MATHEMATICAL MODELING OF PROCESSES AND SYSTEMS

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SOME ASPECTS OF ACOUSTIC EMISSION AT MACHINING COMPOSITE MATERIALS

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Abstract**—***The processing of outcomes acoustic emission signals simulation is conducted at ascending composite machining speed and cutting depth, change of treated composite physical-mechanical characteristics with definition the ratio of acoustic emission signal amplitude average level to acoustic emission signal amplitude average level standard deviation. Are determined the regularity of dimensionless coefficient change, which characterizes the ratio of acoustic emission signal amplitude average level to its standard deviation at change of the influential factors. The processing of experimental acoustic emission signals is conducted at composite machining speed ascending and ascending cutting depth with definition the regularity of dimensionless coefficient change, which characterizes the ratio of acoustic emission signal amplitude average level to its standard. It is shown that the theoretical and experimental regularity of investigated coefficient value change at ascending machining speed and cutting depths will be agreed one another.*

Index Terms—Acoustic emission; composite material; signal; amplitude; statistical parameters; machining.

I. INTRODUCTION

For optimization, verification and control of machining materials technological process are carried out researches with usage of acoustic emission (AE) method. The researches concern both machining materials with crystalline structure, and composite material (CM).

The AE researches at CM machining encompass all kinds of executed operations – turning, milling, drilling, grinding and other. Thus the looking up of AE legitimacies parameters change is carried out at change of the influential factors. As demonstrate the obtained outcomes, such factors are: technological process machining parameters (machining speed and depth, feed rate of treating tool), physical-mechanical characteristics treated and treating materials, condition of treating tool or its wear. The outcomes of researches demonstrate composite nature of each influencing factor on AE. Thus the problem of interpretation the obtained outcomes and legitimacies of AE parameters change is conditioned by a sharp response of AE method to submicro, micro and macro processes CM surface layers deformation and destruction. The problem becomes complicated by looking up both mining yardsticks of verification and controls the robotic CM machining technological processes using neural networks.

In the given aspect values have AE analytical investigations at CM machining, with allowance for operating different factors. Thus theoretical regularity of AE parameters change can be the basis in establishing dimensionless criteria, which one will ensure realization verification and control of technological processes. Such dimensionless criteria, unconditionally, should allow for features of AE change at CM machining, and also level differences in the parameters of AE equipment used.

II. STATEMENT OF THE TASK

The purpose of article is theoretical and experimental researches the ratio of AE signal amplitude average level to AE signal amplitude average level standard deviation legitimacies at CM machining and changes of the influential factors.

For achievement the purpose of article the following problems were put:

– to conduct processing outcomes simulation AE signals at increasing CM machining speed, change of treated CM physical-mechanical characteristics and cutting depths with definition the ratio of AE signal amplitude average level to AE signal amplitude average level standard deviation legitimacies change;

– to conduct processing experimental AE signals at ascending CM machining speed and ascending cutting depth with definition the ratio of

AE signal amplitude average level to AE signal amplitude average level standard deviation legitimacies change;

– to conduct matching the obtained ratio of AE signal amplitude average level to AE signal amplitude average level standard deviation legitimacies change at ascending CM machining speed and cutting depths.

III. Review of Publications

The researches of acoustic radiation at machining materials, including CM, demonstrate influencing different technology factors (machining speed, feed rate, cutting depth, physical-mechanical characteristics treated and treating materials, treating tool wear) on registered AE signals parameters.

In article [1] influencing machining technological parameters on statistical AE amplitude parameters is investigated. It is shown, that at ascending machining speed there is not a linear ascending mean and root mean square value (RMS) of AE signals amplitude. Thus decreasing of amplitude distribution skewness and kurtosis is watched. However obtained relations have composite nature of change. Composite nature of change have also relations of AE statistical amplitude parameters change at ascending of treating tool feed rate and machining depth. It is shown, that the ascending of treating tool wear results in decreasing of statistical AE amplitude parameters. Thus the relations have composite nature of change. In article [2] is determined, that at ascending machining speed, feed rate and cutting depth there is ascending of AE signal RMS amplitude. Thus the ascending of machining speed and feed rate results in practically linear ascending of AE signal RMS amplitude. However at ascending machining cutting depth the obtained relation has composite nature of change.

The research of statistical AE energy parameters in time at fulfillment of machining operation and treating tool wear is conducted in article [3]. It was shown that at machining there is ascending of AE energy average level. To ascending the tool wear there is decreasing skewness value of AE signals energy distribution. Thus the kurtosis has stable value on pioneering stages of wear increase. However at defined wear value there is its discontinuous change (from positive up to negative value). In article [3] is marked, that the obtained results make it possible to control the mechanisms of tool wear during materials machining. Outcomes of researches obtained in article [4], have shown, that to ascending tool wear there is decreasing of AE signal amplitude. The regularity is determined and the dependence interrelationships of AE signal amplitude with the treating tool wear is described. The dependence has linear nature of dip. The good correlation connection of AE signals RMS amplitude, registered with usage of the low frequency sensor, with tool wear is marked in article [5].

To assess the treating tool wear and quality of tread material are developed the various indices that obtained at AE signals processing. In article [6] the fractal analysis for realization of estimations complexity registered AE signal and keeping track by its characteristics change will be used. Thus on AE signals the calculations and analysis of fractal parameters are carried out, which one allow to evaluate complexity, irregularity (ruggedness) and evolution of AE signal change, which reflects the evolution of treating tool wear. In article [7] the results of AE signals analysis for estimation the quality of machined surface and treating tool wear are considered. It is determined, that the original AE signals include information about the cutting processes of the materials and different noise components, that do not allow to conduct state estimations of treating tool. Using a frequency filtering and energy analysis on obtained signal spectra, as the writers of article mark, is possible to conduct estimations of tool state transition during cutting before its destruction (breaking). The results of AE signals analysis usage the Wavelet transformation at treating tool wear are considered in article [8]. It is shown, that in given frequency bands of analysis there is connection between treating tool wear and RMS of AE signals amplitude. In article [9] at research of treating tool wear usage a principal component analysis (PCA) or the joint analysis of data obtained using different sensors is considered. PCA is used to analyze the data table, which represents the results of several interrelated parameters measurements. The analysis is directed at extraction important information from data table and its representation by the way of set new orthogonal variables, called as main components [10]. In article [9] the measurement of cutting three forces, three of acceleration values and AE signals RMS amplitude is carried out, which one reshape the data table. Further data processing is performed with their normalization, calculation the covariance matrix, determination eigenvectors and eigenvalues, which represent a set of new data or main components. Processing a set of the new data allows classifying condition of cutting tool or of a cutting tool wear. The similar approach will be used and in article [11].

Investigation influence of treated material microstructure on AE during machining operation is conducted in article [12]. Thus influencing tool feed rate on AE signal RMS amplitude was analyzed. It is determined, that to ascending tool feed rate there is ascending of AE signal RMS amplitude for all investigated microstructures. Thus is marked, that influencing of treated materials microstructure on AE signals RMS amplitude are watched only at high tool feed rate.

Theoretical and experimental researches of AE at CM machining are reviewed in article [13] – [16]. In article [13] is shown, that the ascending parameter, that describing the CM physical-mechanical characteristics, results in decreasing of AE resultant signal amplitude average level, its standard deviation and dispersion. At the same time, at general dip of AE amplitude parameters the greatest sensitivity to change the influential parameter there is an AE resultant signal amplitude average level dispersion. In article [14] the experimental researches of AE statistical amplitude parameters are conducted at alteration of CM machining speed. It is determined, that at ascending of machining speed there is ascending of statistical AE signals amplitude parameters. Thus the percentage increment of AE signals amplitude average level dispersion advances a percentage increment of amplitude average level and its standard deviation. It is shown that the experimental and theoretical regularities are similar and have a good agreement with each other. Theoretical regularity of AE signals energy parameters change at CM machining is reviewed in article [15]. It is shown, that the relations of ascending reshaped AE signals energy parameters are well described by power functions. Thus the most sensitive AE energy parameter to ascending CM machining speed is the AE signal energy average level dispersion. In article [16] the simulation of acoustic radiation is conducted at treating tool wear from CM, which occurs during CM machining with a not controlled cutting depth. Are determined the regularity of AE signals statistical amplitude parameters decreasing at increase of treating tool wear. It is shown, that at increasing tool wear decreasing of AE signals amplitude average level dispersion advances decreasing AE signals amplitude average level and its standard deviation value. From the point of view verification, monitoring and control machining technological processes, including neural networks, it is interest to search parameters, that characterize stability processes which are flowing past in a zone of contact interplay treated and treating materials.

IV. RESULTS OF EXPERIMENTAL RESEARCHES

The outcomes theoretical and experimental researches demonstrate, that at CM machining, and also materials with crystalline structure, parameters of technological processes (machining speed, cutting depth, tool feed rate), physical-mechanical characteristics of pair interacting materials and tool wear influence on AE [13] – [16]. However in of acoustic radiation nature changes is not watched. The registered AE signals are continuous signals with the hardly indented form. Thus there is change of acoustic radiation amplitude and energy parameters. Change the values of influential factors results in change the average values of acoustic radiation amplitude and energy parameters and values of their spread. Let's consider the outcomes theoretical and experimental researches the ratio of AE signals amplitude parameters increment at CM machining, taking into account effect the number of influential factors.

The outcomes of AE signals simulation at CM machining were obtained, according to the approaches and conditions reviewed in articles [13], [14].

For want of treating tool wear the AE signal is represented as a sum of successively generated pulse signals, which arise when treated CM surface layer elementary areas destruction

$$U_p(t) = \sum_j U_j(t - t_j), \qquad (1)$$

where $t_j = j\Delta t_j \pm \delta$ is the moments of time AE pulse signals U_j appear when arising at CM *j*th areas destruction; Δt_j is the time interval between beginnings formation of the subsequent AE pulse signal compared to the previous; $j = 0, \ldots, n$ is the number of consequently destructed areas; δ is the random component in an instant of appearance each subsequent AE pulse signal, which can be caused by the instability of machining parameters.

At the prevailing mechanism of surface layer elementary areas mechanical destruction the reshaped AE pulse signal is described by expression of the form

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

where $u_0 = N_0 \psi \delta_S$ is the maximum possible elastic displacement, which is distributed in the material at the instantaneous destruction of a given CM area; N_0 is the number of CM single elements in a given destruction area; ψ is the proportionality coefficient; δ_S is the value which is proportional to the pulse disturbance duration when CM single element fracture; α is the fracture speed; υ_0, r are constants, which are determined by the physical-mechanical characteristics treated CM; t is the time.

By the results of AE signals simulation calculations of the coefficient K_U were conducted, which one characterizes the ratio of increment AE signal amplitude average level to the AE signal amplitude average level standard deviation for a given influential factor value.

$$K_U = \frac{\bar{U}}{s_{\bar{U}}}, \tag{3}$$

where $\bar{U}$ is AE signal amplitude average level; $s_{\bar{U}}$ is AE signal amplitude average level standard deviation.

The coefficient K_U is a dimensionless coefficient. It characterizes advance or decreasing of increment AE signal amplitude average level in relation to advance or decreasing of increment AE signal amplitude average level standard deviation at ascending of the influential factor value.

In Figure 1 shows the theoretical dependences K_U change with increasing of machining speed ($\tilde{\alpha}$) and increasing the value of parameter $\tilde{\upsilon}_0$, that characterizing CM physical-mechanical characteristics.

The relations in a Fig. 1 are obtained at processing of outcomes simulation, which are conducted at following relative values of parameters included in expression (1) and (2). For Figure 1a: $\tilde{\upsilon}_0 = 100000$; $\tilde{r} = 10000$. The value $\tilde{\alpha}$ ranged of values from $\tilde{\alpha} = 12$ up to $\tilde{\alpha} = 52$ with increment step 10. For initial value $\tilde{\alpha} = 12$ value $\Delta\tilde{t}_j$ received equal: $\Delta\tilde{t}_j = 0.0000101$. The value $\tilde{\delta}$ ranged of values from 0 up to 0.0000103 arbitrarily. For other values $\tilde{\alpha}$ the values $\Delta\tilde{t}_j$ and $\tilde{\delta}$ decreased proportionally to decreasing duration of reshaped AE pulse signals. For Figure 1b: $\tilde{\alpha} = 22$; $\tilde{r} = 10000$. The value $\tilde{\upsilon}_0$ ranged of values from $\tilde{\upsilon}_0 = 100000$ up to $\tilde{\upsilon}_0 = 500000$ with increment step 100000. For initial value $\tilde{\upsilon}_0 = 100000$ value $\Delta\tilde{t}_j$ received equal: $\Delta\tilde{t}_j = 0.0000068$. The value $\tilde{\delta}$ ranged of values from 0 up to 0.0000079 arbitrarily. For other values $\tilde{\upsilon}_0$ the values $\Delta\tilde{t}_j$ and $\tilde{\delta}$ decreased proportionally to decreasing duration of reshaped AE pulse signals.

According to the obtained data, at ascending CM machining speed the ascending of AE signal amplitude average level standard deviation advances ascending of AE signal amplitude average level. This leads to decreasing the value of coefficient K_U (Fig. 1a). Thus the relation of coefficient K_U decreasing has not linear nature of change. At ascending parameter characterizing CM physical-mechanical characteristics, the decreasing of AE signal amplitude average level standard deviation advances decreasing of AE signal amplitude average level, that results in ascending value of coefficient K_U (Fig. 1b). Thus the relation of coefficient K_U ascending has not linear nature of change.

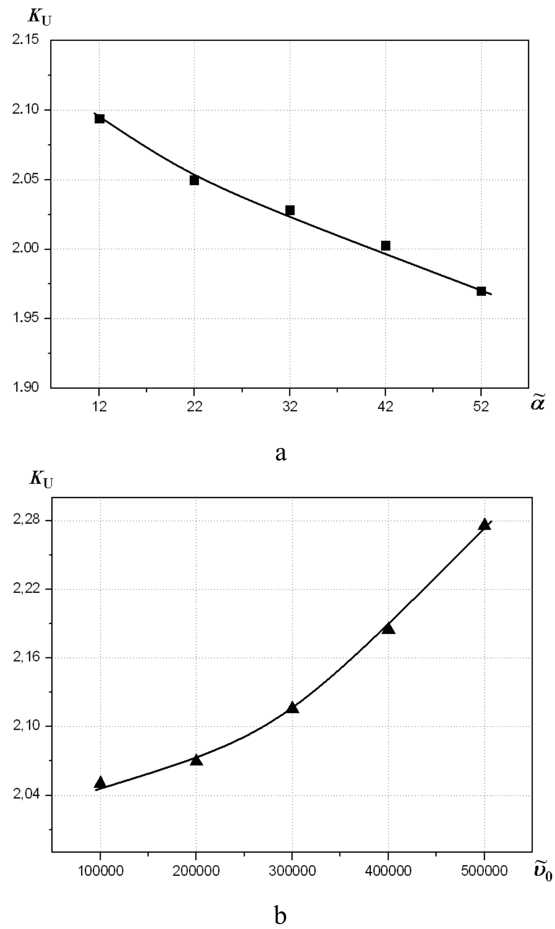


Fig. 1. Theoretical dependences K_U change at ascending of CM machining speed (a) and ascending parameter characterizing CM physical-mechanical characteristics (b)

In Figure 2 the experimental relation of change K_U at ascending CM machining speed is shown. The relation is obtained at following values of CM machining parameters. Cutting depth was peer 0.1 mm; feed rate was peer 0.1 mm/rev. The cutting speed ranged of values from 100 m/min up to 500 m/min with increment step 100 m/min. The CM machining was carried out using a CD10 plate with PCD insert.

The outcomes of data processing demonstrate, that at ascending of CM machine speed the ascending of AE signal amplitude average level standard deviation advances ascending of AE signal amplitude average level that results to a nonlinear decrease the value of coefficient K_U. The obtained experimental results are in agreement with the results of theoretical studies.

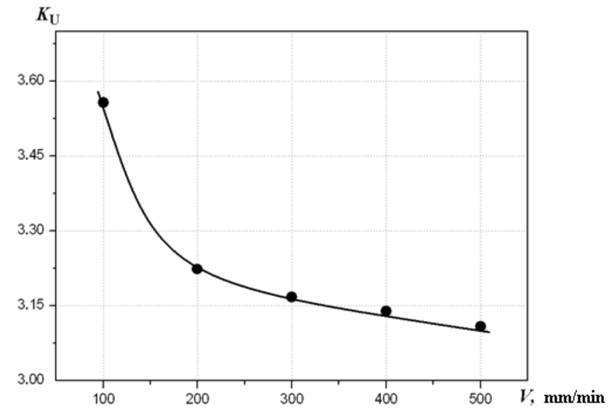
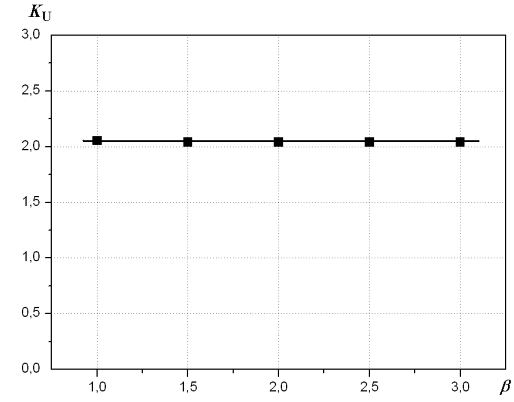


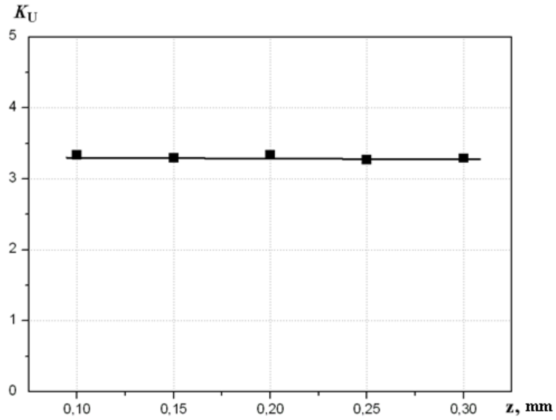
Fig. 2. Experimental dependences K_U change at ascending of CM machining speed

The theoretical and experimental outcomes influencing of CM machining depth on value of coefficient K_U are adduced in a Fig. 3. The relation in Fig. 3a is obtained at processing of outcomes simulation, which one are conducted at following relative values parameters included in expression (1) and (2): $\tilde{\upsilon}_0$ = 100000; $\tilde{r}$ = 10000; $\tilde{\alpha}$ = 22. The destruction area is determined by the number of single destroyed CM elements N_0. To account destruction area, the current value of single number breakable elements was introduced as: $N_T = \beta N_0$ where β is the coefficient characterizing increase of CM destruction area. Value β changed in range of sizes from β = 1 up to β = 3 with increment step 0.5. At change β the duration of AE pulse signals practically does not change. Value $\tilde{\Delta} t_j$ received equal: $\tilde{\Delta} t_j$ = 0.0000068. The value $\tilde{\delta}$ ranged of values from 0 up to 0.0000079 arbitrarily. The relation in Fig. 3b is obtained at following values of CM machining parameters: machining speed – 200 m/min; treating tool feed rate is the 0.1 mm/rev. The machining depth changed from 0.1 mm up to 0.3 mm with the increment step 0.05 mm. The CM machining was carried out using a CD10 plate with PCD insert.

The obtained theoretical and experimental outcomes demonstrate, that at given CM machining technological parameters with the given physical-mechanical characteristics the attitude of AE signal amplitude average level to its standard deviation remains practically by constant at ascending of cutting depth. In other words, ascending of CM treated surface layer destructible area (volume) has identical influencing on ascending of AE signal amplitude average level and its standard deviation under given machining conditions.



a



b

Fig. 3. Theoretical (a) and experimental (b) relations of K_U change at ascending CM machining depth

According to the obtained data (Figs 1 and 2), alteration of machining speed and CM treated physical-mechanical characteristics results in change the value of coefficient K_U. However, as have shown researches, for each set value of technological parameter (for example, machining speed) the ascending of cutting depth does not result in change ratio of AE signal amplitude average level to its standard deviation, i.e. the value of coefficient K_U practically remains by a constant. Such nature of K_U change can be used at the verification and monitoring of CM machining technological processes for obtaining given products quality. First of all, it falls into to the control of irregularity CM treated physical-mechanical characteristics.

V. Conclusion

The outcomes theoretical and experimental researches of legitimacies coefficient K_U change, describing ratio of AE signal amplitude average level to AE signal amplitude average level standard deviation are adduced at CM machining and change of the influential factors. Processing the outcomes simulation AE signals at ascending CM machining speed, change CM treated physical-mechanical characteristics and cutting depths with definition of legitimacies K_U change is conducted. It is shown, that at ascending CM machining speed the ascending of AE signal amplitude average level standard deviation advances ascending of AE signal amplitude average level that results in decreasing the value of coefficient K_U. Thus the decreasing coefficient K_U relation has not linear nature of change. At ascending parameter describing the CM physical-mechanical characteristics, the decreasing of AE signal amplitude average level standard deviation advances decreasing of AE signal amplitude average level, that results in ascending the value of coefficient K_U. Thus the relation of ascending coefficient K_U has not linear nature of change. At ascending cutting depth the value of coefficient K_U remains practically by constant. The processing of experimental AE signals at ascending CM machining speed and ascending cutting depth with definition of legitimacies K_U change is conducted. It is shown, that theoretical and experimental regularity of K_U value change at ascending machining speed and cutting depths will be agreed one another.

The outcomes of conducted researches can be used at the control and monitoring of CM machining technological processes for obtaining given products quality with the control of CM treated surface physical-mechanical characteristics irregularity. At the same time, concern introduces research the ratio of AE signals energy parameters change at CM machining and change the influential factors.

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С. Ф. Філоненко, А. П. Стахова. Деякі аспекти акустичної емісії при механічній обробці композиційних матеріалів

Проведено обробку результатів моделювання сигналів акустичної емісії під час зростання швидкості механічної обробки композита і глибини різання, зміни фізико-механічних характеристик оброблюваного композиту з визначенням відношення середнього рівня амплітуди сигналу акустичної емісії до його стандартного відхилення. Визначені закономірності зміни безрозмірного коефіцієнту, який характеризує відношення середнього рівня амплітуди сигналу акустичної емісії до його стандартного відхилення при зміні факторів, що впливають. Проведено обробку експериментальних сигналів акустичної емісії при зростанні швидкості механічної обробки композита і зростанні глибини різання з визначенням закономірностей зміни коефіцієнту, який характеризує відношення середнього рівня амплітуди сигналу акустичної емісії до його стандартного відхилення. Показано, що теоретичні і експериментальні закономірності зміни значення досліджуваного коефіцієнта при зростанні швидкості механічної обробки і глибини різання узгоджуються між собою.

Ключові слова: акустична емісія; композиційний матеріал; сигнал; амплітуда; статистичні параметри; механічна обробка.

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С. Ф. Филоненко, А. П. Стахова. Некоторые аспекты акустической эмиссии при механической обработке композиционных материалов

Проведена обработка результатов моделирования сигналов акустической эмиссии при возрастании скорости механической обработки композита и глубины резания, изменении физико-механических характеристик обрабатываемого композита с определением отношения среднего уровня амплитуды сигнала акустической эмиссии к его стандартному отклонению. Определены закономерности изменения безразмерного коэффициента, который характеризует отношение среднего уровня амплитуды сигнала акустической эмиссии к его стандартному отклонению при изменении влияющих факторов. Проведена обработка экспериментальных сигналов акустической эмиссии при возрастании скорости механической обработки композита и возрастании глубины резания с определением закономерностей изменения коэффициента, который характеризует отношение среднего уровня амплитуды сигнала акустической эмиссии к его стандартному отклонению. Показано, что теоретические и экспериментальные закономерности изменения значения исследуемого коэффициента при возрастании скорости механической обработки и глубины резания согласуются друг с другом.

Ключевые слова: акустическая эмиссия; композиционный материал; сигнал; амплитуда; статистические параметры; механическая обработка.

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