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ACOUSTIC EMISSION AT CHANGE OF CONTACT INTERACTION AREA OF FRICTION UNIT OF COMPOSITE MATERIAL

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Abstract. *The results of simulation of resulting acoustic emission signals at friction surfaces of the composite material were shown. It was shown that at increase of contact interaction area of the friction unit is increase of the average amplitude of the acoustic emission, their standard deviation and variance. The approximation expressions for the regularities of changes of the amplitude parameters of acoustic emission signals which are generated by the increase of the contact interaction area of the friction unit were defined. The comparison of experimental results with theoretical research was conducted. It was shown that the most sensitive parameter to change the contact interaction area of the friction unit is the variance of the average amplitude of the formed resultant acoustic emission signal.*

Keywords: acoustic emission; amplitude; area; composite material; friction; parameter; signal; variance.

1. Introduction

The research results of friction interaction between surfaces of Composite Materials (CM), which are carrying out in different countries shows their high tribological characteristics. This makes more usable of CM at friction units of aviation and space assignment, transportation, shipbuilding and other types of equipment. While the research and monitoring of friction units of CM traditional methods to analyze of such traditional characteristics as coefficient of friction, friction torque, friction coefficient, temperature in the zone of frictional contact and others are widely used. At the same time the fractographic research suggests different mechanisms of surface layers fracture of friction contact of CM including their brittle fracture. These types of destruction significantly worsen tribological characteristics of the friction units and accelerate the transition to catastrophic stage of the wear. However the fixation of initial stages of emergence of processes which lead to catastrophic wear with help of traditional methods is almost impossible. This is due to their not high sensitivity to friction processes which are developing in micro level.

The research of friction and wear of materials with traditional structures and CM is carried out with the use of Acoustic Emission (AE) method. This research results show high sensitivity of such method. Acoustic radiation which is registered in the operation of the friction units is complex and its interpretation in the scientific literature is absent. Acoustic emission was characterized by continuous transformation at all stages of friction and wear. It is difficult to determine the regularities of change and the informativeness of AE parameters, the identifying of stable regularities with the processes of friction and wear and the consequent difficulties of developing methods of monitoring and diagnostics of friction units. In terms of the interpretation of AE information in friction and wear are important theoretical research of acoustic radiation formation. The difficulty of such research is conditioned upon the presence of various influenced factors. Their account of course is actual scientific direction.

2. Analysis of sources and publications

In articles [Filonenko, Stadnychenko, Stakhova 2008; Filonenko, Stakhova, Kositskaya 2008; Filonenko et al. 2009] the model and simulation results of acoustic radiation at friction of materials surfaces with traditional structure were presented. The formation of the observed acoustic emission during fracture of secondary structures of type I and II, as well as regularities of change of various factors – loading of friction unit, speed of rotation, the amount of material which came in plastic deformation of the surface area of destruction and others were considered. Also it was shown that obtained results had good agreement with experimental results.

Theoretical research of acoustic radiation at friction of surfaces with CM was reviewed in [Filonenko et al. 2010]. The model of resultant AE signal is based on the use of the FBM concept (fiber bundle model) that is the representation of CM as a set of elements which were the projections of contact interactions that are destroyed at friction of CM surfaces. This performance form is a contact interaction area S_T which is small and some continued in time on the platform of surface area S of CM (Fig. 1).

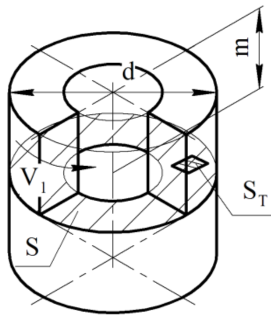

Fig. 1. Kinematic scheme of friction unit in the form of rollers with terms of frictional contact:
V_1 – rotational speed of friction unit;
S – area of surface overlap of friction unit;
S_T – platform of surfaces contact in the area of friction unit overlap;
d, *m* – linear dimensions of the samples

At working of friction unit within given area S_T the destruction of specified quantity of elements is occured.

Physical and mechanical properties and the dimensions are given to the elements of CM. Change of contact interaction area in time is provided by rotation speed of friction unit. Rotational speed and load on friction unit with given size of the elements define the regularities of change of equivalent stress and the threshold stress of CM elements destruction start.

Subject to terms and adopted approach that was used to describe the resultant AE signal at friction and wear of friction surface contact with traditional materials [Filonenko, Stakhova, Kositskaya 2008; Filonenko et al. 2009; Filonenko et al. 2010], the resultant AE signal at surfaces friction with CM is represented as follows

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

where j – serial number of the j contact interaction area (j = 0, 1, 2, ..., m);

$U_j(t_j)$ – AE pulse signal which is formed in the j contact interaction area;

t_j – time moment of j AE signal;

m – pulse number of AE signals on the length of realization (time of friction unit working).

Model of AE pulse signal which is formed during the destruction of CM with given size under the influence of shear load was considered in [Filonenko, Kalita, Kosmach 2012]. Model of AE pulse signal is based on the usage of the concept of FBM in the analysis process of destruction of the CM under shear load [Raischel et al. 2005], taking into account the kinetic of its development. The expression for AE pulse signal [Filonenko, Kalita, Kosmach 2012] was presented in the form

$$U(t) = U_0\upsilon_0[\alpha t(1-\alpha t)(1-g\sqrt{\alpha t}) - \alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})]\times$$
$$\times e^{r[\alpha t(1-\alpha t)(1-g\sqrt{\alpha t})-\alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})]}\times$$
$$\times e^{-\upsilon_0 \int_{t_0}^{t} e^{r[\alpha t(1-\alpha t)(1-g\sqrt{\alpha t})-\alpha t_0(1-\alpha t_0)(1-g\sqrt{\alpha t_0})]}dt} \qquad (2)$$

where $U_0 = N_0\,\beta\,\delta_S$ – maximal possible displacement at instant destruction of elements;

N_0 – initial quantity of CM elements;

β – coefficient of proportionality;

δ_S – parameter which numerical value is defined by form of single disturbance impulse at destruction of single element (has the dimension of time);

α – speed of elements loading;

t, t_0 – respectively, the current time and start time of the elements destruction;

g – coefficient which depends on geometrical sizes of elements (area of cross-section and length);

r, υ_0 – constants which depend on their physical and mechanical characteristics.

In [Filonenko, Kalita, Kosmach 2012; Filonenko, Kosmach, Kositskaya 2012; Filonenko, Kosmach 2012] simulation results of AE pulse signals at influence of different factors were considered. It was shown that the destruction of the CM with given quantity of elements leads to the formation of the AE signal which represent the video pulse. The basic regularities of parameters change of AE signals at different factors – speed of CM loading were determined, its physical and mechanical characteristics, dimensions of elements were destroyed.

In [Filonenko, Kalita, Kosmach 2012] was conducted the research of resultant AE signals at change of physical and mechanical characteristics of friction unit of CM that is parameters which were included in equation (2). It was shown that the resultant AE signals are continuous signals.

They can be characterized by some average level of amplitude and value of its variation. Also the regularities of change of amplitude and energy parameters of resultant AE signals with increasing of υ_0 values were determined. While the simulations it was supposed that the contact interaction area or the quantity of elements N_0 in the area of contact interaction remains constant.

In the real conditions at working of friction unit the area of contact interaction can vary. Therefore let's conduct the simulations of resultant AE signals that are generated by friction surfaces with CM including the changes in the area of contact interaction. In this case let's define the basic regularities of acoustic radiation change and let's compare the simulation results with experimental results.

In this article the simulations of resultant AE signals which were generated by friction of CM surfaces with growing of contact interaction area of the friction unit will be carried out. It will be shown that with increasing of contact interaction area of the friction unit there is the growth of the average amplitude level of the resultant AE signals and the value of its standard deviation and variance. In this case the variation of the average amplitude level is growth ahead of its standard deviation and average amplitude level and takes the part of most sensitive parameter. It will be shown that the obtained results of simulation have good agreement with experimental results.

3. Results of researches

While simulation of acoustic emission let's take into consideration the terms of friction unit operation similar to the ones discussed above (Fig. 1). We also assumed that the change in the contact interaction areas occurs in consistent manner that provides constant rotation speed of friction unit. This means that consistent manner is the formation of AE pulse signals, which were described by expression (2). Under such conditions, according to (1) the resultant AE signal was represented as the sum of pulse signals. These signals are formed at successive moments t_j at sequential destruction of elementary platform which consist on specified quantity of elements N_0.

The time moment t_j of AE pulse signals appearance can be represented as stationary and random components

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

where Δt_j – the time interval between the start appearance of the next and previous j-th pulse AE signal (determined by the rate of change or destruction of contact interaction areas);

δ – random component at the time of each subsequent occurrence of AE signal.

The insertion of a random component δ is conditioned upon possible instability of the position of the contact interaction platforms S_T (platforms which are destroyed) in the area S of the surface overlapping of friction unit, dispersion properties of CM and other factors. These factors lead to the appearance of some variation of occurrence time of each subsequent pulse signal AE and change the conditions of their overlap in time.

Simulation of the resultant AE signals will be carried out in relative units, and all parameters which were included in the expression (1), (2) and (3) will be reduced to dimensionless variables. The parameters $\tilde{\upsilon}_0$, $\tilde{r}$, $\tilde{g}$, $\tilde{\alpha}$ which included in equation (1) in relative units take equal:

$\tilde{\upsilon}_0 = 100000$,

$\tilde{r} = 10000$,

$\tilde{g} = 0.1$,

$\tilde{\alpha} = 500$.

Start time of the elements destruction $\tilde{t}_0$ of CM takes equal

$\tilde{t}_0 = 0.0006$.

Threshold stress $\tilde{\sigma}_0$ of destruction of CM elements which corresponds to given time $\tilde{t}_0$ let's determine from calculation of normalized regularity of the equivalent stress changes in time, according to the articles [Filonenko, Kosmach, Kositskaya 2012; Filonenko, Kosmach 2012]. Values $\tilde{\sigma}_0$ and $\tilde{t}_0$ are constant. The calculation results showed that the value of the threshold stress destruction for $\tilde{t}_0 = 0,0006$ in relative units is $\tilde{\sigma}_0 = 0,1984978263$.

Quantity of elements N'_0 at each simulation step was described by growing ratio q that is the number of elements N'_0 was calculated by using of expression in the form

$$N'_0 = qN_0,$$

where q – coefficient of quantity increase of CM elements;

N_0 – maximum quantity of CM elements.

Values of coefficient q will be changed in the range from 0,4 to 1,0.

Simulations will be carried out in two stages. In the first stage we calculate AE pulse amplitude signals in time according to (2) for given values of N'_0 (for given values of q). For obtained results the length of formed AE signals was determined based on which the parameters $\Delta\tilde{t}_j$ and $\tilde{\delta}$ were chosen. In the second stage the amplitude of the resultant AE signals in time, according to (1) was calculated. We perform data processing with analysis of regularities of resultant AE signals parameters with increasing of values q that is the area of contact interaction.

The simulation results of the first stage are given in Table in relative units.

The calculation results of the first stage of modeling

$\tilde{q}$	$\tilde{t}_0$	$\tilde{\sigma}_0$	$\tilde{U}_m$	$\tilde{\tau}_m \cdot 10^{-6}$
0,4	0,0006	0,19849782629	43,7	1,76
0,6	0,0006	0,19849782629	65,5	1,78
0,8	0,0006	0,19849782629	87,4	1,80
1	0,0006	0,19849782629	108,9	1,82

Note: $\tilde{q}$ – coefficient which characterize the growth of the quantity of CM elements; $\tilde{t}_0$ – start of CM elements destruction; $\tilde{\sigma}_0$ – threshold stress of destruction start of CM element; $\tilde{U}_m$ – maximum amplitude of formed AE pulse signal; $\tilde{\tau}_m$ – duration of the formed AE pulse signal.

It should be noted that the duration of the leading edge $\tilde{\tau}_0$ of AE pulse signals during the growth of $\tilde{q}$, as shown by the simulation does not change and is equal to $\tilde{\tau}_0 = 0.67 \cdot 10^{-6}$ (in relative units).

The results of these calculations show that an increase of $\tilde{q}$ is an increase of the amplitude and duration of the AE pulse signal. Therefore, in the second stage of simulation, the value of the time interval $\Delta\tilde{t}_j$ between the appearance of the next and previous AE signals (subsequent destruction of the next and previous area of contact interaction) $\tilde{q} = 0{,}4$ let's take equal $\Delta\tilde{t}_j = 1{,}3 \times 10^{-6}$. The value $\tilde{\delta}$ will change in the range of sizes from $\tilde{\delta} = 0$ to $\tilde{\delta} = 5{,}0 \times 10^{-7}$ in random manner. For other values $\tilde{q}$ the values $\Delta\tilde{t}_j$ and $\tilde{\delta}$ will be set proportionally to the change of duration of AE pulse signals.

Results of the second stage of the simulation in the form of regularities of the amplitude of the resultant AE signals over time in relative units are shown in Fig. 2. Simulation parameters: $\tilde{\upsilon}_0 = 10^6$, $\tilde{r} = 10^4$, $\tilde{g} = 0.1$, $\tilde{\sigma}_0 = 0{,}1984978263$, $\tilde{\alpha} = 500$. Start time of the destruction $\tilde{t}_0$ of composite material elements $\tilde{t}_0 = 0{,}0006$. During calculation the processing of 5000 AE pulse signals was carried out.

The obtained results show that with the increasing of contact interaction area the change in the character of the resultant AE signals doesn't take place. They are continuous signals with highly rugged form. With the growth $\tilde{q}$ is the average amplitude of the resultant AE signals and the value of its spread.

Statistical analysis of simulation results in the form of dependences of percentage growth ($\Delta\tilde{Z}$, %) average amplitude level $\bar{\tilde{U}}$ and its standard deviation $s_{\bar{\tilde{U}}}$ and variance $s^2_{\bar{\tilde{U}}}$ at growth of $\tilde{q}$, relative to their initial values at $\tilde{q} = 0{,}4$ is shown in Fig. 3.

Analysis of the regularities (Fig. 3) showed that the increase in the average amplitude of the resultant AE signal and its standard deviation with increasing of $\tilde{q}$ is well described by linear function in the form

$$\Delta\tilde{Z}_{\bar{\tilde{U}},S} = A_1 + B_1\,\tilde{q},$$

where $\Delta\tilde{Z}_{\bar{\tilde{U}},S}$ – respectively, the percentage increase of $\bar{\tilde{U}}$ or $s_{\bar{\tilde{U}}}$;

A_1 and B_1 – coefficients of approximating expression.

Therefore the coefficients A_1 and B_1 are as follows:

– according to changes in average AE amplitude level A_1 = -234,64, B_1 = 572,51;

– according to changes in standard deviation of the AE average amplitude A_1= -241,66, B_1 = 590,37.

The correlation coefficients R for the regularities of change $\bar{\tilde{U}}$ and $s_{\bar{\tilde{U}}}$, therefore, are as follows: R = 0,99911 and R = 0,999.

To confirm the results of theoretical studies the experimental tests of the friction units of CM with different areas of contact interaction surfaces was conducted.

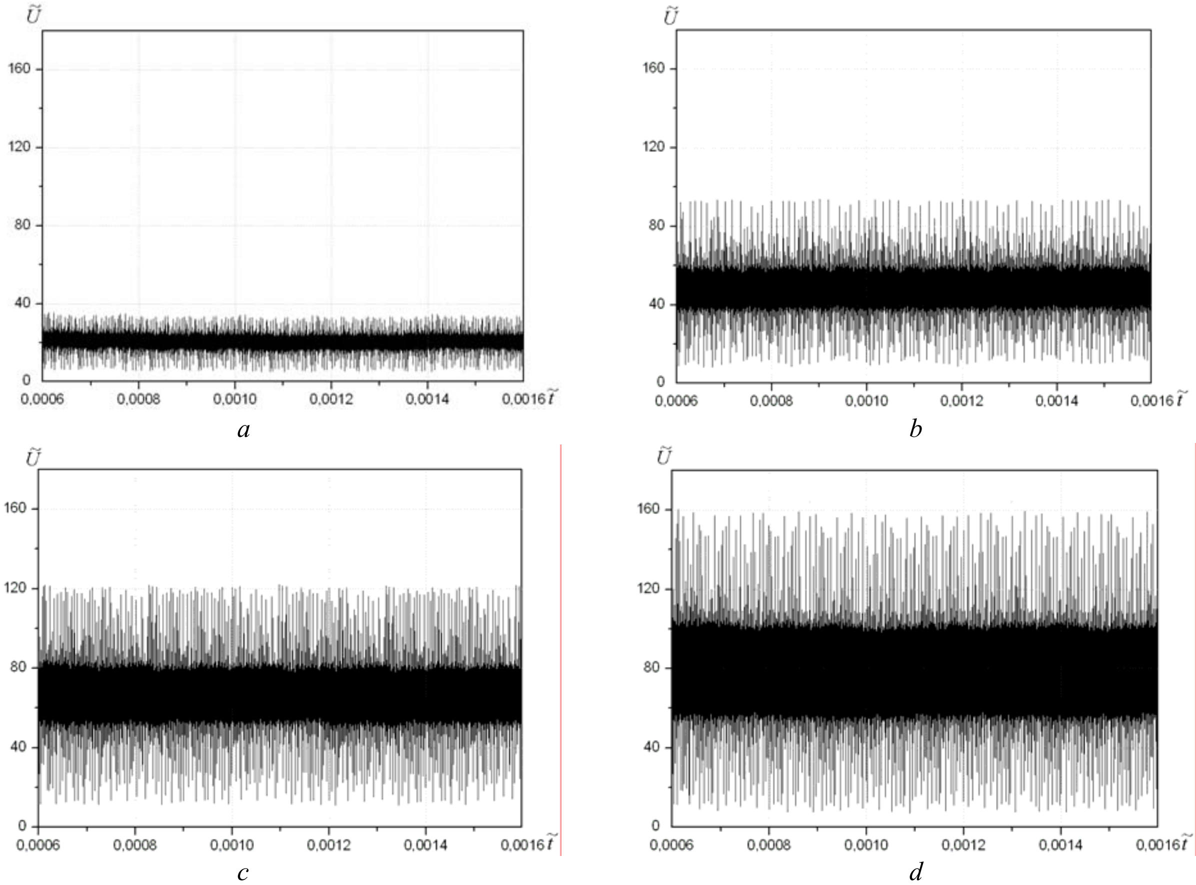

Fig. 2. Graphs of the amplitude of the resultant AE signals in time according to (1) in relative units with increasing of values $\tilde{q}$ which characterize the area of contact interaction of friction unit of CM:

a – $\tilde{q}$ = 0,4;

b – $\tilde{q}$ = 0,6;

c – $\tilde{q}$ = 0,8;

d – $\tilde{q}$ = 1,0

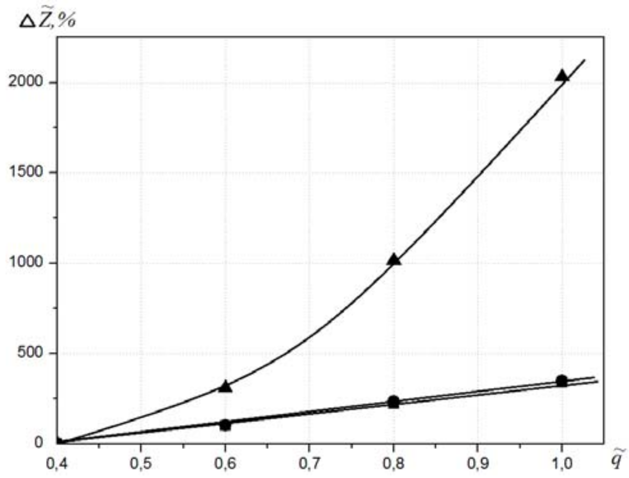

Fig. 3. Graphs of changes in percent increase of average amplitude level (■), its standard deviation (●) and variance (▲) with increase of $\tilde{q}$ relative to their initial values at $\tilde{q}$ = 0,4

4. Results of experimental research

For the experimental studies of AE signals that generated at friction of surfaces with CM samples of aluminum alloy D16 and steel 30HGSA were manufactured. On both surfaces of the samples hard facing based on carbide coating WK6 were coated. Used samples were in the form of bush type (Fig. 4) which had variable surface area of contact interaction.

During research the area of contact interaction of samples with steel 30HGSA the whole front of the area was covered. For samples of aluminum alloy were used with various areas of contact interaction with WK6. They are characterized by overlapping coefficient K_S, which is a ratio of the area of contact interaction to the total surface area. In studies two types of samples with values K_S = 0,25 and K_S = 1,0 (Fig. 4) were used.

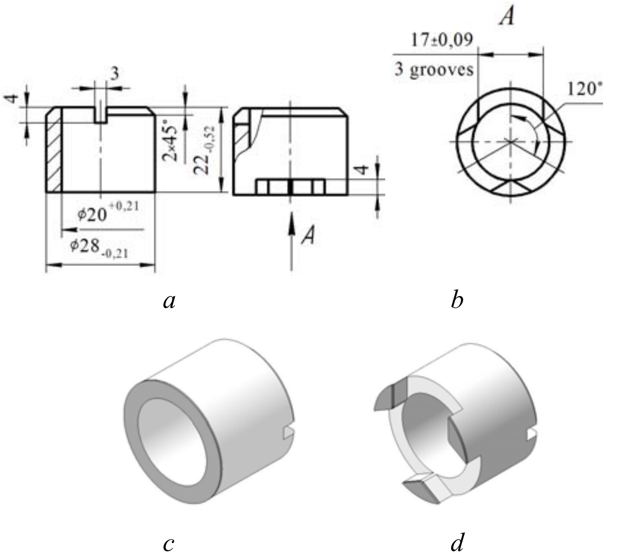

Fig. 4. Detail drawing of testing samples (*a*, *b*), as well as their general view (*c*, *d*)

To obtain the required coefficient K_S preliminary calculations with defining the specified size of the width of the grooves on the working front surfaces were performed. The choice of materials samples was used due to their widespread in transmissions aircraft, vehicle and engines.

Test samples were carried out by using structural patterns of interaction of “disc – disc” on the modernized testing machines SMT-1. According to the test scheme (Fig. 5), one of the samples 1 of friction unit was remained stationary, while the other sample 6 was placed in the holder 5 of friction machine and rotated with constant controlled speed. Fixed sample was placed in the cartridge of loading mechanism 4.

The process of studied friction unit loading was carried out by using motors which were operated by computer system. While research constant conditions of friction were used. Rotational speed of sample was v = 600 min^{-1} and the axial load P was P = 300 N. Axial load was created by special mechanism such as weight which was influenced on the fixed sample 1 (Fig. 5).

As lubricating medium during experiments type of lubricant M10H2K was used. Lubricant remained constant and was 1,2 liter per hour. Feed of lubricant in the zone of friction of surfaces was carried out by using the pump system through the element 3 (Fig. 5).

Before test the surfaces of the samples were manufactured by standard methods for study of friction surfaces. The roughness on the working surfaces of friction brought to values Ra ≤ 0,48 μ*m* and then held their washing in a solute of acetone and further drying. For reproducibility of the results of research the preliminary pre operate of samples with defined coupling end of their working surfaces in the contact area the value of which was not less than 90% was conducted.

During testing of samples recording and processing of formed AE signals were carried out. For this purpose on the fixed sample 1 (Fig. 5) hard fixed waveguide 7 was mounted.

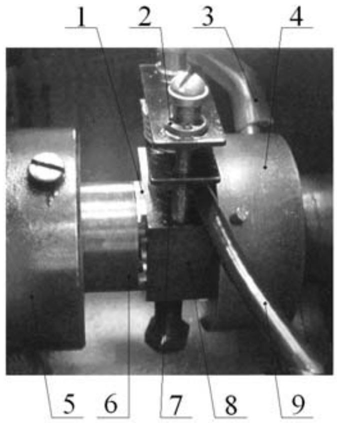

Fig. 5. Fragment of samples interaction during tests with the registration of acoustic emission signals:
1, 6 – testing samples;
2 – fixing mechanism for sensor;
3 – feeding element for liquid lubricant
4 – fixed holder;
5 – movable holder;
7 – acoustic emission sensor;
8 – waveguide;
9 – coaxial cable

AE sensor was mounted on waveguide. Its surface was greased by acoustic-transparent lubricant like “Ramsay”. To permanence mutual contact of surfaces of the waveguide and sensor the special attaching mechanism 2 was used.

The signal from the output of the AE sensor via coaxial cable 9 was amplified in the amplifier path and came into the Acoustic Emission Diagnostic Complex (AEDC). In studies analog-to-digital converter of signals with sampling interval Δt = 11,41 ± 0,033 ms was used.

Processing and analysis of recorded AE signals were carried out by using special software of AEDC. Software of AEDC allows to storage recorded information with the analysis of the main parameters of AE signals: the average amplitude and energy level, total energy accumulated and averaged total energy, and their average values in the series of experiments.

The results of data processing can be performed on display of regularities of AE parameters change in time and conduct their analysis and translate the obtained results into format encoding ASCII, which is necessary for further statistical analysis of the received information in software products for mathematical processing.

Processing of AE data was carried out with averaging. Averaging time was 15 ms. Insertion of data is averaged due to large amounts of initial information which was recorded at friction of samples surfaces which need to save as file structures. Studies have shown that data averaging effects on the contribution of component processes in resultant AE signal with minimal losses.

During the experiments the registration of resultant AE signals was carried out under normal wear of surfaces after stage of pre working at constant temperature conditions in the zone of friction and friction coefficient. In studies short-term tests of interval analysis within $T_a = 50$ s were conducted.

The obtained results show that for the adopted loading conditions (for given values of axial load and rotational speed) of friction pair the registered resultant AE signal is continuous signal with chopped form. It is characterized by some average amplitude level and value of its spread (Fig. 6).

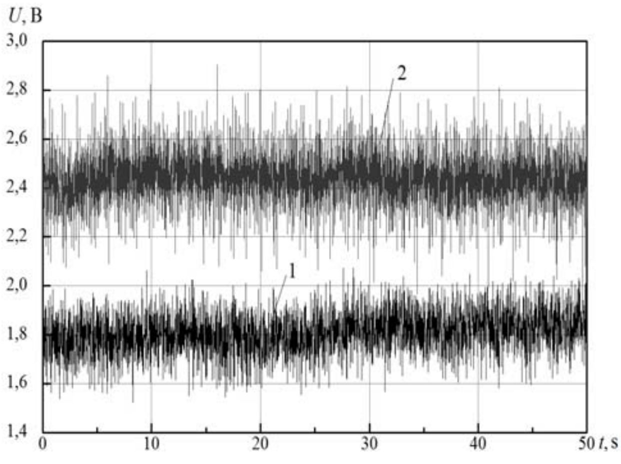

Fig. 6. The output resultant signals of AE:
1 – $K_S = 0,25$;
2 – $K_S = 1$

The output resultant signals of AE which were recorded during testing of friction unit of CM at different areas of the friction surfaces overlap. Rotational speed $v = 600$ min^{-1}, axial load $P = 300$ N.

Statistical analysis of the data showed that for all of conducted research the distribution of the averaged amplitudes of formed AE signals with probability of 0,95 is described by normal distribution.

Conducted research showed (Fig. 6) that with increase of contact interaction area between friction surfaces of the CM at the stage of growth at normal wear there is a growth of average amplitude of the resultant AE signal and the value of its variation.

Let's analyze the obtained data in terms of informativeness of parameters of resultant AE signals with definition of the average level, variance and standard deviation. Length of the sample in the analysis was the same and the number of intervals in the length of the sample analysis was 4000.

Thus at study of friction unit with $K_S = 0,25$ the average amplitude level of the resultant AE signal is $\overline{U} = 1,8$ V, and the variance and standard deviation, respectively, are equal to:

$\varepsilon = 0,00806$ V^2 and $\sigma = 0,0898$ V.

Further the data analysis was carried out with respect to the values which obtained for $K_S = 0,25$. Increased area of contact interaction in 4 times (that is $K_S = 1$) leads to an increase of $\overline{U}$ to 35,55% ($\overline{U} = 2,44$ V). This variance ε is increased by 78,66% and the standard deviation σ is increased to 33,63%.

In Fig. 7 the results of processing parameters of studied averaged amplitudes of resultant AE signals in normalized form, depending on the area of mutual overlap of friction surfaces which were recorded during testing of friction units for $K_S = 0,25$ and $K_S = 1$ were presented. Rotational speed $v = 600$ min^{-1}, axial load $P = 300$ N.

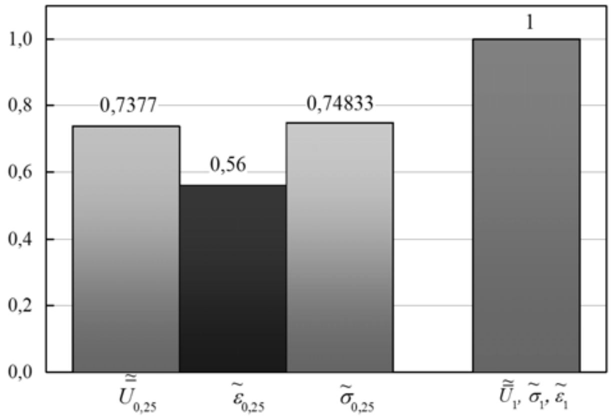

Fig. 7. Level of averaged amplitude, variance and standard deviation of AE signals

The results of experimental studies showed that the most informative parameter of formed resultant AE signal is the averaged amplitude variance, which had the largest increase of value.

5. Conclusions

The simulation results of acoustic radiation show that at friction of surfaces of the CM continuous AE signal was formed. This signal can be characterized by an average level of amplitude and the value of its spread (standard deviation and variance). Simulations results showed that the increase in the area of mutual overlapping surfaces of frictional contact of CM leads to increase in the average amplitude level of the AE and the values of the standard deviation and variance.

Statistical analysis of the obtained data with approximation dependences of the amplitude parameters of resultant AE signals was conducted. It was determined that changes percent increase depending on the average amplitude and standard deviations at growth of areas of mutual overlap of the friction unit is good described by linear law. At the same time the regularities of changes of percent increase of average amplitude variance at growth of areas of mutual overlapping surfaces were described by nonlinear law.

Analysis and simulation results show that the variance of average amplitude of the resultant AE signal is the most sensitive to changes in the area of mutual overlapping surfaces of friction unit of CM.

In real experiment the results of theoretical investigations of resultant AE signals at changing of areas of mutual overlapping surfaces of friction units were confirmed.

At the same time the parameters study of averaged and the total energy of AE signals and analysis of their rate of accumulation at changing of the overlapping areas of mutual friction surfaces of the CM generated the special interest.

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С.Ф. Філоненко[1], О.П. Космач[2], Т.М. Косицька[3]. Акустична емісія при зміні площі контактної взаємодії пари тертя з композиційного матеріалу

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Розглянуто результати моделювання результуючих сигналів акустичної емісії при терті поверхонь з композиційного матеріалу. Показано, що зі зростанням площі контактної взаємодії пари тертя відбувається зростання середнього рівня амплітуди акустичного випромінювання, їх стандартних відхилень та дисперсій. Визначено апроксимуючі вирази для залежностей зміни амплітудних параметрів формованих сигналів акустичної емісії при зростанні площі контактної взаємодії пари тертя. Проведено порівняння експериментальних результатів із результатами теоретичних досліджень. Показано, що найбільш чутливим параметром до зміни площі контактної взаємодії пари тертя є дисперсія середнього рівня амплітуди результуючого сигналу акустичної емісії.

Ключові слова: акустична емісія; амплітуда; дисперсія; композиційний матеріал; параметр; сигнал; тертя.

С.Ф. Филоненко[1], А.П. Космач[2], Т.М. Косицкая[3]. **Акустическая эмиссия при изменении площади контактного взаимодействия пары трения из композиционных материалов**
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Рассмотрены результаты моделирования результирующих сигналов акустической эмиссии при трении поверхностей из композиционного материала. Показано, что с ростом площади контактного взаимодействия пары трения происходит рост среднего уровня амплитуды акустического излучения, их стандартных отклонений и дисперсий. Определены аппроксимирующие выражения для зависимостей изменения амплитудных параметров формируемых сигналов акустической эмиссии при росте площади контактного взаимодействия пары трения. Проведено сравнение экспериментальных результатов с результатами теоретических исследований. Показано, что наиболее чувствительным параметром к изменению площади контактного взаимодействия пары трения является дисперсия среднего уровня амплитуды формируемого результирующего сигнала акустической эмиссии.

Ключевые слова: акустическая эмиссия; амплитуда; дисперсия; композиционный материал; параметр; сигнал; трение.

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