# MATHEMATICAL MODELING OF PROCESSES AND SYSTEMS

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## SIMULATION OF ACOUSTIC RADIATION ENERGY AT COMPOSITE MECHANICAL DESTRUCTION SURFACE LAYER

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***Abstract*—*Results of modeling acoustic emission energy during the change of composite material machining speed for a prevailing mechanical destruction he surface layer are observed. It is shown that increasing of composite material machining speed leads to increase of acoustic emission signal average level energy and its deviation. Statistical energy parameters of acoustic emission signals for different composite material machining speed are determined.*

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

## I. Introduction

To ensure the quality of the products from composite materials (CM) mining's the methods of diagnostics, monitoring and control of their machining technological processes are conducted. Thus acoustic emission (AE) method is widely spread. Its use is based on the method's sensitivity to deformation and destruction processes of materials, including CM materials.

Researches show that use of the AE method to carry out operations of machining allows obtaining significant volumes of information about dynamic destruction processes of the CM surface layers. These processes depend on many factors, which are CM machining technological operations parameters, physical and mechanical characteristics of materials being processed. Their availability, and also the complexity of registered AE signal character leads to the problem of AE signal interpretation.

Solution of this problem is based on the theoretical studies of AE during CM machining. These researches allow carrying out the analysis of influence of each factor on the character and parameters of AE. Also they allow determining the regularities of AE change and sensitivity of registered signal parameters to the change of CM machining technological processes parameters and their properties. Results of these researches are aimed at solving a number of problems. At first, on optimization of experiments and technological parameters of CM machining. Secondly, development of the methods diagnostics, monitoring, management and control of CM machining technological processes for obtaining items of given quality.

## II. Statement of the Task

The aim of this paper is the research of influence of CM machining speed for the mechanical model of the surface layer destruction on the acoustic emission energy parameters. To achieve these aims next tasks were set: carry out the modeling of acoustic radiation energy in time during the change of CM machining speed for the mechanical model of destruction surface layer; perform statistical processing of modeling results with obtaining of data about AE signals energy parameters; determine influencing of CM machining speed on energy parameters of AE signals.

## III. Review of Publications

Technological processes of CM machining cover all types of macro and micro machining – turning, drilling, milling, grinding. Researches of these processes are carried out with use of different methods. One of them is the method of AE [1] – [3]. Basic direction of AE method usage is optimization of CM machining technological parameters, control and monitoring of the cutting tool for obtaining given surface quality.

Researches of AE during materials machining, including CM, are based on the assumptions about different sources of acoustic radiation [2], [4] – [6], which are connected with processes of workpiece surface layer destruction, friction, wear and both destruction of the tool and shavings. However during the experimental researches two types of signals are registered [7], [8]: continuous AE signals and AE signals with the rugged amplitude. This type of signals determine basic AE processed parameters [9, 10] – mean or RMS value of the amplitude, their statistical characteristics, specters of amplitude and other.

Results of researches show that CM machining technological parameters (cutting speed, cutter longitudinal feed rate, cutting depth), and also wear of the cutting tool [8], [10] – [12] affect the character of

AE and its parameters. However, obtained regularities of connection of AE parameters with CM machining technological process have a complicated character of change. They are unstable and contradictory. Thus sensitivity of AE analyzed parameters to the change of CM machining technological process parameters practically is not investigated. From this point of view, theoretical studies are important.

In papers [13], [14] researches of AE signal amplitude parameters and regularities of their change during CM machining for the thermoactivative model of the surface layer destruction are carried out. In researches influencing CM machining speed and depth of cut on AE signals amplitude parameters are reviewed. It was shown that with an increase of machining speed and depth of cut an increase of AE signals amplitude parameters (amplitude average level, its standard deviation and dispersion). Thus the analysis of increment values of technological parameters on AE parameters has shown, that the most sensitive AE amplitude parameters is a dispersion of amplitude average level. Its increment outstrips an increase of AE signals amplitude average level and its standard deviation. The similar researches of influencing CM machining speed on AT amplitude parameters were carried out for the mechanical model of the surface layer destruction [14]. Results of these researches have shown that with an increase of CM machining speed there is an increase of AE amplitude parameters. However, in this case, AE signals amplitude average level dispersion growth outstrips the growth of amplitude average level and its standard deviation.

It should be noticed, that the most capacious parameter of AE signals are energy parameters. From the point of their sensitivity to the change of machining technological parameters, it's interesting to research of influencing CM machining speed on AE energy parameters for the mechanical model of the surface layer destruction. Such researches are indispensable for mining control methods of CM machining technological processes.

## IV. Results of Researches

Let's carry out the modeling of acoustic radiation energy during the CM machining for the mechanical model of surface layer destruction. Let's assume that CM machining is performed with given physical and mechanical characteristics. Technological parameters of machining (speed, depth of longitudinal feed of cutting tool and cutting depth) are constant values. In such conditions, sequential deformation and destruction of elementary areas of CM surface layer occurs. We will assume that deformation of each elementary area occurs in elastic range up to destruction with prevailing mechanical destruction mechanism. Also, destruction of each elementary area is accompanied by forming of single AE pulse, and their consecutive destruction leads to consequence of AE pulse signals formed in time. Complex of pulse signals determines the resultant AE signal, which energy we will describe in the next way

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

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

Amplitudes of AE pulse signal $U_{jM}$ for the mechanical model of CM destruction, according to [15], is described in the next way

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

where $u_0$ is the maximum possible elastic displacement, which spread in the material during instant destruction of the given CM area; $\alpha$ is the load speed; $\upsilon_0$, $r$ are constants, which are determined by CM physical and mechanical characteristics.

During the modeling of AE resultant signal's energy, according to (1), by the results of calculation amplitude $U_{jM}$ of the AE pulse signals in time, according to (2), we will carry out calculations of their energy in the next way

$$E_{jM}(t) = \Delta t_k \sum_i U_{jiM}^2 (i \cdot \Delta t_k), \tag{3}$$

where $i$ = 0, …, $k$ is the number of calculated amplitude value of $j$th AE signal on its duration; $\Delta t_k$ is the time interval between two calculated amplitude values of $j$th AE signal ($\Delta t_k$ = const).

Modeling of acoustic emission energy, according to (1), taking into account (2) and (3) will be conducted with the next conditions. The parameters, which one are included in expression (2), we shall put to non-dimensional values. Amplitude of signals we shall set norms on value $u_0$. In the modeling parameters $\upsilon_0$, $r$ and $\alpha$ will be taken the same as work [15]: $\tilde{\upsilon}_0$= 100000, $\tilde{r}$ = 10000. The value $\alpha$ we will change in the diapason from $\tilde{\alpha}$ = 10 to $\tilde{\alpha}$ = 50 with the step of increment 10. For the start value $\tilde{\alpha}$ = 10 value $\Delta t_j$ will be taken as $\widetilde{\Delta t}_j$ = 0.000011. Value $\tilde{\delta}$ we will change in the diapason from 0 to 0.000011 arbitrarily. For other $\alpha$ magnitudes values $\widetilde{\Delta t}_j$ and $\tilde{\delta}$ will be decreased proportionally to the decrease of the formed pulse signals duration. At calculation of energy, according to (3), value $\Delta t_k$ made: $\Delta\widetilde{t_k}$ = 0.000002.

Results of the performed modeling in the form of dependencies AE resultant signals energy change in time in the relative units for different values of CM cutting speed $\tilde{\alpha}$ are shown in the Fig. 1. In the graphs Fig. 1 time is normalized by the time of the CM surface layer destruction process during its machining. During the formation of graphs in the Fig. 1 the calculations are conducted 5000 amplitudes and energies of each resultant AE signal.

Obtained results (Fig. 1) show that for the given modeling parameters during the CM machining acoustic radiation energy in time is represented as a continuous signal. With an increase of machining speed a change of acoustic radiation character doesn't occur. However, ascending an average energy level of AE resultant signals and value of its scatter is observed.

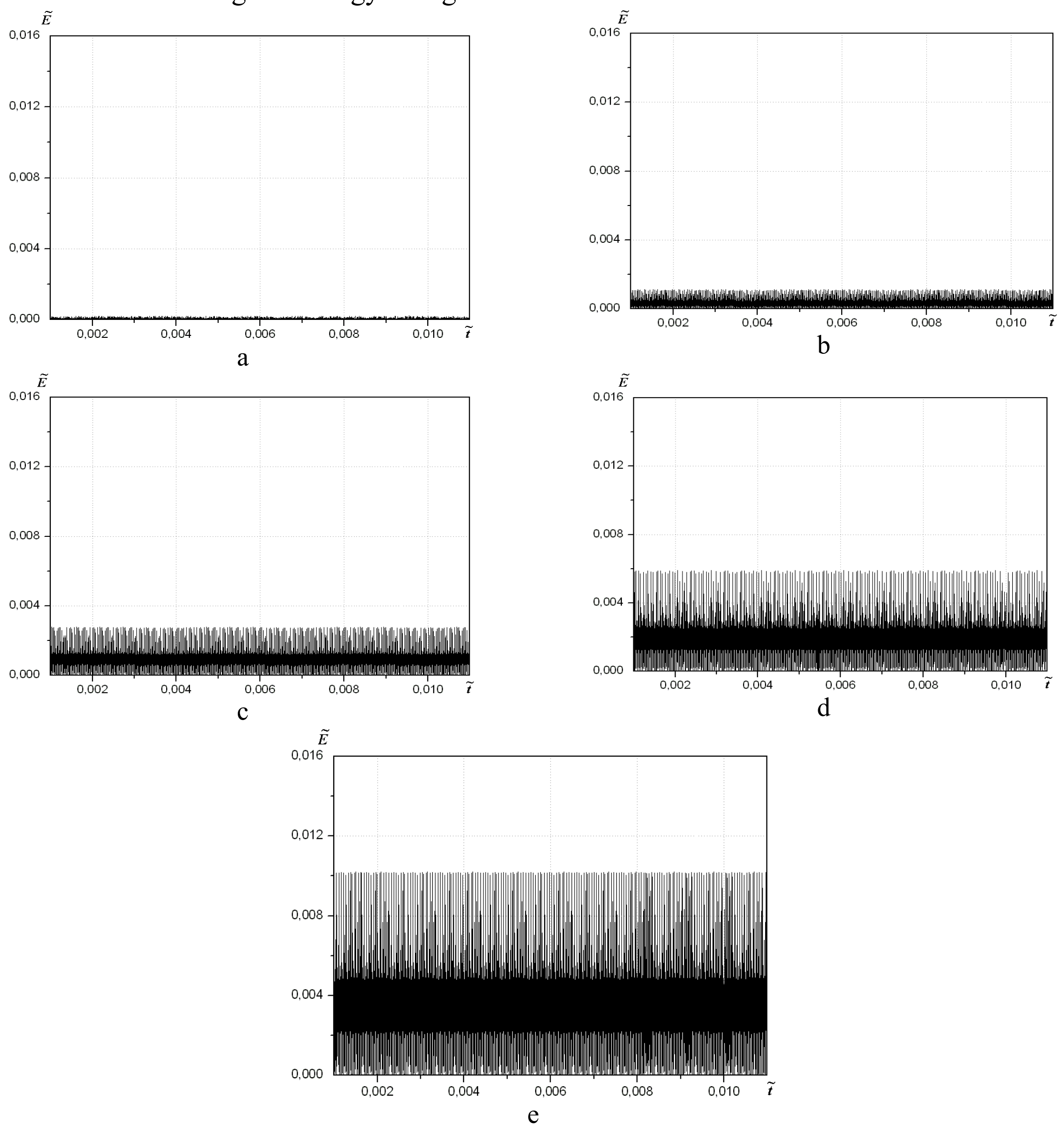


Fig. 1. Graphs of AE resultant signals energy change in time, according to (1), in relative units during the machining for the mechanical destruction of the CM surface layer and different machining speeds. Modeling parameters: $\tilde{\upsilon}_0$ =100000, $\tilde{r}$ = 10000. Starting value $\tilde{\Delta}t_j$ = 0.000011, $\tilde{\delta}$ should be changed in diapason from 0 to 0.000011 arbitrarily. CM destruction speed in relative units: (a) is the $\tilde{\alpha}$=10; (b) is the $\tilde{\alpha}$=20; (c) is the $\tilde{\alpha}$=30; (d) is the $\tilde{\alpha}$=40; *e* is the $\tilde{\alpha}$=50

Truly, as the statistical processing of modeling results has shown, at initial value of speed $\tilde{\alpha} = 10$ of CM machining of acoustic radiation energy parameters in relative units make: average energy level is the $\tilde{\tilde{E}} = 5.40834 \cdot 10^{-5}$; standard deviation of average energy level is the $s_{\tilde{\tilde{E}}} = 4.47738 \cdot 10^{-5}$; dispersion of average energy level is the $s^2_{\tilde{\tilde{E}}} = 2.0047 \cdot 10^{-9}$. At ascending value $\tilde{\alpha}$ in 2 times (up to value $\tilde{\alpha} = 20$) there is an increase of energy parameters of acoustic radiation, i.e. average energy level $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, respectively, in 6.19372 times, in 6.46471 times and in 41.79239 times. The further ascending $\tilde{\alpha}$ in 3 times (up to value $\tilde{\alpha} = 30$) leads to increase the values of parameters $\tilde{\tilde{E}}$, $s_{\tilde{\tilde{E}}}$ and $s^2_{\tilde{\tilde{E}}}$, respectively, in 14.72552 times, in 15,05634 times and in 226,69262 times. At ascending value $\tilde{\alpha}$ in 4 times (up to value $\tilde{\alpha} = 40$) there is a further increase the values of parameters $\tilde{\tilde{E}}$, $s_{\tilde{\tilde{E}}}$ and $s^2_{\tilde{\tilde{E}}}$, respectively, in 26.72722 times, in 27.73223 times and in 769.0739 times. If $\tilde{\alpha}$ increases in 5 times (up to value $\tilde{\alpha} = 50$), that value of parameters $\tilde{\tilde{E}}$, $s_{\tilde{\tilde{E}}}$ and $s^2_{\tilde{\tilde{E}}}$ increase, respectively, in 49.69835 times, in 54.03821 times and in 2920.118.

Results of statistical data processing show that an increase of CM machining speed for the prevailing mechanical destruction of its surface layer must conduct to an increase of all acoustic radiation energy parameters. However, the highest increase is observed in the dispersion of acoustic radiation average energy level. In other words, with an increase of CM machining speed an increase of dispersion of AE signal average energy level outstrips an increase of average energy level and its standard deviation.

## V. Conclusion

During the CM machining for the mechanical model destruction of its surface layer in dependence of machining speed a modeling of acoustic radiation energy was held. For different machining speed dependencies of AE energy change in time were obtained. It was shown that energy of acoustic radiation in time has a continuous character of change. An increase of CM machining speed leads to an increase of AE average energy level, and also the size of its scatter. Statistical processing of modeling data was held with the determination of acoustic radiation energy parameters – average energy level, its standard deviation and dispersion. Calculations of increase of AE signals energy parameters with an increase of machining speed in relation to their initial values were performed. It is shown that of AE signals average energy level dispersion has the highest sensitivity to an increase of CM machining speed.

Results of performed researches show that an analysis of AE signals average energy level dispersion can be used to develop the methods of monitoring, management and control of CM machining parameters of CM. At the same time, it is necessary to perform researches of regularities with the description of AE signals energy parameters change, when changing the CM machining speed.

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**С. Ф. Філоненко. Моделювання енергії акустичного випромінювання при механічному руйнуванні поверхневого прошарку композиту**

Розглянуто результати моделювання енергії акустичного випромінювання при зміні швидкості механічної обробки композиційного матеріалу для переважного механічного руйнування поверхневого прошарку. Показано, що зростання швидкості механічної обробки композиційного матеріалу приводить до збільшення середнього рівня енергії сигналу акустичної емісії і величини його розкиду. Визначено статистичні енергетичні параметри сигналів акустичної емісії для різних швидкостей механічної обробки композиційного матеріалу.

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

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**С. Ф. Филоненко. Моделирование Энергии акустического излучения при механическом разрушении поверхностного слоя композита**

Рассмотрены результаты моделирования энергии акустического излучения при изменении скорости механической обработки композиционного материала для преобладающего механического разрушения поверхностного слоя. Показано, что возрастание скорости механической обработки композиционного материала приводит к увеличению среднего уровня энергии сигнала акустической эмиссии и величины его разброса. Определены статистические энергетические параметры сигналов акустической эмиссии для различных скоростей механической обработки композиционного материала.

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

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