODELING OF PROCESSES AND SYSTEMS

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SIMULATION OF LEGITIMACIES ACOUSTIC RADIATION ENERGY CHANGE FOR THE CONTROL OF COMPOSITE MACHINING PROCESS

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Abstract**—***Regularities of acoustic emission energy parameters change during of composite materials machining speed increase for the prevailing mechanical destruction its surface layer is observed. Description of the obtained regularities is carried out. It is shown that during composite materials machining speed increase a percentage growth of acoustic emission signal energy average level dispersion outstrips a percentage growth of energy average level and its standard deviation*.

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

I. INTRODUCTION

Wide application of composite materials (CM) is based on their physical and mechanical characteristics, wear resistance, temperature and aggressive environments. However some CM is sensitive to various types of defects and, first of all, to micro fissures. It demands mining develop the methods of control, monitoring and diagnostics of CM both in static conditions, and in manufacturing conditions with application of CM machining operations. To solve these problems, researches of CM machining technological processes are conducted with use of the traditional and nontraditional methods. Thus, a method of acoustic emission (AE) is widely spread.

As researches show, the method of AE has a small inertia and represents the dynamics of CM machining processes. However, the problems of interpretation the registered information limit practical application of AE method. It conditioned by the complexity of CM machining process, and as by availability of large number the influential factors. Such factors are the parameters of technological process and physical-mechanical characteristics of the processed and processing CM.

The problem of interpretation of the AE information, first of all, is related to development of theoretical researches that suppose development of AE models during the CM machining and modeling of influence different factors on the AE parameters, including the wear of cutting tool. This allows determining the regularities change, transformation and sensitivity of AE to change of the influential factor, i.e. sensitivity of AE amplitude and energy parameters. Results of researches are basic for optimization of CM machining parameters for obtaining the given quality of items. These results also are basic for the development the methods of monitoring for a control of CM machining technological process parameters.

II. STATEMENT OF THE TASK

The purpose of the article is research of AE energy parameters regularities change during an increase of CM machining speed for the mechanical model of its surface layer destruction. To achievement the purpose the following tasks were put: carry out the statistical processing of the modeling data with determination of AE energy parameters for the given CM machining speed at prevailing mechanical destruction of its surface layer; get regularities of AE energy parameters change during an increase of machining speed; describe the obtained regularities and their statistical characteristics; define the sensitivity of AE signals energy parameters towards increasing of CM machining speed.

III. REVIEW OF PUBLICATIONS

Analysis and processing of AE signals, registered at CM machining, are focused on optimization of technological process parameters, development the methods of its control, diagnostics and monitoring, and also assessing the state of the cutting tool. The results of experimental researches show that during the CM machining a continuous AE is registered [1] – [4]. During the operation of CM machining, and also during the technological parameters values change occurs a change of AE parameters. However is a not watched change of acoustic radiation nature. The basic processed of AE parameters are: average or root mean square (RMS) value of AE signal amplitude; amplitude of basic low-frequency and high-frequency components in spectrum of AE registered signal, and also rate of their change; statistical characteristics of AE signal amplitude; AE signal energy and others parameters [1] – [7].

Researches of the AE signals parameters are carried out depending on CM machining speed, speed of longitudinal feed of cutter, depth of cutting, breakage or wear of cutting tool. However the dependences obtained by the miscellaneous authors show complex character of their change and they are contradictory. So, in paper [7] it is shown that during the growth of longitudinal speed of milling cutter a drop of AE registered signal amplitude occurs. At the same time, the increase of cutting depth leads to an increase of AE amplitude. In paper [8] dependences of AE signals RMS change during an increase of all technological parameters of material machining are shown. From the obtained data we can see that increase of CM machining speed is accompanied by reduction of AE signals RMS. However, an increase of longitudinal speed of cutter and cutting depth leads to an increase of AE signals RMS. In paper [5] it is marked that there is an increase of AE amplitude (average value) during the growth of machining speed and cutting depth. However at the hi-bottoms of cutting the obtained dependences have complicated character of change and they are not stable. Complicated character of AE statistical energy parameters change (standard deviation, dispersion, coefficients of asymmetry and excess) at implementation of CM machining are shown in paper [2]. In paper [6] it is obtained, that with an increase of machining speed there is a nonlinear increase of AE signals average level amplitude and RMS amplitude, and as values of its variation. However the coefficients of excess and asymmetry of amplitude distributions have complicated character of change. Analogical complicated character of AE signals amplitude statistical characteristics change is observed during an increase of longitudinal speed of cutter and cutting depth. At the same time, in paper [9] it is obtained, that growth of machining speed, longitudinal speed of cutter and cutting depth leads to the slight increase of AE registered signals RMS value.

Theoretical researches of AE amplitude parameters at the change of CM machining speed and dispersion of CM properties for the case of prevailing mechanical destruction of its surface layer are considered in papers [10], [11]. The modeling of AE is carried out at the machining technological parameters change and dispersion of CM properties. Data processing is held with the calculations of AE signals statistical amplitude parameters. The relations of AE signals amplitude parameters change are determined at change of the influential factors. It is shown that with an increase of machining speed and decreasing of CM properties dispersion there is an increase of AE signal average level amplitude, its standard deviation and dispersion. It is also shown that for researched influence factors the most sensing AE parameter is dispersion of AE signal average level of amplitude.

However it is interesting to research of AE energy as the most capacious parameter of AE signals. Thus it is necessary to define and research regularities of AE energy parameters change in dependence of CM machining speed. It is of interest for providing reliability of CM machining technological parameters control.

IV. RESULTS OF RESEARCHES

In the paper [12] the modeling of AE energy at the CM machining speed change for the case of prevailing mechanical destruction of its surface layer is conducted. Modeling was carried out by next expression

$$E_p(t) = \sum_j E_{jM}(t - t_j), \qquad (1)$$

where $t_j = j\Delta t_j \pm \delta$ is the moments of time when AE signals appear with energy E_{jM}, which appear during sequential mechanical destruction of CM jth areas; j is the number of CM destructed area or a number of formed AE pulse signal (j = 0, 1, …, n); Δt_j is time interval between the beginning of the next AE impulse signal generation in regard to the previous one; δ is the random component in a moment of time when each next AE pulse signal appear; $E_{jM} \sim U_{jM}^2$; U_{jM} are amplitudes of jth AE signal.

Model of AE signal pulse U_{jM} for the mechanical model of CM destruction is described with the next expression

$$U_{jM}(t) = u_0 t\alpha\upsilon_0 e^{r\alpha t} e^{-\frac{\upsilon_0}{r\alpha}\left(e^{r\alpha t}-1\right)}, \qquad (2)$$

where u_0 is the maximum possible elastic displacement, which spread in the material during instant destruction of the given CM area; α is the load speed; υ_0, r are constants, which are determined by CM physical and mechanical characteristics.

During the modeling of AE energy parameters, which are included in expression (2), were brought to the dimensionless values, and the amplitude of signals was normalized on value u_0. During calculations the next values of parameters were taken: $\tilde{\upsilon}_0$ = 100000, $\tilde{r}$ = 10000. Value α was changed in the diapason from $\tilde{\alpha}$ = 10 to $\tilde{\alpha}$ = 50 with the step of increase 10. For a start value $\tilde{\alpha}$ = 10 value of Δt_j made up $\tilde{\Delta t_j}$ = 0.000011. Value $\tilde{\delta}$ was randomly changed from 0 to 0.000011. For other α magnitudes values $\tilde{\Delta} t_j$ and $\tilde{\delta}$ will be decreased proportionally to the decrease of the formed pulse signals duration.

Statistical processing results of modeling data are shown in the Table I, where following notation is accepted: $\tilde{\alpha}$ is the CM machining speed; $\tilde{\tilde{E}}$ is the AE resultant signal energy average level; $s_{\tilde{\tilde{E}}}$ is the standard deviation of AE resultant signal energy average level; $s^2_{\tilde{\tilde{E}}}$ is the dispersion of AE resultant signal energy average level.

In Fig. 1 are shown dependences of the AE resultant signal energy average level ($\tilde{\tilde{E}}$), its standard deviation ($s_{\tilde{\tilde{E}}}$) and dispersion ($s^2_{\tilde{\tilde{E}}}$) change during the change of CM machining speed ($\tilde{\alpha}$), according to the data in Table I.

Results of the modeling and data processing show (Fig. 1), that increase of $\tilde{\alpha}$ leads to an increase of AE resultant signals energy parameters.

Thus the AE resultant signal energy average level, its standard deviation and dispersion increase by the non-linear character. Analysis of the obtained data with approximating relations, reduced

$$\tilde{Z} = ab^{\tilde{\alpha}}, \qquad (3)$$

where $\tilde{\tilde{Z}}$ is the AE signal energy average level or its standard deviation or its dispersion; *a* and *b* are coefficients of approximating expression.

The values of coefficients *a* and *b* of approximating expression (3) make: for the AE signal energy average level – a = 0.0001, b = 1.06799; for the standard deviation of AE signal energy average level – a = 0.00008, b = 1.07097; for the dispersion of AE signal energy average level – $a = 7.7716 \cdot 10^{-9}$, b = 1.14166. Thus determination coefficients R^2 at the description of AE resultant signal energy average, its standard deviation and dispersion are, accordingly, make: R^2 = 0.9935; R^2 = 0.99534, R^2 = 0.99986. Selection criteria of approximating functions for the description of relations Fig. 1abc would be the minimum of residual dispersion.

Let's conduct determination of AE resultant signals energy parameters sensitivity to an increase of CM machining speed. To do this we shall conduct data processing (Table I) with definition of percentage increment of AE signal energy parameters at increase of machining speed, in relation to their initial values at $\tilde{\alpha}$ = 10. The results of data processing are shown in Fig. 2, where the following notations are adopted: $\Delta\tilde{Z}$ is the percentage increment of AE resultant signal energy average level or its standard deviation or its dispersion; $\tilde{\alpha}$ is the CM machining speed.

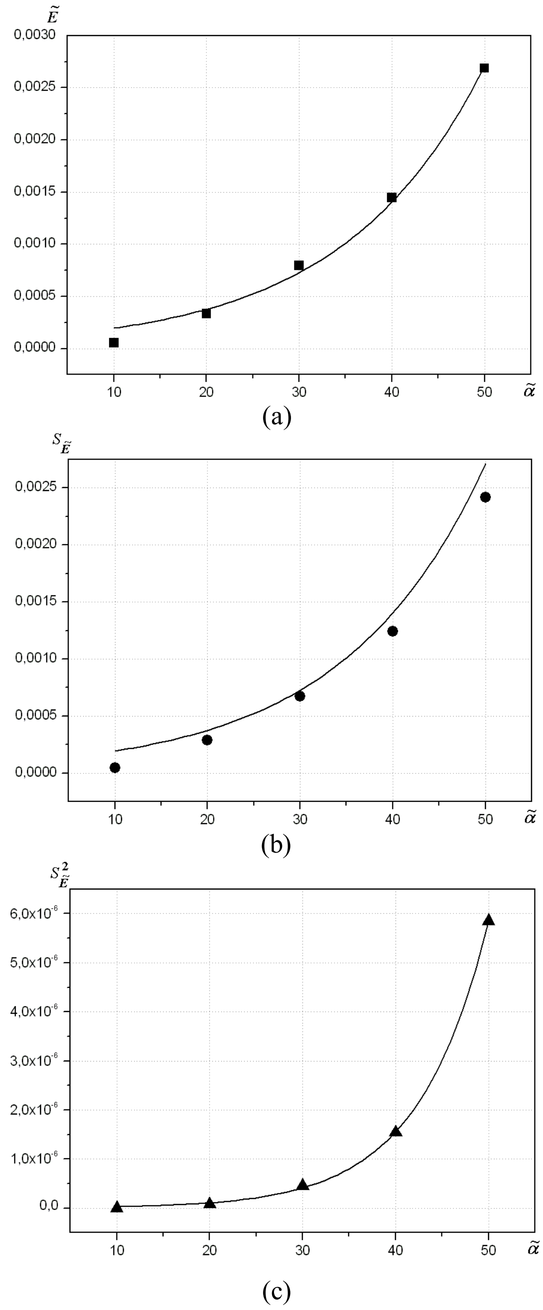

Fig. 1. Graphs of change of AE resultant signals energy average level $\tilde{\tilde{E}}$ (■), its standard deviation $s_{\tilde{\tilde{E}}}$ (●) and dispersion $s^2_{\tilde{\tilde{E}}}$ (▲) depending on CM machining speed ($\tilde{\alpha}$) for the mechanical model destruction of CM surface layer

The results of researches are shown that for prevailing mechanical destruction CM surface layer the increase of machining speed should lead to an increase of AE energy parameters (Table I, Figs 1, 2). At the same time, with an increase of CM machining speed a percentage growth of AE resultant signal energy average level dispersion outstrips a percentage growth of the energy average level and its standard deviation (Fig. 3). For example, during an increase of CM machining speed by 4 times (from $\tilde{\alpha}$ = 10 up to $\tilde{\alpha}$ = 40) a percentage growth of energy parameters of AE signal (energy average level $\tilde{\tilde{E}}$ of the AE resultant signal, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$), accordingly, make: 2572.722 %, 2673.22 % and 76807.39 %. At ascending CM machining speed $\tilde{\alpha}$ by 5 times (up to $\tilde{\alpha}$ = 5) percentage increment of AE signals energy parameters, accordingly, make: 4869.83 %, 5303.82 % and 291911.80 %.

TABLE I

ENERGY CHARACTERISTICS OF AE RESULTANT SIGNALS DURING AN INCREASE OF CM MACHINING SPEED

$\tilde{\alpha}$	$\tilde{\tilde{E}}$	$s_{\tilde{\tilde{E}}}$	$s^2_{\tilde{\tilde{E}}}$
10	$5.40834\cdot10^{-5}$	$4.47738\cdot10^{-5}$	$2.0047\cdot10^{-9}$
20	$3.34977\cdot10^{-4}$	$2.8945\cdot10^{-4}$	$8.37812\cdot10^{-8}$
30	$7.96406\cdot10^{-4}$	$6.7413\cdot10^{-4}$	$4.54451\cdot10^{-7}$
40	0.00145	0.00124	$1.54176\cdot10^{-6}$
50	0.00269	0.00242	$5.85396\cdot10^{-6}$

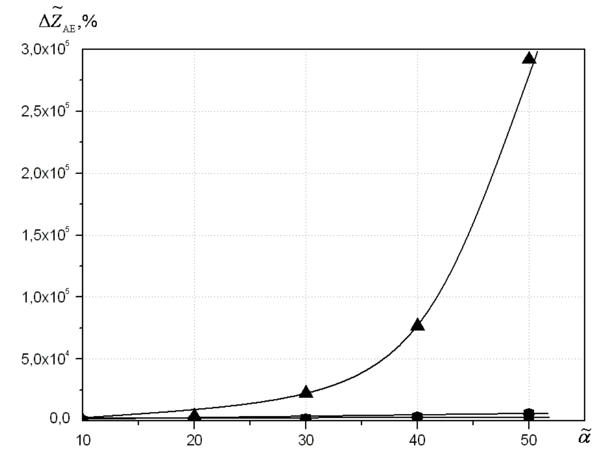

Fig. 2. Graphs of the percentage increment of AE resultant signals energy parameters change depending on CM machining speed ($\tilde{\alpha}$) for the prevailing mechanical destruction surface layer: energy average level $\tilde{\tilde{E}}$ (■), its standard deviation $s_{\tilde{\tilde{E}}}$ (●) and dispersion $s^2_{\tilde{\tilde{E}}}$ (▲)

V. CONCLUSION

The statistical processing of acoustic radiation energy modeling results during the CM machining speed change for the case of prevailing mechanical destruction of its surface layer was carried out. Regularities of AE resultant signal energy average level, its standard deviation and dispersion change during the change of CM machining speed are obtained and described. It was shown that regularities of AE resultant signal energy parameters change are well described by power functions. Determination coefficients in the description of obtained regularities are determined. Calculations of the percentage growth of AE energy parameters during an increase of CM machining speed were carried out. It was determined that the percentage growth of the AE resultant signal energy average level dispersion outstrips the percentage growth of an energy average level and its standard deviation, i.e. the most sensitive AE parameter to an increase of CM machining speed is the AE resultant signal energy average level dispersion.

Obtained results may be used to develop the methods of monitoring and control of CM machining technological processes. In this, analysis of AE resultant signal energy average level dispersion can be used to control the CM machining speed.

At the same time, research of AE energy parameters during the change of physical and mechanical characteristics of CM machining for the case of mechanical destruction its surface layer is of interest.

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С. Ф. Філоненко. Моделювання закономірностей зміни енергії акустичного випромінювання для керування процесом механічної обробки композита

Розглянуто закономірності зміни енергетичних параметрів акустичного випромінювання при зростанні швидкості механічної обробки композиційного матеріалу для випадку переважного механічного руйнування поверхневого прошарку. Проведено опис отриманих закономірностей. Показано, що при зростанні швидкості механічної обробки композиційного матеріалу процентний приріст дисперсії середнього рівня енергії сигналу акустичної емісії випереджає процентний приріст середнього рівня енергії та його стандартного відхилення.

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

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С. Ф. Филоненко. Моделирование закономерностей изменения энергии акустического излучения для управления процессом механической обработки композита

Рассмотрены закономерности изменения энергетических параметров акустического излучения при возрастании скорости механической обработки композиционного материала для случая преобладающего механического разрушения поверхностного слоя. Проведено описание полученных закономерностей. Показано, что при возрастании скорости механической обработки композиционного материала процентный прирост дисперсии среднего уровня энергии сигнала акустической эмиссии опережает процентный прирост среднего уровня энергии и его стандартного отклонения.

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

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