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# SIMULATION OF ACOUSTIC EMISSION IN COMPOSITE MATERIAL MACHINING WITH REGARD TO ITS PHYSICAL AND MECHANICAL CHARACTERISTICS

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# МОДЕЛЮВАННЯ АКУСТИЧНОЇ ЕМІСІЇ ПІД ЧАС ОБРОБЛЕННЯ КОМПОЗИЦІЙНОГО МАТЕРІАЛУ З УРАХУВАННЯМ ЙОГО ФІЗИКО-МЕХАНІЧНИХ ХАРАКТЕРИСТИК

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# МОДЕЛИРОВАНИЕ АКУСТИЧЕСКОЙ ЭМИССИИ ПРИ ОБРАБОТКЕ КОМПОЗИЦИОННОГО МАТЕРИАЛА С УЧЕТОМ ЕГО ФИЗИКО-МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК

*Acoustic emission signal in the machining of composite material for the prevailing thermal activation mechanism of destruction of the surface layer with the change of the parameter, which coincides in size with the period of vibrations of the lattice atoms of the solid body, was simulated. It was shown that the resulting signal of the acoustic emission is a continuous signal of a strongly peaked shape. The regularities of changes in amplitude parameters of the acoustic emission with the change of the parameter, which coincides in size with the period of vibrations of the lattice atoms of the solid body, were determined.*

***Key words:*** *acoustic emission, composite material, resulting signal, thermal activation model, amplitude, parameters, regularities, sensitivity, machining.*

*Проведено моделювання сигналу акустичної емісії під час механічного оброблення композиційного матеріалу для переважного термоактиваційного механізму руйнування поверхневого шару з урахуванням зміни параметра, що збігається за величиною з періодом коливань атомів гратки твердого тіла. Показано, що результуючий сигнал акустичної емісії є неперервним сигналом із сильно порізаною формою. Визначені закономірності зміни амплітудних параметрів акустичного випромінювання при зміні параметра, який збігається за величиною з періодом коливань атомів гратки твердого тіла.*

***Ключові слова:*** *акустична емісія, композиційний матеріал, результуючий сигнал, термоактиваційна модель, амплітуда, параметри, закономірності, чутливість, механічне оброблення.*

*Проведено моделирование сигнала акустической эмиссии при механической обработке композиционного материала для преобладающего термоактивационного механизма разрушения поверхностного слоя с учетом изменения параметра, совпадающего по величине с периодом колебаний атомов решетки твердого тела. Показано, что результирующий сигнал акустической эмиссии является непрерывным сигналом с сильно изрезанной формой. Определены закономерности изменения амплитудных параметров акустического излучения при изменении параметра, совпадающего по величине с периодом колебаний атомов решетки твердого тела.*

***Ключевые слова:*** *акустическая эмиссия, композиционный материал, результирующий сигнал, термоактивационная модель, амплитуда, параметры, закономерности, чувствительность, механическая обработка.*

**Problem statement.** Products made of composite materials (CM) are widely used in various industries due to their high durability and performance specifications. To achieve the desired product quality, research is carried out with the development of the methods of control, diagnosis and monitoring of technological machining processes for CM. One of such methods used in the machining of materials of crystalline structure and CM is the acoustic emission method (AE). The essence of the AE method is that the recorded acoustic emission is the reflection of internal processes that develop in the surface layers of the material in machining. The method is characterized by low inertia. AE method is sensitive to changes in the process which develop during machining, resulting in a change in the parameters of the generated acoustic emission.

Analysis and processing of the acoustic emission parameters, with further definition of the acoustic emission regularities, is an important issue in the application of the AE method during CM machining. This is due both to the difficulties of experimental research in the process of machining, and a significant number of parameters affecting the AE signal. From this viewpoint, theoretical studies that involve analysis of the acoustic emission under changing of the machining parameters acquire in importance. The results obtained during the simulation are fundamental in the development of methods for monitoring and diagnosis of CM machining processes.

**Analysis of recent research and publications.** In developing the methods of control and monitoring of technological machining processes for materials, continuous AE signal parameters are analyzed. In this case, we investigate the influence of various factors on the analyzed parameters of the sensed AE signals. These factors act as machining parameters (cutting speed, depth of cut, cutter feed) and physical and mechanical properties of the materials.

Empirical regularities in the change of the AE signals under change of the influencing factors, obtained by most of the authors, are not stable, and some studies are contradictory. Most of the published results relate to experimental studies [1–4]. At the same time, there are rather few theoretical studies related to the development and simulation of the acoustic emission during machining of materials [5–9]. Therefore, creation of the acoustic emission models, describing the material machining process, with further simulation, is one of the main tasks of theoretical studies.

Studies [6; 9] consider the model of AE resulting signal generated during machining of materials of traditional structure (turning operation). The model is based on the principles of generation of the acoustic emission at deformation and fracture of the surface layers of the material during machining. The results of the simulation showed that the generated AE signals are continuous signals of strongly irregular shape. The obtained theoretical results agree with the experimental data [3; 6; 9].

Results of AE signals simulation under the change of one of the material machining parameters (machining speed), discussed in study [9], showed that change of the material machining speed leads to the change in the average amplitude level of the resultant AE signal, its standard deviation and dispersion.

Approaches used in the modeling of the acoustic emission discussed in [6], can be applied to making the acoustic emission model in the case of CM machining.

**Research tasks.** The study will include simulation of the AE signal in the machining of composite material for the prevailing thermal activation mechanism of destruction of the surface layer, with the influence of the parameter coinciding in size with the period of vibrations of the lattice atoms of the solid body. Dependences of the change of the amplitude parameters of the resulting AE signal under the change of the parameter coinciding in size with the period of vibrations of the lattice atoms of the solid body, will be analyzed. Sensitivity of AE amplitude parameters will be determined.

**Theoretical results.** In general, the model of the resulting AE signal in the CM machining, excluding wear of cutting tools, is discussed in [10] as follows

$$U_p(t) = \sum_j U_R(t - t_j), \tag{1}$$

where $t_j$ – is the occurrence times of AE pulse signals $U_R$, arising under the prevailing thermal activation destruction of certain CM areas of the set size.

The occurrence time of each subsequent AE signal can be formulated as follows

$$t_j = j\Delta t_j, \tag{2}$$

where $\Delta t_j$ – is the time interval between the beginning of generation of the subsequent AE pulse signal in relation to the previous one.

As the model of the AE pulse signal, we used the signal model [7], which is generated during thermal activation destruction of CM

$$U_R(t) = u_0 \alpha t e^{-\chi(t_0 - t)} e^{-\frac{1}{\tau_0 \chi}\left(e^{-\chi(t_0 - t)} - e^{\chi t_0}\right)}, \tag{3}$$

where $\tau_0$ – is the parameters which coincides in size with the period of thermal vibrations of the lattice atoms of the solid body; $\alpha$ – the rate of the applied load variations; $t$ – current time; $u_0 = \frac{N_0}{\tau_0}\beta\delta_s$ – the maximum possible shift at instantaneous destruction of the set CM area consisting of $N_0$ elements (the initial number of elements); $\beta$ – coefficient of proportionality between fracture stress and amplitude of a single pulse of perturbation at destruction of a single CM element; $\delta_s = \int_{t-\frac{\delta}{2}}^{t+\frac{\delta}{2}} a(\tau)d\tau$; $\delta$ – duration of a single perturbation pulse; $a(\tau)$ - function defining the form of a single perturbation pulse; $\chi = \frac{\gamma\alpha}{kT}$; $t_0 = \frac{U_0}{\gamma\alpha}$; $U_0$ – the initial activation energy (the value of the initial energy barrier) of the destruction process; $k$ – Boltzmann's constant; $T$ – temperature; $\gamma$ – structural-sensitive factor.

CM machining speed determines the duration of the destruction process for a given CM area and time parameters of AE pulse signals, i.e. their duration. Ideally, for the set CM machining parameters, time intervals $\Delta t_j$ of occurrence of AE pulse signals, according to (2), shall be the same. However, the duration of the successive CM destruction processes in time will be influenced by various factors. For example, dispersion properties of the processed CM, instability of the work piece rotation speed, line feed speed or others. In this case, the time point $t_j$ can be formulated as follows

$$t_j = j\Delta t_j \pm \delta, \tag{4}$$

where $\delta$ – is a random component in the occurrence point of each subsequent AE pulse signal.

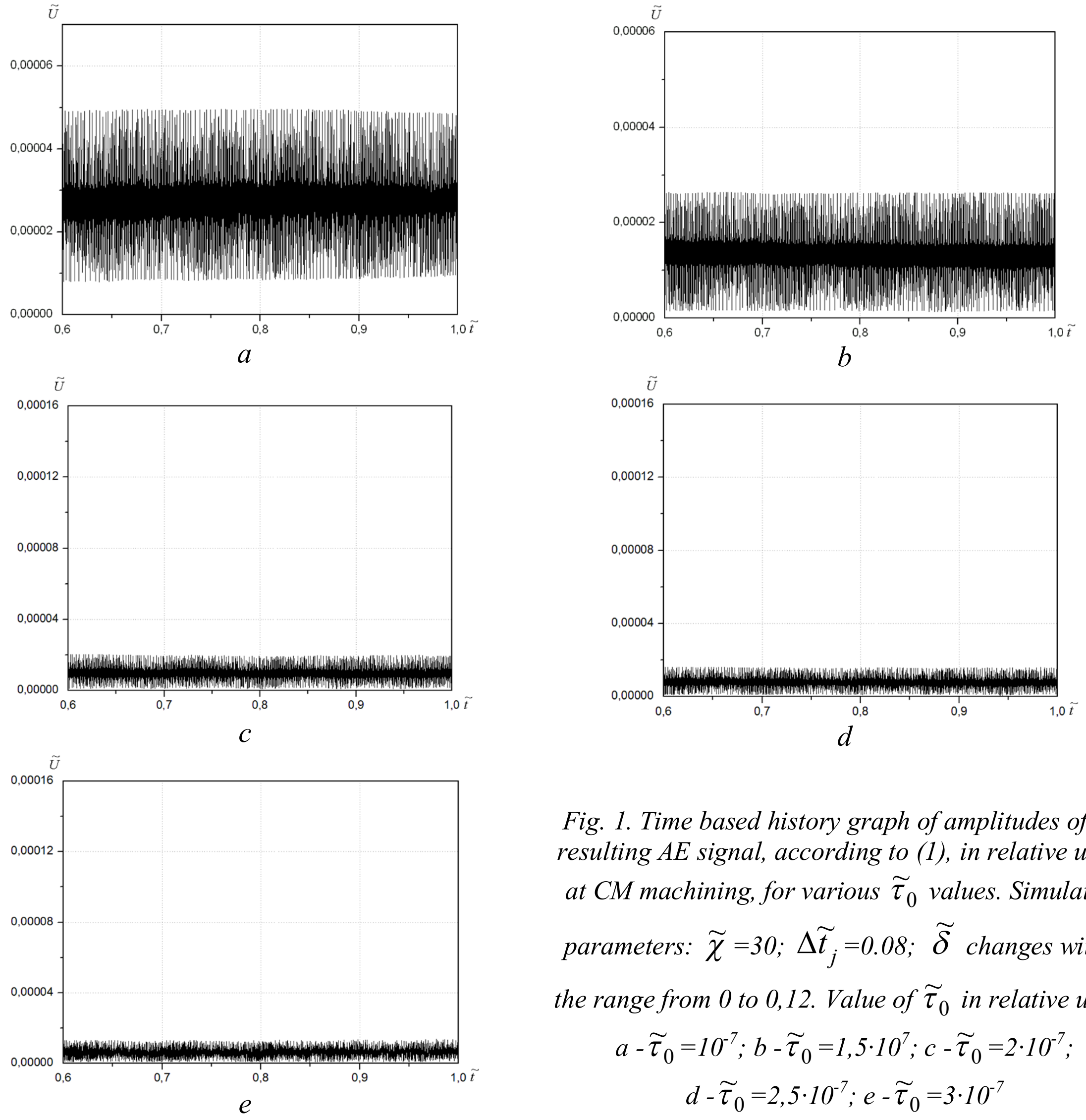
According to (1), with due account of (2) and (4), let us simulate the resulting AE signals in relative units as a function of parameter changes, coinciding in size with the period of thermal vibrations of the lattice atoms of the solid body $\tau_0$. Simulation is carried out under the following conditions. Parameters in equation (2) are reduced to the dimensionless values, and time is normalized to $t_0$. We assume that at initial conditions, the unit of the material area is destructed for a certain cutting depth. The amplitude of the signals will be normalized to the initial value $u_0$. Value $\frac{\gamma}{kT}$ is reduced to a single normalized value. Under such conditions $\chi = \alpha$. Value for parameter $\tau_0$ is taken equal to $10^{-7}$. Value of $\tilde{\chi}$ or $\tilde{\alpha}$ is taken as $\tilde{\chi}$=30. At simulation, value $\tilde{\tau}_0$ will be changed within the range from $\tilde{\tau}_0$= $10^{-7}$ to $\tilde{\tau}_0$=$3\cdot 10^{-7}$ with growth increment $0{,}5\cdot 10^{-7}$.

Value of $\Delta\tilde{t}_j$ is taken based on the calculation of the duration of AE pulse signal, as per (3). Basing on the calculation for the set speed $\tilde{\chi}$ and $\tilde{\tau}_0$= $10^{-7}$ value of $\Delta\tilde{t}_j$ is taken equal to: $\tilde{\chi}$=30 - $\Delta\tilde{t}_j$=0,08. Value of $\tilde{\delta}$ for $\tilde{\chi}$=30 will be changed with the range from 0 to 0,12 arbitrarily. For other $\tilde{\tau}_0$ values, $\Delta\tilde{t}_j$ and $\tilde{\delta}$ will be changed in proportion to the change of the pulse signal duration.

Simulation of the resulting AE signals for the assumed conditions, in the relative units, in the form of their amplitude time dependencies is presented in Fig. 1. Charts in fig. 1 are based on the calculation results for 4,000 amplitude values for each resulting AE signal. For charts in Fig. 1, the current time was normalized to the time of the destruction process of CM surface during machining.

The simulation shows (Fig. 1), that the resulting AE signals for the assumed conditions with the prevailing thermal activation destruction mechanism of the CM surface layer, are continuous signals. The signals have a complex and highly rugged form. The signals are of complex and strongly peaked shape. To characterize these signals, we may use their average amplitude ($\overline{\tilde{U}}$), standard deviation $s_{\tilde{U}}$ and dispersion $s^2_{\tilde{U}}$.

Fig. 1 shows that increasing parameter $\tilde{\tau}_0$, with the constant other influencing factors, reduces the average amplitude of the resulting AE signal and its dispersion value.



a b c d e

*Fig. 1. Time based history graph of amplitudes of the resulting AE signal, according to (1), in relative units, at CM machining, for various $\tilde{\tau}_0$ values. Simulation parameters: $\tilde{\chi}$ =30; $\Delta\tilde{t}_j$ =0.08; $\tilde{\delta}$ changes within the range from 0 to 0,12. Value of $\tilde{\tau}_0$ in relative units: a - $\tilde{\tau}_0 = 10^{-7}$; b - $\tilde{\tau}_0 = 1{,}5\cdot 10^{7}$; c - $\tilde{\tau}_0 = 2\cdot 10^{-7}$; d - $\tilde{\tau}_0 = 2{,}5\cdot 10^{-7}$; e - $\tilde{\tau}_0 = 3\cdot 10^{-7}$*

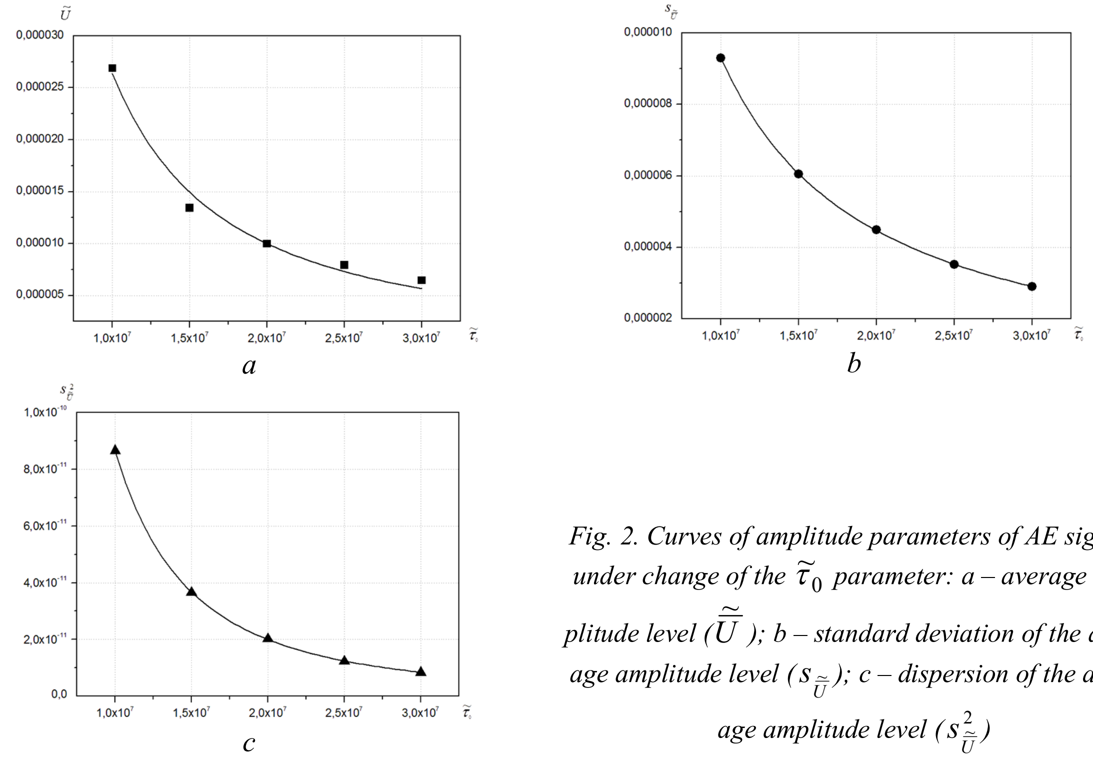
Fig. 2 shows the regularities in the change of amplitude parameters of the resulting AE signals: average amplitude level $\tilde{\tilde{U}}$ ; standard deviation of the average amplitude level ($s_{\tilde{\tilde{U}}}$); dispersion of the average amplitude level ($s^2_{\tilde{\tilde{U}}}$) under change of the signal parameter $\tilde{\tau}_0$.

Figure 2 shows that increasing $\tilde{\tau}_0$ leads to sharp decrease of the average amplitude level $\tilde{\tilde{U}}$ , standard deviation of the average amplitude level ($s_{\tilde{\tilde{U}}}$) and dispersion of the average amplitude level ($s^2_{\tilde{\tilde{U}}}$).

Analysis of the data obtained with the approximation of dependencies (Fig. 2 *a, b, c*) showed that they can be well described by the following equation:

$$\tilde{\tilde{U}} = aX^b, \qquad (5)$$

where *a* and *b* – are the coefficients of the approximating equation. Values of the coefficients of the approximating equations a and b are as follows: for the average amplitude level of the resulting signal $\tilde{\tilde{U}}$ – *a*= 168047,37802, *b*=-1,400063; for its standard deviation $s_{\tilde{\tilde{U}}}$ – *a*= 236,01062, *b*=-1,05777; for dispersion of the average amplitude level of the resulting signal $s^2_{\tilde{\tilde{U}}}$ – *a*=54056,46953, *b*=-2,11371.



*a* *b* *c*

*Fig. 2. Curves of amplitude parameters of AE signals under change of the $\tilde{\tau}_0$ parameter: a – average amplitude level ($\tilde{\tilde{U}}$ ); b – standard deviation of the average amplitude level ($s_{\tilde{\tilde{U}}}$); c – dispersion of the average amplitude level ($s^2_{\tilde{\tilde{U}}}$)*

Statistical analysis of the data shows that $R^2$ determination coefficients at approximation of dependencies in Fig. 2, which can be expressed as (5), are as follows: for the average amplitude level of the resulting signal $\tilde{\tilde{U}}$ – $R^2$=0,98687; for standard deviation of the average amplitude level of the resulting signal $s_{\tilde{\tilde{U}}}$ $-R^2$=0,99996; for dispersion of the average amplitude level of the resulting signal $s^2_{\tilde{\tilde{U}}}$ $-R^2$=0,99998.

The obtained regularities (Fig. 2) also show that under change of the parameter $\tilde{\tau}_0$, dispersion of the average amplitude level of the resulting signal is the most sensitive parameter as compared to the standard amplitude deviation of the resulting AE signal.

**Conclusion.** A model of the resulting AE signal while turning the CM for the prevailing thermal activation destruction of the surface layer was considered. According to the presented model, time dependences of changes in the amplitude of the resulting AE signals under changes of $\tilde{\tau}_0$ parameter was simulated. It is shown that the resulting AE signals for the given CM machining conditions, are continuous. AE signals are characterized by the complex changes and strongly irregular shape. Statistical processing of the data showed that increasing of the $\tilde{\tau}_0$ parameter reduces the amplitude parameters of the generated AE signals – the average amplitude, its standard deviation and dispersion. It is shown that dispersion of the average amplitude level is the most sensitive parameter under changes of the parameter coinciding in size with the period of thermal vibrations of the lattice atoms of the solid body $\tilde{\tau}_0$. At the same time, study of regularities of energy parameters under changes of the $\tilde{\tau}_0$ parameter is of interest.

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