MATHEMATICAL MODELING OF PROCESSES AND SYSTEMS

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ACOUSTIC ENERGY AT CONTROLLED CUTTING DEPTH OF COMPOSITE MATERIAL

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Abstract—*The simulation of acoustic radiation energy at machining composite material and treating tool wearing for a case of controlled cutting depth is conducted. It is shown, that at controlled cutting depth wearing of the treating tool results in increasing acoustic radiation energy parameters. Is determined, that the increase of acoustic radiation energy average level dispersion advances increase of its average level and standard deviations. It is shown, that the increasing of acoustic radiation energy parameters advances increasing its amplitude parameters deviation.*

Index Terms—Acoustic emission, composite material, signal, model, energy, machining, wear, control, statistical characteristics.

I. INTRODUCTION

One of the factors, which influences on surface quality, is the cutting tool wear. For mining the monitoring and the controls methods of machining materials, switching and composite materials (CM), are carried out researches of technological parameters – cutting forces, cutting temperature and other.

Cutting tool wear is one of the technological processes parameters. Its researches, as a rule, are directed on maintenance the critical cutting tool wear control or diagnostic of cutting tool condition. However conventional researches methods are inertial and have small sensitivity to tool wear. They do not allow to partition and to interpretation processes relating a treated surface and treating tool. It complicates mining monitoring and technological processes control methods.

For research of cutting tool wear broad usage has a method of acoustic emission (AE). As demonstrate researches, the method has a sharp response to internal deformation and destruction processes both treated, and treating CM. It allows to receive large amounts of information about flowing past processes. However interpretation of the information introduces considerable complexities. Regularity of AE parameters changes composite nature. It is conditioned by a number of causes. At first, influencing on acoustic radiation of CM machining technological parameters. Secondly, change of interplay conditions treated and treating materials at cutting tool wearing.

With given the points of view, value has AE analytical investigations. Such researches allow receiving of AE parameters regularity at operating the different factors. To determine the paramount influencing factor for technological processes parameters control, and also to design the monitoring and control methods. One of such factors is a cutting tool wear. Unconditionally, the research of its influencing on acoustic radiation parameters introduces scientific and practical concern.

II. PROBLEM STATEMENT

The purpose of this article is the research of acoustic radiation energy parameters at CM machining, with allowance for cutting tool wear, for the mechanical model surface layers destruction and controlled cutting depth. To achieve these aims next tasks were set: to conduct simulation of acoustic radiation energy at CM machining at CM treating tool wearing and controlled the cutting depth; to conduct statistical processing outcomes simulation with data retrieval on AE energy parameters for want and with wearing of the treating tool from CM; to compare influencing of CM treating tool wearing at controlled cutting depth on statistical acoustic radiation energy parameters; to compare influencing of CM treating tool wearing at controlled cutting depth on statistical acoustic radiation amplitude and energy parameters.

III. REVIEW OF PUBLICATIONS

The plenty of activities is dedicated to researches AE at cutting tool wearing. Thus the main parsed parameters are the AE amplitude characteristics (amplitude average level and root mean square value of amplitude – RMS), and also registered AE signals spectra. The researches demonstrate composite nature of acoustic radiation at operating the different factors, switching on and cutting tool wearing [1] – [4].

Thus the relations of AE signals parameters change are not steady and in many cases contradict one another. It to the full falls into the researches of cutting tool wearing influencing. In article [5] is shown, that at CM turning the acoustic radiation is continuous. Appear of tool wear or its partial destruction results in decreasing AE registered signal amplitude. Thus there is also modification of AE signal spectrum. Decreasing of AE signal low frequency component amplitude in a spectrum and some increasing of high frequency component is watched. It can be used at cutting tool condition monitoring. The similar outcomes are obtained in article [6]. At considerable tool wearing or initial its destruction there is AE signal amplitude. However change of low frequency and high frequency component in AE signals spectrum is not stable. Is watched both decreasing, and ascending of components in signals spectrum. In article [7] is shown, that the increasing of tool wear results in dip of AE signal amplitude average level, its standard deviation and dispersion. However, increasing of AE signal RMS amplitude is watched. The relations of AE signals parameters change have not stable nature, i.e. the considerable fluctuations of AE signals parameters values are watched. At the same time, in spectra of AE signals there is dip amplitude of the main carrier frequency. In article [2] the analysis of AE signals energy is conducted. Is shown, that with increasing wearing is watched increasing of AE signals energy average level standard deviation. Thus there is decreasing parameter that describing of signals amplitudes distribution law. The research of AE signals RMS amplitudes at cutting tool wearing is conducted in article [8]. Is shown, with increasing of tool wearing there is a tendency to increasing of AE signals RMS amplitudes. However there is a considerable fluctuation of their values. Such fluctuation is watched and AE signal spectra. At the same time, in article [9] is marked, that with increasing of cutting tool wearing is watched increasing of carrier frequencies amplitudes in AE signals spectra. In article [10] is shown, that at increasing cutting tool wearing there is a sharp increasing of stored AE signals RMS amplitudes. The outcomes of researches demonstrate that the obtained relations of AE signals parameters change have considerable fluctuations and are discordant.

The analytical investigations of AE signals at CM machining, with allowance cutting tool wearing, for a case of controlled cutting depth are conducted in article [11]. The model of AE resultant signal under following conditions is reviewed. There is CM machining to constant technological parameters. At machining there is consequence destruction of CM surface layer elementary area of the identical size. At destruction of each area there is appear single AE pulse signal U_j. As was considered, that at CM machining descends of cutting tool wearing from CM. Wearing represents consequence destruction of treating tool elementary area from CM. At destruction of each elementary area there is appear single AE pulse signal U_i. Destruction treated and treating CM descends to the prevailing mechanical destruction mechanism [12], [13]. The sequences of pulse signals U_j and U_i reshape a resultant AE signal by the way

$$U_p(t) = \sum_j U_j(t - t_j) + \sum_i U_i(t - t_i), \qquad (1)$$

where $t_j = j\Delta t_j \pm \delta_1$, $t_i = i\Delta t_i \pm \delta_2$ are moments of time when AE signals U_j and U_i appear, accordingly, at destruction of CM treated area and treating CM wearing (destruction); j is the number of CM destructed area or a number of formed AE pulse signal U_j (j = 0, 1,…, n); Δt_j is time interval between the beginning of the next AE impulse signal generation U_j in regard to the previous one; δ_1 is the random component in a moment of time when each next AE pulse signal U_j appear; i is the number of treating CM destructed area or a number of formed AE pulse signal U_i (i = 0,……, m); Δt_i is time interval between the beginning of the next AE impulse signal generation U_i in regard to the previous one; δ_2 is the random component in a moment of time when each next AE pulse signal U_i appear.

Agrees equation (1), the simulation of AE signals with increase of cutting tool wearing and controlled cutting depth was conducted, i.e. the cutting depth is a constant. For adopted conditions was showed that AE signals is continuous signals. The increasing of cutting tool wear results in increase of AE signal amplitude average level and its deviation. The statistical data processing has shown that increasing all AE amplitude parameters is watched. However increase of AE signal amplitude average level advances increase of amplitude average level standard deviation and dispersion.

At the same time, as demonstrate researches, the AE signals energy is more sensitive AE parameters [13], [14]. The change of acoustic radiation energy in time has continuous nature. Its change there is large reacting to operating of CM machining technological processes different factors. The approaches reviewed in [11] – [13], can be used for research of AE energy at treating tool wearing from the CM with controlled CM machining depth that, doubtlessly, introduces scientific and practical concern.

IV. Results of Researches

Let's conduct research of acoustic radiation energy at CM machining and wearing of the treating tool from CM. For researches we shall accept conditions, which are reviewed in article [11]. On the initial stage of CM machining misses cutting tool wearing. Thus the acoustic radiation energy is connected to destruction of treated CM surface layer. Let's consider prevailing mechanical destruction of surface layer. At appearance of the tool wearing in acoustic radiation is added energy, bound with destruction of the tool. The tool wearing descends at operating a shear force and CM destruction, according to model of destruction of "fibers fascicle" [12]. Wearing appear at the some time. The technological parameters of CM machining are constants.

With allowance for the conditions [11] AE signal energy it is possible to write as

$$E_p(t) = \sum_j E_{jM}(t - t_j) + \sum_i E_{iM}(t - t_i), \qquad (2)$$

where $t_j = j\Delta t_j \pm \delta_1$, $t_i = i\Delta t_i \pm \delta_2$ are moments of time when the AE pulse signals E_{jM} and E_{iM} appears, accordingly, at destruction of treated CM area and treating CM wearing; j is the number of consequently destructed treated CM areas or number of a reshaped AE pulse signal E_{jM} (j = 0,……, n); Δt_j is the time interval between the beginnings of the formation subsequent AE pulse signal E_{jM} compared to the previous one; δ_1 is the random component in a moment of time when each next AE pulse signal E_{jM} appear; i is the number of consequently destructed treating CM areas or number of a reshaped AE pulse signal E_{iM} (i = 0,……, m); Δt_i is the time interval between the beginnings of the formation subsequent AE pulse signal E_{iM} compared to the previous one; δ_2 is the random component in a moment of time when each next AE pulse signal E_{iM} appear; $E_{jM} \sim U_{jM}^2$; U_{jM} is the amplitude of jth AE signal; $E_{iM} \sim U_{iM}^2$; U_{iM} is the amplitude of ith AE signal.

The amplitudes of AE signals U_{jM} is described by expression [12]

$$U_j(t) = u_0 t\alpha\upsilon_0 e^{r\alpha t} e^{-\frac{\upsilon_0}{r\alpha}(e^{r\alpha t}-1)}, \qquad (3)$$

where u_0 is the maximum possible elastic displacement, which is distributed in the material at the instantaneous destruction of a given treated CM area, that consisting from N_0 single elements; α is the loading speed; υ_0, r are parameters, which is determined by the physical-mechanical characteristics of CM.

The amplitudes of AE signals U_{iM} is described by expression [13]

$$U_i(t) = U_0 V_0 \psi e^{R\psi} e^{-V_0 \int_{t_0}^{t} e^{R\psi} dt}, \qquad (4)$$

where U_0 is the maximum possible elastic displacement, which is distributed in the material at the instantaneous destruction of a given treating CM area, that consisting from N_1 single elements; $\psi = \alpha t(1-\alpha t)(1-g\sqrt{\alpha t}) - \alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})$; α is the loading speed; V_0, R are parameters, which is determined by the physical-mechanical characteristics of CM; t, t_0 is the running time and time of CM area beginning destruction; g is the coefficient, which dependent on the geometrical CM area sizes.

Energy of AE signals pulse E_{jM} and E_{iM} we shall determine on expressions

$$E_{jM}(t) = \Delta t_k \sum_\ell U_{jM\ell}^2(\ell \cdot \Delta t_k), \qquad (5)$$

$$E_{iM}(t) = \Delta t_k \sum_\ell U_{jM\ell}^2(\ell \cdot \Delta t_k), \qquad (6)$$

where ℓ = 0,…., k is the number of jth and ith AE signals processing value amplitudes on their duration; Δt_k is the time period between jth and ith AE signals processing value (Δt_k = const).

Let's conduct simulation of acoustic radiation energy, agrees (2), with allowance for expressions (3) … (6). Let's consider, that on a initial stage misses of cutting tool wearing. Wearing of cutting tool occurs in some time t_0. The values u_0 and U_0 are proportional to the areas of CM treated and treating elementary destruction areas. On initial stage of simulation (without tool wearing) values u_0 and U_0 we shall accept equal: $\tilde{u}_0$=1, $\tilde{U}_0$=0. At appear wearing the of value u_0 and U_0 will be equal: $\tilde{u}_0$=1,0, $\tilde{U}_0$=0,1; $\tilde{u}_0$=1,0, $\tilde{U}_0$=0,2; $\tilde{u}_0$=1,0, $\tilde{U}_0$=0,3; $\tilde{u}_0$=1,0, $\tilde{U}_0$=0,4.

Parameters in expressions (3) and (4) we shall put to non-dimensional values, and the time will be submitted in normalized units. Let's consider, that disperse of treating CM properties is less than disperse of treated CM properties, i.e. $R > r$. The value of parameters υ_0, r, V_0, R and α will be equal: $\tilde{\upsilon}_0$ = 1000000; $\tilde{r}$ = 10000; $\tilde{V}_0$ = 1000000; $\tilde{R}$ = = 14000; $\tilde{\alpha}$ = 10. For set values of parameters, outgoing from duration of AE pulse signal, according to calculations on expression (3), time period Δt_j we shall accept equal: $\widetilde{\Delta t}_j$ = 0,0000015. The value of $\tilde{\delta}_1$ we shall change in range of sizes from 0 up to 0.0000049 arbitrarily. Time t_0 beginnings of treating CM wearing we shall accept equal $\tilde{t}_0$ = 0.0001. Value of parameter g we shall accept equal $\tilde{g}$ = 0.1. According to calculations [13], value of treating CM beginning destruction stress $\sigma_0 = \alpha t_0$ equally: $\tilde{\sigma}_0$=0.0009958408846174917. For set parameters values, outgoing from AE signal duration, according to calculations on expression (4), a time period Δt_i we shall accept equal: $\widetilde{\Delta t}_i$ = 0.0000015. The value of $\tilde{\delta}_2$ we shall change in range of sizes from 0 up to 0.0000049 arbitrarily.

The results of acoustic radiation energy simulation in time in normalized units for adopted conditions are shown in Fig. 1. At construction of the graphs Fig. 1 were conducted the calculations 5000 AE signals amplitudes and energies for each pair values of parameters u_0 and U_0.

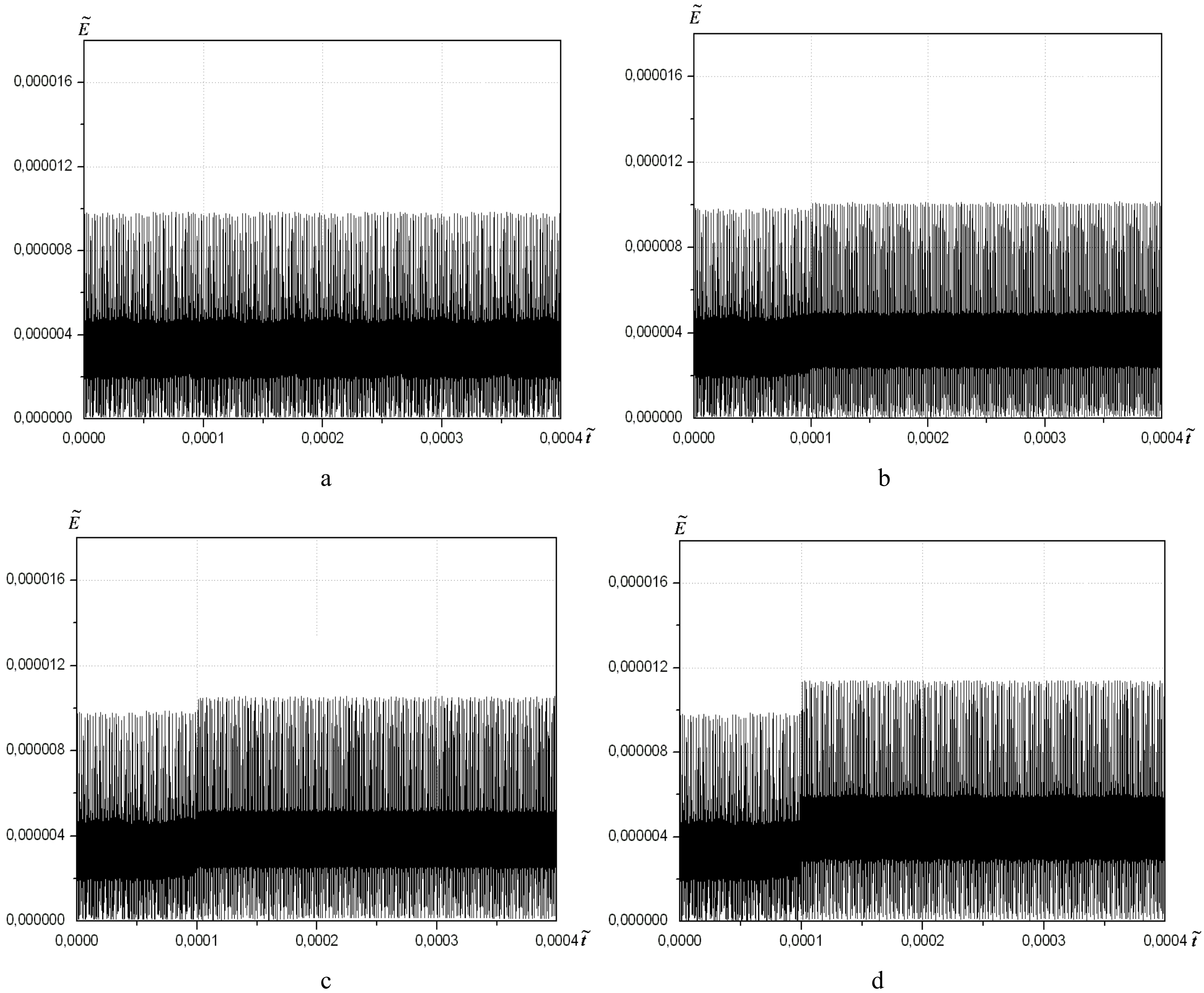

Fig. 1. Relation of AE energy change in time in relative units at CM machining by the tool from CM. Time periods: 0….0.0001 is the absence of tool wearing; 0.0001…0.0004 is the availability of tool wearing.
Values of parameters u_0 and U_0 : (a) $\tilde{u}_0$=1, $\tilde{U}_0$ = 0; on time period 0 … 0.0001 for Fig. (b) – (e) $\tilde{u}_0$=1, $\tilde{U}_0$ = 0; on time period 0.0001…..0.0004: (b) $\tilde{u}_0$=1, $\tilde{U}_0$ = 0.1; (c) $\tilde{u}_0$=1, $\tilde{U}_0$ = 0,2; (d) $\tilde{u}_0$ = 1, $\tilde{U}_0$ = 0,3; (e) $\tilde{u}_0$ = 1, $\tilde{U}_0$ = 0,4

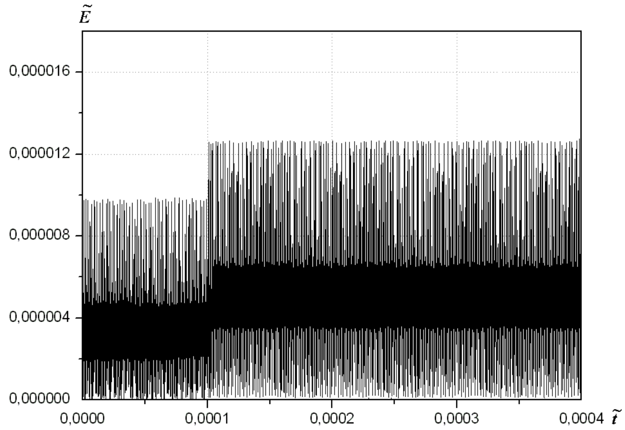

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Fig. 1. Ending. (See also p. 96)

The obtained results demonstrate that at increase of cutting tool wearing and controlled cutting depth the increasing of AE signal energy average level advances increasing of energy average level standard deviation. However increasing of AE energy average level dispersion advances increasing energy average level and its standard deviation.

Let's conduct matching increasing of AE signals amplitude and energy parameters at increase of cutting tool wearing. According to the data in article [11] at the same simulation parameters at $\tilde{u}_0 = 1$, $\tilde{U}_0 = 0$ of AE resultant signal amplitude average levels, its standard deviation and dispersion, accordingly, are peer $\tilde{\tilde{U}} = 11.63615$, $s_{\tilde{\tilde{U}}} = 5.66525$ and $s^2_{\tilde{\tilde{U}}} = 32.0951$. The results of increasing AE signal statistical amplitude parameters at increase of tool wearing in relation to their values without tool wearing are shown in Table I.

TABLE I

INCREASING OF AE SIGNALS STATISTICAL AMPLITUDE PARAMETERS AT INCREASE OF TREATING TOOL WEARING AND CONTROLLED CUTTING DEPTH IN RELATION TO THEIR VALUES WITHOUT TOOL WEARING

$\tilde{u}_0$	$\tilde{U}_0$	Increasing of AE signal amplitude parameters		
		$\tilde{\tilde{U}}$	$s_{\tilde{\tilde{U}}}$	$s^2_{\tilde{\tilde{U}}}$
1	0	1	1	1
1	0.1	1.08651	1.00473	1.00947
1	0.2	1.16756	1.01983	1.04006
1	0.3	1.23461	1.03802	1.07749
1	0.4	1.32202	1.05704	1.11733

The outcomes calculations demonstrate, that at increasing of cutting tool wearing increasing the acoustic radiation energy advance increasing its amplitude parameters.

So, at increase of wearing up to 0.4 ($\tilde{u}_0 = 1$, $\tilde{U}_0 = 0$) the increasing of AE signal energy average level $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$ advances increasing of AE signal amplitude average level $\tilde{\tilde{U}}$, its standard deviation $s_{\tilde{\tilde{U}}}$ and dispersion $s^2_{\tilde{\tilde{U}}}$, accordingly, in 1.21926 times, in 1.28811 times and in 1.65921 times.

The conducted researches demonstrate, that at controlled cutting depth the increasing of cutting tool wearing results in increasing acoustic radiation energy parameters (energy average level, its standard deviation and dispersion).

Thus the increasing ascending of AE signals energy parameters advances increasing their amplitude parameters. At the same time, as against amplitude parameters, greatest increasing there is a dispersion of AE signal energy average level.

V. CONCLUSION

The simulation of acoustic radiation energy at CM machining with a controlled cutting depth and treating tool wearing from CM is conducted. Is showed that cutting tool wearing nature of AE radiation energy does not change. Energy of acoustic radiation is continuous. The statistical processing of acoustic radiation energy parameters for want of cutting tool wearing is conducted. The statistical processing of acoustic radiation energy parameters at increasing of cutting tool wearing is conducted. The values of AE signal energy average level, its standard deviation and dispersion are determined. Is shown that increasing of treating tool wearing at constant cutting depth results to increase of AE energy parameters. However increase of AE signal energy average level dispersion advances increasing its average level and standard deviations. The matching acoustic radiation amplitude and energy parameters at increase of cutting tool wearing is conducted. Is shown that increase of AE signals energy parameters advances ascending their amplitude parameters.

The obtained results can be used at mining condition monitoring methods of cutting tool and control of CM machining technological processes. At the same time, for increase veracity of CM machining technological processes control the concern introduces research and description legitimacies of acoustic radiation energy parameters change.

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С. Ф. Філоненко. Акустична енергія за умови керованої глибини різання композиційного матеріалу

Проведено моделювання енергії акустичного випромінювання за умови механічної обробки композиційного матеріалу і зношенні оброблювального інструменту із композиційного матеріалу для випадку контрольованої глибині різання. Показано, що за умови контрольованої глибини різання зношення оброблювального інструменту приводить до зростання енергетичних параметрів акустичного випромінювання. Визначено, що зростання дисперсії середнього рівня енергії акустичного випромінювання випереджає зростання його середнього рівня і стандартного відхилення. Показано, що зростання енергетичних параметрів акустичного випромінювання випереджає зростання його амплітудних параметрів.

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

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С. Ф. Филоненко. Акустическая энергия при управляемой глубине резания композиционного материала

Проведено моделирование энергии акустического излучения при механической обработке композиционного материала и износе обрабатывающего инструмента из композиционного материала для случая контролируемой глубины резания. Показано, что при контролируемой глубине резания износ обрабатывающего инструмента приводит к возрастанию энергетических параметров акустического излучения. Определено, что увеличение дисперсии среднего уровня энергии акустического излучения опережает увеличение его среднего уровня и стандартного отклонения. Показано, что возрастание энергетических параметров акустического излучения опережает возрастание его амплитудных параметров

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

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