MODERN AVIATION AND SPACE TECHNOLOGY

UDC 620.179:534.6

Sergii Filonenko

ACOUSTIC EMISSION MODEL WITH THERMOACTIVATIVE DESTRUCTION OF COMPOSITE MATERIAL SURFACE

National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
E-mail: fils01@mail.ru

Abstract. *Modeling of acoustic emission energy during the composite material machining for termoactivative model of acoustic radiation is simulated. The regularities of resultant signals energy parameters change depending on composite materials machining speed are determined. Obtained regularities with their statistical characteristics are described. Sensitivity of acoustic emission energy parameters to the change of composite material machining speed is shown.*

Keywords: acoustic emission; amplitude; composite material; energy; machining, resultant signal; statistical characteristics.

1. Introduction

At manufacturing of items from composite materials (CM) the considerable attention is paid to problems of optimization, monitoring and diagnostics of technological processes of their machining, including diagnostics of the treating tool and worked material. Their solution is aimed at ensuring of the quality of manufactured products. The main problems caused by complexity of the structure, wide range of physical and mechanical characteristics of the CM and their tendency to occurrence of defects such as surface defects, cracks and flaking.

In the research of CM machining processes both traditional and non-traditional methods are used. Traditional methods allow to inspecting cutting forces, wear of the cutting tool, the machined surface roughness, specters of vibration signals and other parameters. However, the non-traditional method – the AE method is widely spread. Its application is caused by high sensitivity of method to the processes of deformation and fracture materials under static and dynamic conditions of loading. This method is a low-inertia method. The method is a reflection of the internal processes occurring in materials during their destruction (destruction of the surface layers). At the same time, the influence of various factors (speed and depth of cut, type of machining materials, etc.) on the modification of AE complicates its interpretation, finding interrelations and practical applications. From this point of view, theoretical researches with modeling of an impact of various factors on the patterns of AE shape and parameters change are very important. One of the influencing factors is the CM machining speed. Its change may lead to the variation of AE energy parameters.

2. Analysis of the latest researches and publications

One of the non-traditional methods to research of CM machining, which becomes more and more widespread, is the AE method [1 – 3]. Registration and analysis of AE is carried out in the performance of different types of materials (steel, CM, alloy) machining (whetting, drilling, milling). Obtained results demonstrate that registered AE signals are similar to each other by their shapes [4 – 8]. They are continuous signals with amplitude variations, whose parameters vary over time at different stages of machining materials. At processing of such signals parameters, as a rule, analysis of the root-mean-square (RMS) value of their amplitudes, low-frequency and high-frequency peaks in the specters of signals, the area under the signals or their accumulated values, energy (accounts energy), accounts of signals during the introduction of a threshold limit are carried out [7 – 11].

In the basis of spent researches the submissions about potential sources of acoustic radiation lie at machining of materials. It is assumed that such sources may be [1, 12]: plastic deformation and destruction of the machined material; temperature-phase transformations in the machined material; the

Copyright © 2016 National Aviation University
http://www.nau.edu.ua

friction of the machining tool and the surface of the machined material; friction of fillings and the tool; destruction of fillings; collision of fillings with machined materials; destruction of the tool etc. Such emission sources imply the formation of two types of AE signals – continuous and discrete (short-term). It's almost impossible to take into account the assumed detailing of the emission sources in conducting research of AE. However, from an energy point of view, the main source of AE is the deformation and destruction of machined material. Hence, the parameters of AE registered signals are analyzed in conjunction with the parameters of machined materials with traditional structure and CM (cutting speed, cutting depth, cutting angle), also with status of cutting tools (tool wear), parameters of formed shavings and the condition of machined surface detail.

Researches allowed obtaining a number of dependencies, which show the influence of the parameters of a particular type of machined materials on AE parameters. However, received dependencies are not generalizing. They relate to the specific conditions of implementation of the machining materials technological processes. Dependencies, in many cases, are of complex character and contradict each other, which complicates their interpretation and using during the monitoring and diagnostics of machining materials technological processes, including CM. At the same time, there is limited amount of theoretical researches of AE, which allow obtaining the expected patterns of its parameters changes during the machining materials, taking into account various factors.

The model of the AE and the results of modeling during CM machining and prevailing thermoactivative destruction of its surface layer are reviewed in the articles [13, 14]. The model of AE resultant signal, taking into account the sequence the surface layers destruction processes of the machined material, for prevailing thermoactivative formation of AE is represented in the next way

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

where t_j – the moments of time when AE pulse signals U_R appear, arising at the prevailing thermoactivative destruction of certain areas of CM. The instant of appearance each subsequent signal AE can be written to a kind

$$t_j = j\Delta t_j, \qquad (2)$$

where Δt_j – the time interval between the beginnings of the formation of the subsequent AE pulse signal compared to the previous.

The studies have shown that the formed AE resultant signal is a continuous signal with a highly rugged form. In the simulation of these AE signals it was thought that the machined CM dispersion properties, instability of the workpiece rotation speed, longitudinal feed speed or other factors may affect the duration of consecutive destruction surface layers processes, i.e. the duration of generated AE pulse signals. Therefore, moment of time t_j is represented in a next way

$$t_j = j\Delta t_j \pm \delta, \qquad (3)$$

where $j = 0,\ldots\ldots, n$ – the number of consequently destructed areas; δ – random component in a moment of occurrence of each subsequent AE pulse signal.

In view of accepted conditions, it is shown that with increasing of CM machining speed descends increase of the AE resultant signal average level amplitude, its standard deviation and dispersion. Thus by the greatest sensitivity to ascending of CM machining speed is a dispersion of AE resultant signal average level amplitude.

At the same time, the most capacious AE parameter is its energy. Of course, it is interesting to study the influence of CM machining speed on the energy characteristics of AE resultant signal.

3. Research tasks

In the paper, modeling and analysis of AE resultant signals energy characteristics in time during prevailing thermoactivative acoustic radiation in dependence of CM machining speed is carried out. Regularity change of the AE signals average level energy, its standard deviation and dispersion with increasing of CM surface layer destruction speed will be identified and described. It will be also shown that dispersion of the AE resultant signal average level energy is most sensitive to an increase of CM machining speed.

4. Researches results

Modeling of AE resultant signals energy in time during CM machining for prevailing thermoactivative destruction will be carried out in the next way. In the first stage, we shall conduct simulation of AE resultant signal amplitude change in time. At that, calculations of AE pulse signals amplitude change in time will be conducted according to the next expression

$$U_T(t) = u_0 \alpha t e^{-\chi(t_0 - t)} e^{-\frac{1}{\tau_0 \chi}(e^{-\chi(t_0 - t)} - e^{\chi t_0})}, \quad (4)$$

where τ_0 – is the parameter match value of the period of thermal vibrations of the lattice atoms of a solid body; α – speed of change of the enclosed loading; t – time; $u_0 = \frac{N_0}{\tau_0}\beta\delta_s$ – maximum possible displacement in the instant destruction of a given CM area, made from N_0 destructible elements; β – the coefficient of proportionality between stress fracture and amplitude of a single impulse perturbations in the destruction of one CM element; $\delta_s = \int_{t-\frac{\delta}{2}}^{t+\frac{\delta}{2}} a(\tau)d\tau$; δ_s – the duration of a single impulse perturbations in the destruction of one element; $a(\tau)$ – the function that determines the shape of a single impulse perturbation; $\chi = \frac{\gamma\alpha}{kT}$; $t_0 = \frac{U_0}{\gamma\alpha}$; U_0 – starting energy of activation (the size of the starting energy barrier) of the destruction process; k – the constant of Boltzmann; T – temperature; γ – structure sensitive coefficient.

On the second stage we will perform calculations of AE resultant signals energy, according to the next equation

$$E_p(t) = \Delta t_k U_k^2, \quad (5)$$

where k = 1…..n – the amount of the calculated values of the resulting AE signal amplitude on the implementation length n; Δt_k – the time interval for calculating of the resulting AE signal amplitude; U_k – estimated value of the resulting AE signal amplitude at the k *-th* interval.

According to previous calculations there will be built dependency of the AE resulting signals energy changes in time and it will be analysed.

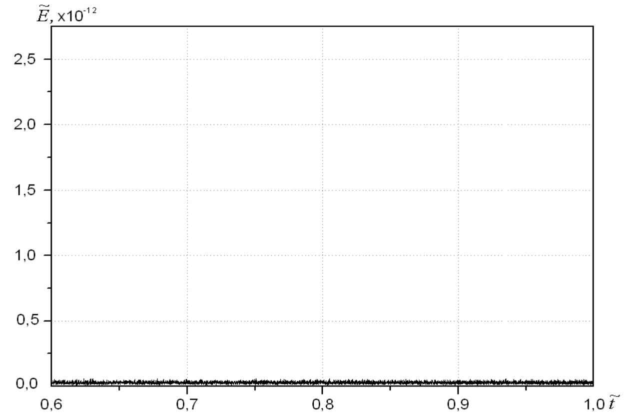
At the modelling of AE signals, agrees (1), assumed that during CM machining occurs sequential destruction of the individual fields of the material i.e. the cutting depth is a constant value. Parameters included in equations (3) and (4) will be given to dimensionless quantities and the time is normalized to t_0. Signal amplitude will be normalized to u_0. Value γ/kT will be proceeding to a single normalized value. In this conditions $\chi = \alpha$. Value of parameter τ_0 will be assumed equal to $\tilde{\tau}_0 = 10^{-7}$. Value of $\tilde{\chi}$ ($\tilde{\alpha}$) will be changed in diapason from 20 to 60 with step of increment 10.

Taking into account the changes in duration of AE pulse signals for given values of $\tilde{\chi}$, value of $\Delta\tilde{t}_j$ is assumed to be: $\tilde{\chi}$=20 – $\Delta\tilde{t}_j$=0,1; $\tilde{\chi}$=30 – $\Delta\tilde{t}_j$=0,08; $\tilde{\chi}$=40 – $\Delta\tilde{t}_j$=0,06; $\tilde{\chi}$=50 – $\Delta\tilde{t}_j$=0,04; $\tilde{\chi}$=60 – $\Delta\tilde{t}_j$=0,03. The value $\tilde{\delta}$ for $\tilde{\chi}$= 20 will change in the range from 0 to 0,16 in an arbitrary manner. For other $\tilde{\chi}$ values, $\tilde{\delta}$ will be reduced in proportion to the reduction of $\Delta\tilde{t}_j$.

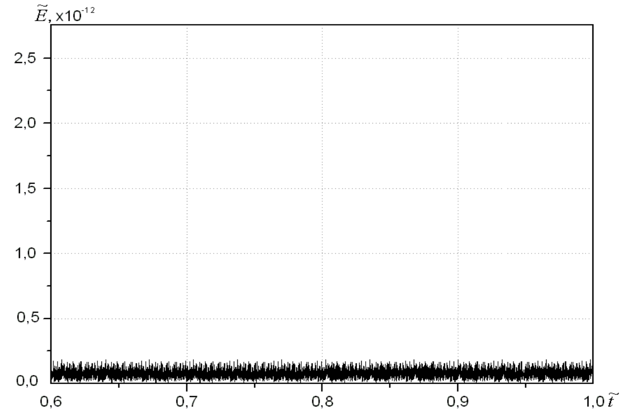
According to taken conditions, upon the results of AE resulting signal amplitudes in time, calculations of their energy changes will be performed according to (5). The calculations of AE resultant signals energy change in time in relative units are shown in fig. 1. On the graphs fig. 1 time is normalized to the time of the destruction CM surface process during its machining. In constructing the curves, that shown in fig. 1, 4000 values of the amplitudes were calculated, respectively, energy for every AE resultant signal.

Results of the researches (fig. 1) show that increasing of $\tilde{\chi}$ leads to increment of AE resultant signals average level energy and the value of its spread.

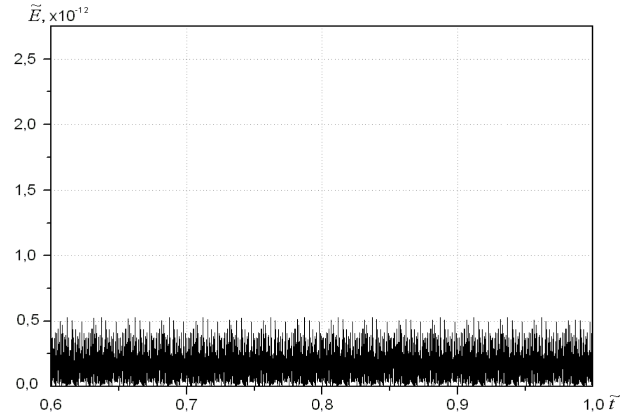
Truly, according to statistical analysis of the values at $\tilde{\chi}$=20, average energy level $\tilde{\tilde{E}}$ of AE resultant signal is $\tilde{\tilde{E}}$=2,95702$\cdot 10^{-14}$, and its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, respectively, are equal: $s_{\tilde{\tilde{E}}}$= 8,61053$\cdot 10^{-15}$; $s^2_{\tilde{\tilde{E}}}$= 7,41411$\cdot 10^{-29}$. The increase of $\tilde{\chi}$ by 2 times (up to 40) leads to an increment of $\tilde{\tilde{E}}$, $s_{\tilde{\tilde{E}}}$ and $s^2_{\tilde{\tilde{E}}}$, respectively, increases in 2,62 times, in 4,72 times and in 225,61 times. Further increasing of $\tilde{\chi}$ by 2.5



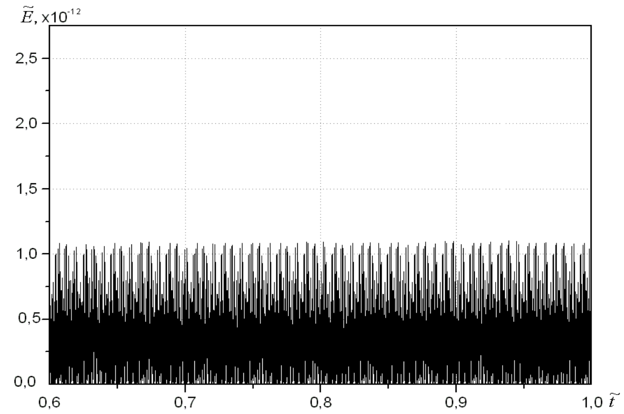
a



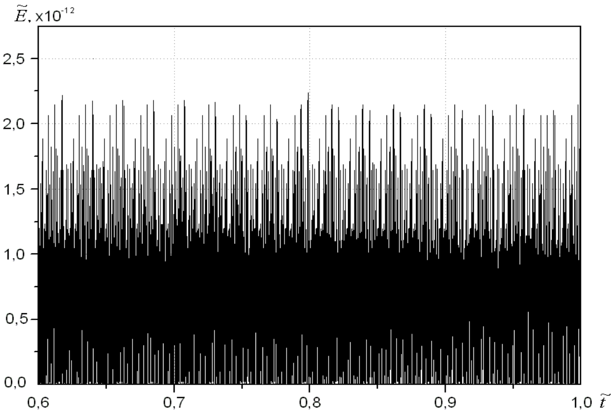
b



c



d



e

Fig. 1. Graphs of the AE resultant signal energy change in time in relative units during CM machining: *a*- $\tilde{\chi}$ =20, $\Delta\tilde{t}_j$=0,1; *b*- $\tilde{\chi}$ =30; $\Delta\tilde{t}_j$=0,08; *c*- $\tilde{\chi}$ =40, $\Delta\tilde{t}_j$=0,06; *d*- $\tilde{\chi}$ =50, $\Delta\tilde{t}_j$=0,04; *e*- $\tilde{\chi}$ =60, $\Delta\tilde{t}_j$=0,03. $\tilde{\tau}_0$=10^{-7}. Initial value $\tilde{\delta}$ changes in diapason from 0 to 0,16 proportionally with a decrease of $\Delta\tilde{t}_j$

times (up to 50) values of the AE resultant signal average energy $\tilde{\tilde{E}}$ level, its standard deviation $s_{\tilde{\tilde{E}}}$ and dispersion $s^2_{\tilde{\tilde{E}}}$, respectively, increases in 10,6 times, in 37,85 times and in 1432,78 times. If $\tilde{\chi}$ increases by 3 times (up to 60), the values $\tilde{\tilde{E}}$, $s_{\tilde{\tilde{E}}}$ and $s^2_{\tilde{\tilde{E}}}$, respectively, increases in 17,9, in 70,0 and in 4903,0 times.

Fig. 2 shows the dependence of AE resultant signal average energy level change, its standard deviation and dispersion during an increase of $\tilde{\chi}$.

Analysis of the obtained dependences have shown that dependences of the AE resultant signal average energy level change, its standard deviation and dispersion with an increase of $\tilde{\chi}$ is well described with the next function

$$\tilde{W} = a \cdot b^{\tilde{\chi}}, \qquad (6)$$

where *a* and *b* – coefficients of approximated expression.

The values of approximating expression coefficients are: for the dependence of AE resultant signal average energy level – $a = 1,479 \cdot 10^{-14}$; b = 1,062; for the standard deviation of the AE resultant signal average energy level – $a = 6,997 \cdot 10^{-15}$; b = 1,077; for the dispersion of the AE resultant signal average energy level – $a = 1.480 \cdot 10^{-28}$; b =1,139.

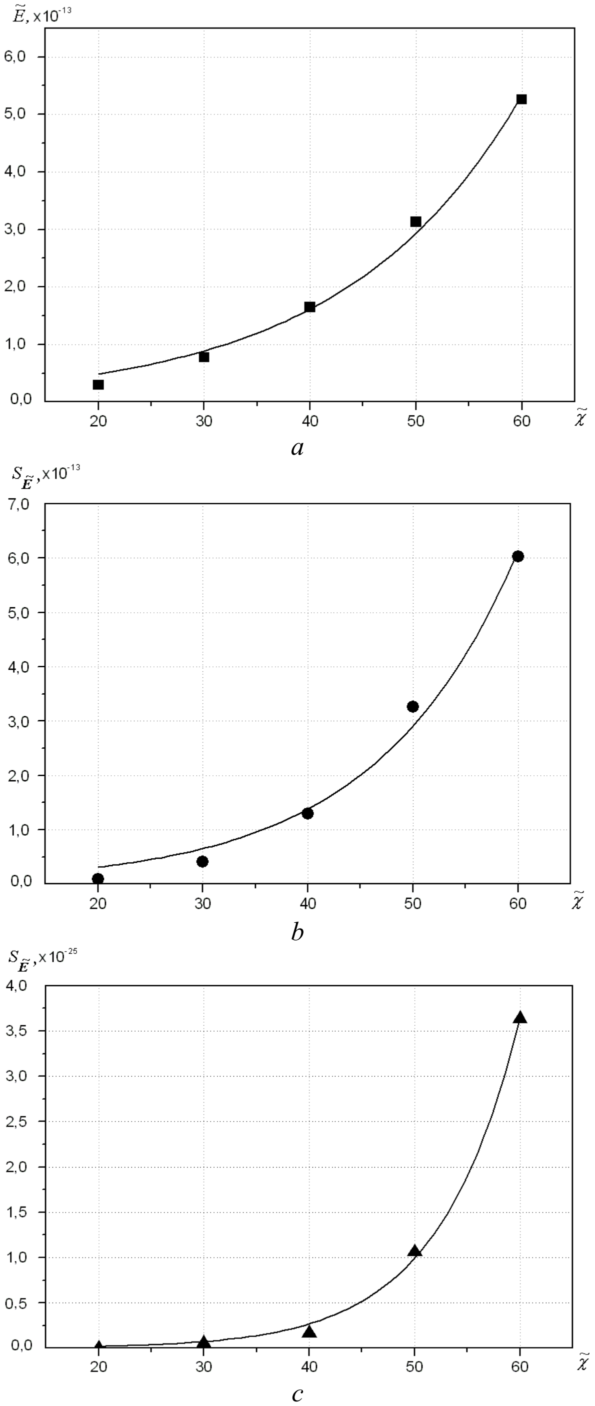


Fig. 2. Dependences of the AE resultant signal energy change (*a*), its standard deviation (*b*) and dispersion (*c*) during an increase of $\widetilde{\chi}$

At the description of relations (fig. 2, *a, b, c*) determination coefficient R^2 and the residual dispersion SD^2 make: for the average energy level of the AE resultant signal – R^2 = 0,99414, SD^2=3,164$\cdot 10^{-28}$;for the standard deviation of the AE resultant signal average energy level – R^2= 0,9896, SD^2=8,427$\cdot 10^{-28}$; for the dispersion of the AE resultant signal average energy level - R^2= 0,9982, SD^2=6,396$\cdot 10^{-53}$.

Processing results of the percentage growth of the AE resultant signal average level amplitude, its standard deviation and dispersion, of the AE resultant signal average energy level, its standard deviation and dispersion during an increase of $\widetilde{\chi}$ in relation to their initial values when $\widetilde{\chi}$=20 are shown in fig 3.

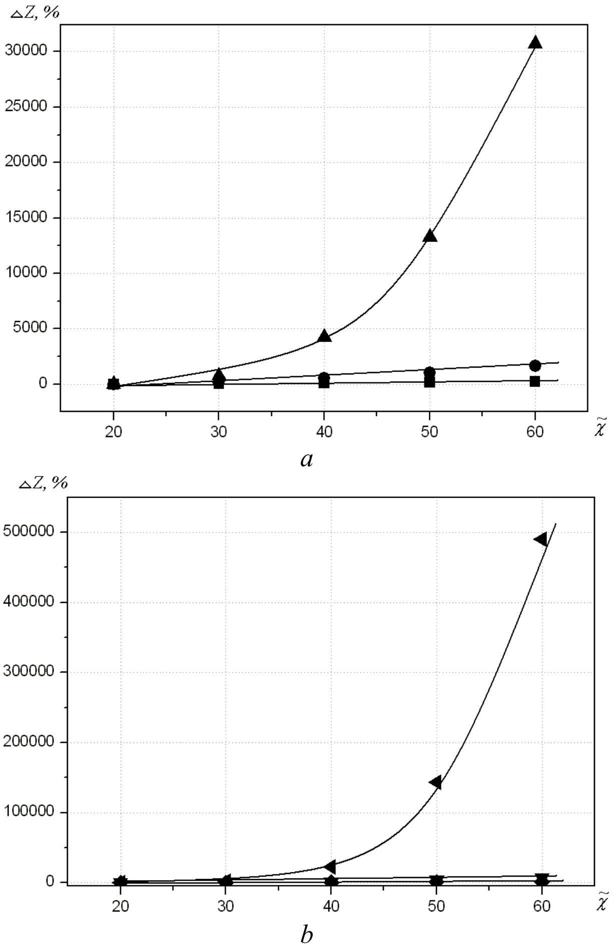


Fig. 3. Graphs of change of a percentage growth: *a* – amplitude average level $\widetilde{\widetilde{U}}$ (■), its standard deviation $s_{\widetilde{\widetilde{U}}}$ (●) and dispersion $s^2_{\widetilde{\widetilde{U}}}$ (▲); *b* – energy average level $\widetilde{\widetilde{E}}$ (◆), its standard deviation $s_{\widetilde{\widetilde{E}}}$ (▼) and dispersion $s^2_{\widetilde{\widetilde{E}}}$ (◀) in dependence of $\widetilde{\chi}$ during CM machining for a thermoactivative model of acoustic radiation

Researches show that for a thermoactivative model of acoustic radiation with an increase of CM machining speed we should expect an increase of AE resultant signal average level amplitude and energy, their standard deviations and dispersions (fig. 3). However dispersion of AE resultant signal average level energy during an increase of $\tilde{\chi}$ is the most sensitive parameter of AE. Percentage growth of dispersion of AE resultant signal average level energy is the highest (fig. 3).

6. Conclusions

Modeling of AE resultant signals during CM machining for a thermoactivative model of acoustic radiation have shown that regularities of energy change in time of the formed signals are continuous. AE signals have hardly rugged shape. Obtained data processing has shown that increasing of CM machining speed leads to an increase of AE resultant signal average energy level, its standard deviation and dispersion. Regularities of AE resultant signal average energy level change, its standard deviations and dispersions have nonlinear character of increase. The statistical analysis of the data with approximation of the obtained relations has shown, that they are well described with power functions. However an increase of CM machining speed has a different impact on the degree of AE resultant signals average amplitude and energy level increase, their standard deviations and dispersions. It was defined that dispersion of AE resultant signal average energy level is the most sensitive AE parameter during an increase of CM machining speed. Percentage growth of AE resultant signal average energy level dispersion is the highest. At the same time, it is interesting to research regularities change of accumulation AE energy processes when changing CM machining parameters.

References

[1] *Teti, R.; Jemielniak, K.; O'Donnell, G.; Dornfeld, D.* Advanced monitoring of machining operations. CIRP Annals – Manufacturing Technology. – 2010. – v.59. – P.717–739

[2] *Dongre, P.R.; Chiddarwar, S.S.; Deshpande, V. S.* Tool Condition Monitoring In Various Machining Operations Use of Acoustic Signature Analysis. Int. J. on Mechanical Engineering and Robotics. – 2013. – V.1. – No1. – P.34–38

[3] *Jaber, A. A.; Bicker, R.* The State of the Art in Research into the Condition Monitoring of Industrial Machinery. Int. J. of Current Engineering and Technology. – 2014. – v.4. – No.3. – P.1986-2001

[4] *Qin, F.; Hu, J.; Chou, Y.K.; Thompson, R.G.* Delamination wear of nano-diamond coated cutting tools in composite machining. Wear. – 2009. – v. – 267. – P. 991–995

[5] *Sudha, A. J.; Sampathkumar, B. S.; Vijaya, C.A.* AE waveform analysis of delamination in GFRP composite materials during drilling. Int. J. of Engineering and Technology. – 2009. – V.1. – No.1. – P.63–66.

[6] *Neslušan, M.; Šipek, M.; Mrazik, J.* Analysis of chip formation during hard turning through acoustic emission. Materials Engineering. – 2012. – V.19. – P. 1–11

[7] *Kulandaivelu, P.; Kumar, P. S.; Sundaram, S.* Wear monitoring of single point cutting tool using acoustic emission techniques. Sadhana. – 2013. – V.38, Part 2. – P.211–234.

[8] *Bhuiyan, M.S.H.; Choudhury, I.A.; Nukman, Y.* An innovative approach to monitor the chip formation effect on tool state using acoustic emission in turning. Int. J. of Machine Tools & Manufacture. – 2012. – V.58. – P.19–28

[9] *Lu, P.; Chou, Y. K.; Tomthpson, R.G.* Short-time Fourier transform method in AE signal Analysis for diamond coating failure Monitoring in Machining applications. Proceedings of the ASME2010 Manufacturing Science and Technology MSEC2010 (12–15 October 2010, Erie, Pennsylvania, USA). – P.1–10.

[10] *Mcleay, T.; Turner, M. S.* Failure Mode Analysis to Define Process Monitoring Systems. J. of Machine Eng. – 2011. – V.11. – No.4. – P.118–129

[11] *Mathew, M.T.; Pai, P.S.; Rocha, L.A.* An effective sensor for tool wear monitoring in face milling: Acoustic emission. Sadhana.-2008.-v.33, Part 3/-P. 227–233.

[12] *Dhale, A.; Khan, F.* Acoustic emission method for selection of optimum cutting parameters in turning using different fluids: A Review. Int. J. of innovative research and development. – 2013. – V.2. – No7. – P.185–188

[13] *Filonenko, S.* Acoustic emission model with thermoactivative destruction of composite material surface. Proceedings of the National Aviation University. – 2015. – N1 (62). – P. 53–58

[14] *Filonenko, S.* Acoustic emission at alteration of composite materials machining speed. Technological systems. – 2015. – №2(71). – P.68–74

Received 15 October 2015.

С.Ф. Філоненко. Енергія акустичного випромінювання при зміні швидкості механічної обробки композиційного матеріалу

Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mail: fils01@mail.ru

Проведено моделювання енергії акустичної емісії при механічній обробці композиційного матеріалу для термоактиваційної моделі акустичного випромінювання. Визначено закономірності зміни енергетичних параметрів результуючих сигналів в залежності від швидкості механічної обробки композиційного матеріалу. Проведено опис отриманих залежностей з їх статистичними характеристиками. Показано чутливість енергетичних параметрів акустичної емісії до зміни швидкості механічної обробки композиційного матеріалу.
Ключові слова: амплітуда; акустична емісія; енергія; композиційний матеріал; механічна обробка; результуючий сигнал; статистичні характеристики.

С.Ф. Филоненко. Энергия акустического излучения при изменении скорости механической обработки композиционного материала

Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mail: [1]fils01@mail.ru

Проведено моделирование энергии акустической эмиссии при механической обработке композиционных материалов для термоактивационной модели акустического излучения. Определены закономерности изменения энергетических параметров результирующих сигналов в зависимости от скорости механической обработки композиционных материалов. Проведено описание полученных закономерностей с их статистическими характеристиками. Показана чувствительность энергетических параметров акустической эмиссии к изменению скорости механической обработки композиционного материала.
Ключевые слова: акустическая эмиссия; амплитуда; композиционный материал; механическая обработка; результирующий сигнал; статистические характеристики; энергия.

Filonenko Sergii. Doctor of Engineering. Professor.
Director of the Institute of Information-Diagnostic Systems, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Polytechnic Institute, Kyiv, Ukraine (1977).
Research area: diagnostics of technological processes and objects, automatic diagnostic systems.
Publications: 270.
E-mail: fils01@mail.ru