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Sergii Filonenko

ACOUSTIC EMISSION MODEL WITH THERMOACTIVATIVE DESTRUCTION OF COMPOSITE MATERIAL SURFACE

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

Abstract. *A model of acoustic emission formation during machining of the composite material for the prevailing thermoactivative destruction of surface layer is represented. It is determined that the resulting acoustic emission signal is a continuous signal with the strongly broken shape. The dependences of the variation of the amplitude and energy of the resulting acoustic emission signal in time are obtained. It is shown that if process of composite material destruction is stable in a different intervals of analysis, stable values of amplitude characteristics of the resultant acoustic emission signal are observed.*

Keywords: acoustic emission; amplitude; composite material; energy; mechanical processing; model; resultant signal; statistical characteristics.

1. Introduction

Acoustic emission (AE) method is widely used to study machining of materials, including the composite materials (CM). Active research is related to the search of patterns of change of registered AE signals parameters with the parameters of technological process of CM machining. Setting such regularities is aimed at solving optimization, monitoring and diagnostics problems of technological processes of CM machining. This issue covers the diagnostics of the machining tool, as well as obtaining the specified quality of the processed material surface.

The research findings show the complex nature of the registered AE and high sensitivity of the method to changes in CM machining conditions. High reaction of AE method at the dynamics of the processes occurring in the surface layers of CM complicates the interpretation of the results obtained and their use to control, monitoring and diagnostics of technological processes of CM machining. The large volumes of received information aggravate the problem. To solve these problems, theoretical studies of AE during CM machining are important. Such researches allow carrying out modeling of AE signals, identifying patterns of change in their parameters under the influence of various influencing factors. The results of this modeling will make it possible to determine the contribution of various processes in the AE and interpretation its modification as conditions of CM machining processing change, which can be used to develop control methods, monitoring and diagnostics of technological process of CM machining. Theoretical researches primarily are related to the development of models of AE formation during CM machining.

2. Analysis of the latest research and publications

AE method is widely used to develop methods for control and monitoring of materials machining and condition of the cutting tool. The studies of AE are conducted in the performance of various types of machining of materials – drilling, milling, turning, grinding [1–4]. When describing and processing of the recorded AE signals, it is assumed that their formation is caused by the presence of various sources of AE – deformation and destruction of the material surface, the deterioration of the cutting tool, destruction of filings and others [5]. In relation to the energy, generated signals must be certainly different from each other. Therefore despite the detailing of the alleged sources of AE it is believed, that the continuous AE signals are formed during operation of the normal or worn cutter and impulse (explosive) signals are generated at failure of the cutting tool or filings. Basing on those assumptions in experimental researches the search of the relation between AE parameters and the parameters of technological process of machining of materials or deterioration of cutting tool is held [6–9].

It should be noted, that empirical AE dependencies have limited application. They are obtained for given technological parameters of machining of materials. In many cases, the dependencies are complex and have contradictory nature of change that complicates the generalization and interpretation of the results. Thus there are practically no theoretical studies with an analysis of the impact of various factors on the parameters of formed AE signals during the machining of the materials. First of all, this applies to CM. The research of theoretical regularities of changes of parameters of the resulting AE signals during the machining of the materials with a crystalline structure is performed in [10, 11]. At the researches was considered that during machining of the material sequential processes of deformation and destruction flow in its surface layer. Under such conditions, the resulting AE signal was presented in the form of

$$U_p(t) = \sum_j U_d(t - t_j) + \sum_i U_T(t - t_i), \quad (1)$$

where t_j, t_i – instants of appearance of AE signals from the plastic deformation U_d and destruction U_T of the surface layer of material.

The AE signals U_d and U_T are described by the following expression – during the flow of plastic deformation in a given material volume

$$U_d(t) = u_o \alpha t \exp(-B\alpha t), \quad (2)$$

where $u_o = a_o M \frac{\upsilon_D}{\ell} \delta_D$ – the maximum amplitude of the displacement at the instantaneous joining of a given volume of material with certain physical and mechanical properties to plastic deformation; a_o – amplitude value of a single perturbation impulse which is formed of a single mobile dislocation; δ_D – the average duration of a single perturbation impulse; υ_D – dislocation movement speed; ℓ – distance passed by the dislocation; M, B – the parameters that depend on the physical-mechanical characteristics of the material and characterize the density of mobile dislocations from deformation (M – related to the number of dislocations and proportional to the volume of the material which comes in plastic deformation); α – loading speed of the material;

– at a destruction of a certain areas of the material

$$U_T(t) = U_0 \alpha^3 t^2 \exp(-b\alpha t), \quad (3)$$

where $U_0 = N_0 ck$ – the maximum amplitude of displacement at the instant destruction of a given area of material with specific physical and mechanical characteristics on strength; N_0 – the total number of micro volumes destroyed in a certain area; k – proportionality factor; c, b – coefficients which depend on the physical-mechanical characteristics of the material (characterize the spreading of elementary destructible volumes by strength); α – loading speed of the material.

Simulation of the resulting AE signals [10, 11], according to (1), showed the following. Generated AE signals in the machining of the materials which have a crystalline structure are continuous signals with strongly broken shape. This result agrees well with experimental results [7, 8, 10, 11, 12]. Processing of simulation results [10, 11] showed that when the machining of the materials speed increases we should expect to increase the average level of the resulting AE signal amplitude, its standard deviation and variance. Herewith the simulation results are consistent with experimental data.

The approaches considered in [10], can be used for theoretical studies of AE in CM machining. Such researches will allow obtaining expected regularities of changes of AE parameters during CM machining taking into account the influence of technological factors and physical-mechanical characteristics of the material.

3. Research tasks

In this paper it will be showed that thermoactivative micro model of AE which appears during the CM destruction can be used to describe the resulting AE signal which is formed during the machining of CM. Modeling of the amplitude and energy of the AE during CM machining will be held. It also will be showed that the generated AE signal in connection with time is a continuous signal with a hardly rugged shape. Such signal can be characterized by the average amplitude and energy level and also by values of their standard deviations and variances.

4. Research results

Let's assume that we have a CM sample with given physical and mechanical characteristics which is subjected to machining using a cutting tool (fig. 1). CM machining is carried out at a constant depth (*h*), cutting speed (V) and the speed longitudinal feed (*r*). Taking into account notions about the sequence of destruction processes [13], we assume that at short time intervals there is a sequential destruction of areas of the CM surface layer. At a constant depth and cutting speed, as well as the value of longitudinal feed, we assume that consequently destructed spaces of CM S_T have the same area (fig. 1) i.e. areas of CM with the same size are destructed per unit of time. Also, we assume that destruction of each area leads to the formation of acoustic radiation in the form of AE impulse signal.

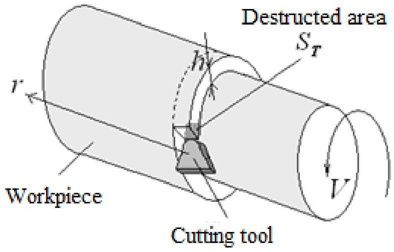


Fig. 1. CM machining

In such conditions resulting AE signal can be represented in the form of a sum of consequently formed impulse signals

$$U_p(t) = \sum_j U_j(t - t_j), \tag{4}$$

where t_j – moments of time, when AE (U_j) signals appear. They are caused by destruction of j-th areas of CM.

Let's assume that destruction of every CM area (S_t, fig. 1) is followed by AE impulse which is being formed during the overwhelming termoactivation process. Such AE signal, according to work [14], is described by kind expression

$$U_T(t) = u_0 \alpha t e^{-\chi(t_0 - t)} e^{-\frac{1}{\tau_0 \chi}\left(e^{-\chi(t_0 - t)} - e^{\chi t_0}\right)}, \tag{5}$$

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 Boltsman; T – temperature; γ – structure sensitive coefficient.

During the constant depth and velocity of cutting as well as the amount of line feed time appearance of every next AE signal in the formula [4] can be recorded as

$$t_j = j\Delta t_j, \tag{6}$$

where Δt_j – the amount of time between the start of formatting the next AE pulse signal in relation to the previous.

For the accepted conditions of CM machining, if there is no random component in time development of the fracture process, the resulting AE signals according to (4), taking into account (5) and (6), will appear as the sinusoidal signal. This corresponds to the sequential occurrence of AE impulse signals at sequential the destruction of CM areas.

However, the dispersion properties of the processed CM, the instability of the rotation speed of the workpiece, the instability of the velocity of longitudinal feed, instability of the sizes of the fracture areas or other factors will affect the duration of successive processes of destruction areas of CM surface layer, i.e. will affect the duration of the formed AE impulse signals. On this basis, the time of occurrence of each subsequent AE signal can be written as

$$t_j = t_1 + j\Delta t_j \pm \delta, \tag{7}$$

where t_1 – the time of the start destruction of the first S_T area during the CM machining or the time the first AE signal appear; δ – the random component in the time of the occurrence of each subsequent AE impulse signal.

Let's carry out the simulation of the resulting AE signals in the form of dependency changes its amplitude and energy over time in relative terms. Modeling the dependence of the amplitude of the resulting AE signal will hold on expression (4), taking into account expressions (5) and (7). According to the results of the simulation we will perform calculations the energy change resulting AE signals in time according to the expression

$$E_p(t) = \Delta t_k U_k^2, \tag{8}$$

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.

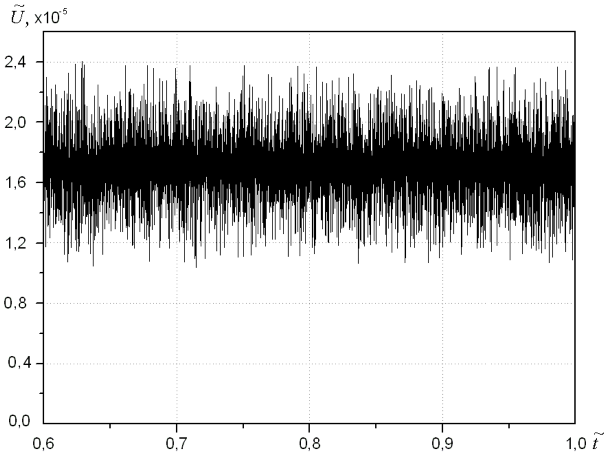
During the modeling of the resulting AE signal amplitude changing in time, parameters that are included in formula (5) we will change into dimensionless quantities and the time is normalized by t_0. The signals amplitude will be normalized by u_0. The value of γ / kT will be turned into a single normalized value. In this conditions $\chi = \alpha$. The value of τ_0 will be equal to $\tilde{\tau}_0 = 10^{-7}$. Value $\tilde{\chi}$ will be equalized to $\tilde{\chi} = 20$. Time interval $\Delta\tilde{t}_j$ between the appearances of every next and previous AE signal will be matched by the length of generated signals. It's value will be equalized to $\Delta\tilde{t}_j$ =0,1. The value of $\tilde{\delta}$ will be randomly substituted in diapason from 0 to 0,16. The time interval Δt_k, which formula (8) includes, will be determined by the results of calculating of 4000 AE signal amplitude values.

The calculations in the form of dependences of the amplitude and energy of the resulting AE signals over time in relative units during CM machining are shown in fig. 2. In the graphs of fig. 2 time is normalized by the progressing of the CM surface destruction process during the machining.

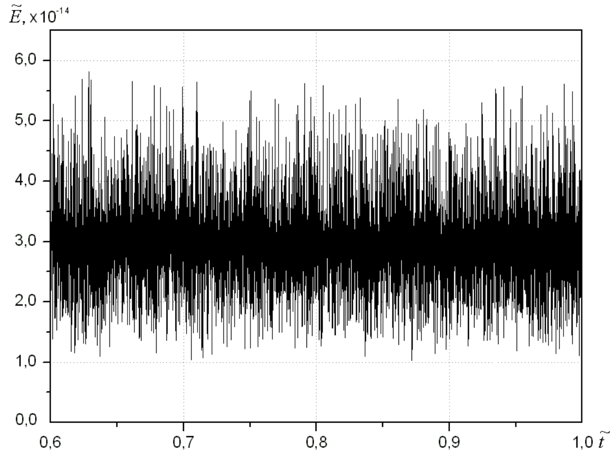
The results of the spent studies (fig. 2) show that for the given modeling conditions of AE in CM machining represent that the AE signals is a continuous signal. The signals, characterizing the dependence of the amplitude and energy of AE in time, have a strongly rugged form. It should be noted that the simulation results are consistent with the data obtained by various authors [15, 16].

Such AE signals can be characterized by medium levels of the amplitude and energy on different analysis intervals and also their standard deviations and dispersion. The results of the statistical analysis of AE signals amplitude at predetermined intervals are showed in table 1.

In table 1 is the following notation: $\tilde{\tilde{U}}$ – medium level amplitude of the resulting AE signal; $s_{\tilde{\tilde{U}}}$ – standard deviation of the medium level amplitude of AE signal; $s^2_{\tilde{\tilde{U}}}$ – dispersion of the medium level amplitude of AE signal.



a



b

Fig. 2. Graphs of the variation of the resulting AE signals amplitude (*a*) and energy (*b*) over time in relative units during machining of CM. Simulation parameters: $\tilde{\chi} = 20$, $\Delta\tilde{t}_j$ = 0,1; $\tilde{\tau}_0$=10^{-7}. The value $\tilde{\delta}$ varies in the range of values from 0 to 0.16. Value Δt_k =0,0001

From the upcoming results (table 1) we can see that during the CM machining in case of the stability destruction process of the surface layer, at various intervals analysis shows stability of the statistical characteristics of the resulting AE signals amplitude. The statistical processing shows maximum deviation of the medium level resulting AE signal amplitude at predetermined analysis intervals (T_1, …, T_4) according to the maximum interval (T_0) does not exceed 0,9 %. For the standard deviation of the medium level resulting AE signals amplitude this deviation does not exceed 0,7 %

Table 1. Statistical characteristics of the resulting AE signals amplitude at predetermined intervals of analysis

Interval analysis (amount of analyzed points)	T_0 0…4000	T_1 0…1000	T_2 1001…2000	T_3 2001…3000	T_4 3001…4000
$\tilde{\tilde{U}}$	$1{,}70117 \cdot 10^{-5}$	$1{,}70704 \cdot 10^{-5}$	$1{,}70983 \cdot 10^{-5}$	$1{,}70155 \cdot 10^{-5}$	$1{,}68585 \cdot 10^{-5}$
$s_{\tilde{\tilde{U}}}$	$2{,}51114 \cdot 10^{-6}$	$2{,}50959 \cdot 10^{-6}$	$2{,}49308 \cdot 10^{-6}$	$2{,}52237 \cdot 10^{-6}$	$2{,}50301 \cdot 10^{-6}$
$s^2_{\tilde{\tilde{U}}}$	$6{,}30581 \cdot 10^{-12}$	$6{,}29804 \cdot 10^{-12}$	$6{,}21545 \cdot 10^{-12}$	$6{,}36233 \cdot 10^{-12}$	$6{,}26506 \cdot 10^{-12}$

For the dispersion of the medium level resulting AE signals amplitude deviation does not exceed 1,4 %.

Certainly, as conditions of the CM surface destruction change (first of all, we mean the increase of cutting tool wear), AE generating conditions also change. In turn, this should lead to the change of values and the statistical characteristics of the resulting AE signals that can be used for controlling, diagnosis and monitoring of technological processes of CM machining.

5. Conclusion

The model of the resulting AE signal during the CM machining for the prevailing termoactivation destruction of the surface layer has been considered. Conditions for the formation of the AE impulse signals during sequential destruction of areas of the CM surface layer have been found. Factors which affect the AE signals formation time instability have been defined. The modeling of the resulting AE signal with calculating the conditions of its amplitude and energy changing has been processed. It is shown that for the predetermined conditions of AE modeling during the CM machining, AE signals are the continuous signals. Herewith AE amplitude and energy time dependence characterizing signals have strongly rugged form. Statistical analysis of the modeling results shows that during the stability of the destruction progressing process of the CM surface layer on the different analysis intervals there are constant resulting AE signals amplitude values has been processed. Their deviation may indicate a change in the CM machining conditions. It can be used for controlling, diagnosis and monitoring of technological CM machining.

At the same time, there is interest in the studying of the influence of various factors of the machining technological process on the resulting AE signals.

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С. Ф. Філоненко. Модель акустичного випромінювання при термоактиваційному руйнуванні поверхні композиційного матеріалу

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

Розглянуто модель формування акустичного випромінювання при механічній обробці композиційного матеріалу для переважного термоактиваційного руйнування поверхневого прошарку. Визначено, що результуючий сигнал акустичної емісії є неперервним сигналом з сильно порізаною формою. Отримано залежності зміни амплітуди та енергії результуючого сигналу акустичної емісії в часі. Показано, що при стабільності протікання процесу руйнування композиційного матеріалу на різних інтервалах аналізу спостерігаються стабільні значення амплітудних характеристик результуючого сигналу акустичної емісії.

Ключові слова: акустична емісія; амплітуда; енергія; композиційний матеріал; механічна обробка; модель; результуючий сигнал; статистичні характеристики

С.Ф. Филоненко. Модель акустического излучения при термоактивационном разрушении поверхности композиционного материала

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

Рассмотрена модель формирования акустического излучения при механической обработке композиционного материала для преобладающего термоактивационного разрушения поверхностного слоя. Определено, что результирующий сигнал акустической эмиссии является непрерывным сигналом с сильно изрезанной формой. Получены зависимости изменения амплитуды и энергии результирующего сигнала акустической эмиссии во времени. Показано, что при стабильности протекания процесса разрушения композиционного материала на различных интервалах анализа наблюдаются стабильные значения амплитудных характеристик результирующего сигнала акустической эмиссии.

Ключевые слова: акустическая эмиссия; амплитуда; композиционный материал; механическая обработка; модель; результирующий сигнал; статистические характеристики; энергия

Filonenko Sergiy. 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: 260
E-mail: fils01@mail.ru