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# REGULARITIES OF ACOUSTIC RADIATION AT INCREASE OF LOADING ON FRICTION UNIT WITH COMPOSITE MATERIALS

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**Abstract**. *The results of simulation of acoustic radiation with increase of load on friction unit with composite material were shown. Was shown that increasing of load leads to increase of amplitude and energy parameters of resulting acoustic emission signals. The regularities of percentage increase of amplitude and energy parameters of the resulting acoustic emission signals were determined. Was described that with increasing of load on friction unit the increase of average amplitude was ahead of its standard deviation and variance. Was considered what most sensitive parameter with increasing of friction pair load is variance of average energy of resulting acoustic emission signal.*

**Keywords**: acoustic emission, signal, amplitude, energy, regularity, composite material, load, parameter, increment, friction, level.

## Introduction

The using of composite materials (CM) in friction units has received much attention in the scientific literature. Conducted researches aimed to optimize the choice of mating CM and optimize of friction units regimes. Obtained results show that the use of CM leads to improvement of tribological characteristics of frictional contact and lifetime extension of friction units. At the same time there is a problem of monitoring and diagnostics of friction units with CM that caused by the specifics of structure and destruction of CM. Conducted researches shows that use of traditional methods (determination of friction torque, coefficient of friction, etc.) allows to fix the development of macro fracture in the surface layers of friction materials. Practically this means that is fixed the accelerated transition from normal to stage of catastrophic wear when occur total disability of friction unit. From this perspective, the most interesting makes the fixation of processes developing in the area of frictional contact on initial stages emergence of the catastrophic destruction of the surface layers with CM.

In recent decades, in study of friction and wear of friction surfaces contact with traditional materials (with crystal structure) and CM acoustic emission (AE) method is used. Registered AE signals are reflection of processes which are developing on submicro, micro and macro levels. Continuing development of those processes leading to modification of acoustic radiation and its parameters can be used in the development of methods for monitoring and diagnosis of friction units including friction with CM. However, small inertia and high sensitivity of AE requires the identification of relationships of detected acoustic emission parameters with the parameters of the developing processes that leads to the problem of determination of the influence parameters of the developing process on AE parameters. Solution to this problem should be based on theoretical studies. Such research at modeling of acoustic radiation can determine the regularities of its radiation for action of various factors – physical and mechanical characteristics of CM, their dispersion properties, rotational speed of friction pair and so on. Such regularities should be the basis of methods of control and diagnostics of friction units with CM. One of the factors which influence on the processes of wear and therefore on AE is the load applied to the pair of friction. Investigations of acoustic radiation in this case of load change are definitely representing scientific and practical interest.

## Analysis of sources and publications

Acoustic emission is widely used at study of friction and wear of the surface layers which made from materials with crystalline structure and CM [1–7]. The research results show the complexity of the changes of registered AE signals on every stage of the process of friction and wear. Comparison of curves character of standard parameters change which were used during the research of friction (curve of friction coefficient, friction torque) and the average amplitudes of acoustic radiation level in time shows significant divergence. For standard parameters of obtained dependences have smooth character of change. A sharp change in the dependences was observed at passing from normal stage to the stage of catastrophic wear of surfaces. For the average level of amplitudes of registered AE signals the obtained dependences have significant dynamic of change in time. Rising and falling of average levels of amplitude AE signals were observed continuously on all stages of the friction process: at normal wear and at stage which prior to the stage of catastrophic wear and at transition from normal stage to stage of catastrophic wear. This modification of the acoustic emission shows low inertia of method and reaction of method for microscopic processes which are developing in the surface layers of materials. However, the interpretation of such processes significantly complicated by difficulties of theoretical studies. The problem is definitely limits the using of the AE method for monitoring and diagnosis of friction units and processes that develop in the surface layers of materials.

Theoretical studies of acoustic radiation in the friction surfaces of materials with traditional structure were considered in [8, 9]. For the analysis of acoustic radiation, which is formed during friction, was used AE signal model at destruction of the secondary structures of I and II types, and the resulting signal has the form

$$U'(t) = U_T(t) + U_d(t); \qquad (1)$$

$$U_d(t) = U_{0d}\varepsilon_{0d}e^{rt}e^{-B\varepsilon_{0d}e^{rt}};$$

$$U_T(t) = U_0''\delta_i\sigma_{0e}^3 e^{4zt}e^{-b\sigma_{0e}e^{zt}};$$

where $U_{0d} = a_0 M \frac{\upsilon_d}{\ell_0}\delta_d$, $U_{0d}$ – displacement amplitude which depends on physical and mechanical characteristics of the material;

$a_0$ –amplitude of single pulse of disturbance during movement of single dislocation; $M$ – coefficient that depends on physical and mechanical characteristics of the material;

$\upsilon_d$ – average velocity of dislocations;

$\ell_0$ – distance between two acts of single dislocation radiation;

$\delta_d$ –average duration a single pulse disturbance during dislocation movement;

$\varepsilon_{0d}$ – initial relative strain;

$r$ and $B$ – coefficients that depend on physical and mechanical characteristics of the material;

$t$ – time;

$U_0'' = kN_0cz$ – maximum possible displacement in case of brittle fracture of non-dispersible by strength of the surface layer of material;

$k$ – coefficient of proportionality;

$c$ – coefficient that depend on the physical and mechanical characteristics of the material;

$z = E/\xi$;

$\sigma_{0e}$ – initial equivalent stress;

$\delta_i$ –average duration of single pulse disturbance in case of brittle fracture of elementary volume of material,

$E$ – elastic modulus

$\xi$ – viscosity coefficient.

On the basis of the developed models in [8–10] the simulations of AE signals at influence of different factors were conducted. Was shown that the resulting AE signals are continuous signals with very rugged form. The studies allowed to determine the main regularities of AE signals parameters in case of changes of influenced factors. These simulation results are consistent with experimental results.

In articles [11–14] reviewed the results of AE signals simulations in case of destruction CM by shear load. Under such loading conditions, taking into account the rule «OR» (CM elements were destroyed due bending or stretching when the equivalent strain reaches certain threshold) and independent uniform distribution of threshold levels with borders [0, 1], and also the kinetics of destruction process of formed CM elements, the AE signal take 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;

$\beta$ – coefficient of proportionality;

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

$\alpha$ – 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);
$r$, $\upsilon_0$ –constants which depending on their physical and mechanical characteristics.

Simulation of AE signals using equation (2) allow determine the main regularities of their parameters change (amplitude, energy and time) at influence of different factors – loading speed of CM, physical-mechanical characteristics (brittleness and dispersion properties by strength) of CM elements, as well as their sizes.

Developed model of AE signal (2) as in the case of materials with traditional structure can be used to describe the resulting AE signal which is forming in friction of CM surfaces. In this case the expression for the AE resulting signal can be written as

$$U_p(t) = \sum_j U_j(t - t_j)\,, \qquad (3)$$

where $j$ – serial number of the $j$ contact interaction area ($j$ = 0, 1, 2, ..., m); $U_j(t_j)$ – AE impulse signal which is formed in the $j$ contact interaction area described by expression (1);
$t_j$ –time moment of $j$ AE signal;
$m$ – pulse number of AE signals on the length of realization (time of friction unit working).

Initial conditions in model (3) as follows. For friction units in the form of rings or rollers the platform of contact interaction is some small and variable in time in the platform $S_T$ of overlap surface area $S$ of CM. When rotating of friction unit within given area take place the destruction of the specified numbers of elements $N_0$ that have certain physical and mechanical properties and dimensions – parameters $\upsilon_0$, $r$ and $g$ which included in the expression (2). Change of position of contact interaction platform in time is provided by friction unit speed $\alpha$. Specified speed and axial load on friction unit with the size of elements define the regularity of equivalent stress changes and the threshold stress $\sigma_0$ of start CM elements destruction

$$\sigma_0 = \alpha t_0 (1 - \alpha t_0)(1 - g\sqrt{\alpha t_0})\,. \qquad (4)$$

According to equation (3) with (2), it is possible to simulate the resulting AE signals which are formed in friction of CM surfaces depending on the influencing different factors. One of these factors is the axial load applied to friction unit with CM.

## Formulation of article objectives

In this paper will be carried out simulations of resulting AE signals which are formed in the friction surfaces of the CM, with increasing axial load on friction unit. It will be shown that with increasing axial load on friction unit increases the average level of amplitude of the resulting AE signals and the values of its standard deviation and variance. Such increase in the average amplitude is increase ahead of its standard deviation and variance. Will be implemented analysis of energy parameters of resulting AE signals. It will be shown that with increasing of the axial load on the friction unit is increase in average energy level resulting AE signals and the values of the standard deviation and variance. The variance increase in the average energy level is ahead of the average energy level and its standard deviation.

## Results of researches

Influence of load on the friction unit as known in [15] leads to change in the conditions of it work and influence on the development of the friction processes and wear. It primarily relates variations of the equivalent stress and interconnected parameters – torque, friction torque and friction force and so on. Certainly, load affects on kinetic of the friction process (kinetic process of destruction of the surface layers of frictional contact). In articles [16, 17] during consideration of kinetic friction processes using «model of earthquakes» (EQ model) shows that with increasing of axial load occurs increase of threshold and kinetic friction that are necessary for course of the friction process. Such growth of friction forces in its turn leads to increase in speed (local rate) movement and reduce time of frictional contact (increasing the number of friction connections that were destroyed per time). Otherwise speaking the continuous development of friction process at the macro level of areas destruction of contact interaction occurs with variable speed which increases with increase of threshold and kinetic friction forces.

For surface frictional contact with CM, this means that an increase in the threshold and kinetic forces is result of the growth of the axial load and approaching to start time moment of destruction elements of CM and speed of equivalent stress increase. Such growth of speed provided by the accumulation of external energy. Thus while achieving the threshold stress fracture of CM elements occurs with higher speed from the initial time of destruction or with additional growth rate which compared to the previous level of axial load.

Considering these conditions let's conduct the simulation of AE resulting signals according to equation (3) and taking into account the change of axial load on the friction unit with CM. During the simulation we assume that in friction unit in the form of rings or rollers the platform of contact interaction is some small and variable in time platform $S_T$ of area $S$ of CM surface overlap. Changing of contact area position $S_T$ in time of interaction provided by rotational speed of friction unit. During the rotation of friction unit within this platform occurs destruction of the elements $N_0$ that have specified physical and mechanical properties and dimensions caused by the parameters, *r* and *g*. We assume that for given initial velocity $\alpha$ value of the axial load is equal to one ($\tilde{P}$ =1), and that with increasing of axial load *P* is increase the rate of destruction of CM elements relative to the initial rate $\alpha$, i.e. the rate of destruction is follows: $\alpha_i = \alpha + \Delta\alpha_i$, where *i* – number of increase in axial load. Simulation will perform in relative units.

The initial conditions of simulation. The initial value $\tilde{\alpha}$ =200, and the value of the axial load $\tilde{P}$ =1.

Under these conditions the start of the destruction $\tilde{t}_0$ of the first platform of contact interaction in relative units is $\tilde{t}_0$ =0,0006.

For given values $\tilde{\alpha}$ and $\tilde{t}_0$ from regularities of equivalent stresses change $\tilde{\sigma}$ we define the limit of fracture stress $\tilde{\sigma}_0$ according to equation (4). Then $\tilde{\sigma}_0$ =0,1528445825.

Values of parameters $\upsilon_0$, $r$ and $g$ that were included in expression (2), accept the following: $\tilde{\upsilon}_0$ =$10^6$, $\tilde{g}$ = 0,1, $\tilde{r}$ =$10^4$.

Axial load *P* of friction unit with CM is not included in explicit form in expression (2). It influence we determine by changing the threshold tensions that we calculate as equivalent stress based on the relationship of shear and normal stresses, according to article [15]. To perform the calculations we set the coefficient of friction $f$ =1 and the axial load increase from 1 to 1.6 in increments of $\Delta\tilde{P}$ =0,15.

Start time $\tilde{t}_0$ of CM elements destruction with increasing of $\tilde{P}$ is unchanged. So for obtained values of the threshold stress let's define the values $\alpha_i$, based on equation (4) or $\Delta\alpha_i$ increment to $\tilde{\alpha}$ =200. The results of the calculations for the simulation of the AE resulting signals are given in the table.

According to the model of AE resulting signal (3) destruction of platforms of contact interaction happens in consistent manner.

Table 1

The calculation results of $\tilde{\sigma}_0$ and $\tilde{\alpha}$

| $\tilde{P}$ | $\tilde{t}_0$ | $\tilde{\sigma}_0$ | $\tilde{\alpha}$ |
|---|---|---|---|
| 1 | 0,0006 | 0,10194190869441454 | 200 |
| 1,15 | 0,0006 | 0,11041324719634700 | 220 |
| 1,3 | 0,0006 | 0,11858646007796404 | 240 |
| 1,45 | 0,0006 | 0,12646368867491953 | 260 |
| 1,6 | 0,0006 | 0,13404688883894890 | 280 |

In these conditions the time moment of AE pulse signals $U_j(t_j)$ occurrence at destruction of each subsequent platform of contact interactions can be written in the form $t_j = j\Delta t_j \pm \delta$, where *j* – number of pulse signal AE (*j* = 1, 2, 3, ...., n);

$\Delta t_j$ – time interval between onset of the next and previous pulse signals AE;

$\delta$ – random component of time moment of occurrence of each subsequent AE signal.

The value of the time interval for $\tilde{\alpha}$ = 200 and $\tilde{P}$ =1 is $\Delta\tilde{t}_j$ =1,1·$10^{-6}$, which was selected by the AE signal duration which formed for $\tilde{\alpha}$ =200, which was considered at calculation of time changes in the amplitude pulse signal according to equation (2).

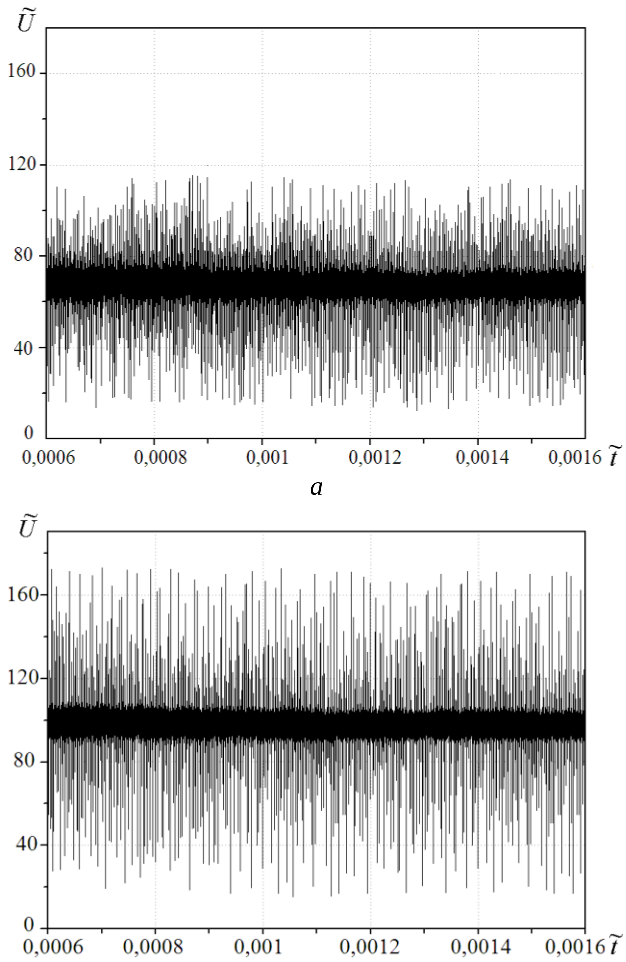
At the same time the values $\tilde{\delta}$ will change in the range from $\tilde{\delta}$ =0 to $\tilde{\delta}$ =5,0·$10^{-7}$ randomly.

As can be seen from table 1, with increasing values pf $\tilde{P}$ takes place the growth of $\tilde{\alpha}$ which in turn leads to decrease in the duration of AE pulse signal according to equation (2). Therefore, the values $\Delta\tilde{t}_j$ and $\tilde{\delta}$ with increase of $\tilde{P}$ ($\tilde{\alpha}$) will be set in proportion to the change of pulse duration of AE signals.

Simulation of the resulting AE signals as graphs of amplitude changes in time in relative units for $\tilde{P}$ =1 and $\tilde{P}$ =1.6 according to equation (3) shown in

Fig. 1. During a simulation resulting AE signals according to equation (3), for each value of $\tilde{P}$ was performed estimation and procession of 5000 pulse signals.

The initial value $\tilde{\alpha}$ is $\tilde{\alpha}$ =200. Start time of the destruction of elements of CM $\tilde{t}_0$ =0,0006. Simulation parameters according to equation (2) $\tilde{\upsilon}_0$ =$10^6$, $\tilde{g}$ =0,1.




*a*

*b*

Fig. 1. Change of amplitude of resultant acoustic emission signals in time according to (3) with values of $\tilde{P}$ :
*a* – $\tilde{P}$ = 1;
*b* – $\tilde{P}$ = 1,6.

The results of the simulations indicate that increasing of axial load which changes the stress state of the friction unit leads to increase of the average level amplitude of AE resulting signals $\tilde{\tilde{U}}$ and the values of its spread. As shows statistical analysis of data, if $\tilde{P}$ =1, the average amplitude level of the resulting signal is AE $\tilde{\tilde{U}}$ =67,1 and standard deviation $s_{\tilde{\tilde{U}}}$ and variance $s^2_{\tilde{\tilde{U}}}$ of average level amplitude, respectively, are: $s_{\tilde{\tilde{U}}}$ =20,92; $s^2_{\tilde{\tilde{U}}}$ =437,65. With increasing of $\tilde{P}$ in 1,15 times, values $\tilde{\tilde{U}}$ and $s_{\tilde{\tilde{U}}}$, $s^2_{\tilde{\tilde{U}}}$ respectively increased in 1,1 times, 1,02 times and 1,04 times.

If $\tilde{P}$ increased in 1,3 times $\tilde{\tilde{U}}$ and $s_{\tilde{\tilde{U}}}$, $s^2_{\tilde{\tilde{U}}}$ consequently increasing in 1,21 times, 1,05 times and 1,1 times.

With increasing $\tilde{P}$ in 1,45 times, values $\tilde{\tilde{U}}$, $s_{\tilde{\tilde{U}}}$, $s^2_{\tilde{\tilde{U}}}$ respectively increased in 1,32 times, 1,07 times and 1,15 times.

If $\tilde{P}$ increased in 1,6 times, the values $\tilde{\tilde{U}}$, $s_{\tilde{\tilde{U}}}$ and $s^2_{\tilde{\tilde{U}}}$ consequently increase in 1,43 times, 1,1 times and 1,2 times.

Graphs of percentage increase $\Delta\tilde{Z}_{AE}$ of average amplitude level $\tilde{\tilde{U}}$ of resulting AE signals, as well as percentage increase in the value of its standard deviation $s_{\tilde{\tilde{U}}}$ and variance $s^2_{\tilde{\tilde{U}}}$ relative to their values when $\tilde{P}$ =1 shown in Figure 2.

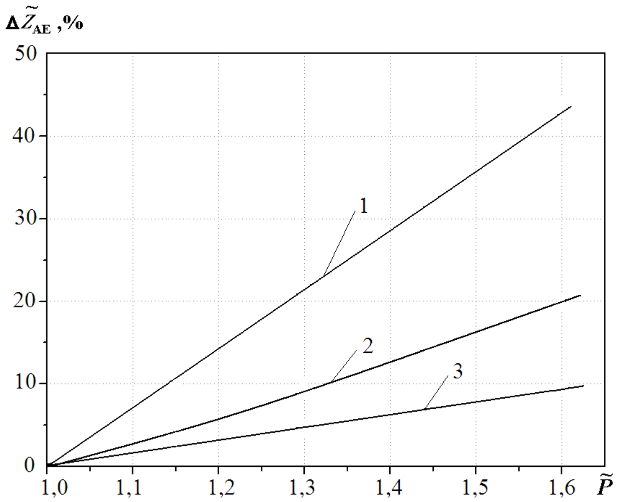



Fig. 2. Change in percentage increase of amplitude average level $\tilde{\tilde{U}}$ (1), its standard deviation $s_{\tilde{\tilde{U}}}$ (3) and variance $s^2_{\tilde{\tilde{U}}}$ (2)

Obtained data (fig. 2) show that the percentage increase in the average level amplitudes of resulting AE signals, its standard deviation and variance with the growth of $\tilde{P}$ takes place linearly. Analysis of the obtained dependences (fig. 2) with their approximation showed that they were good described by an expression of form

$$\Delta\widetilde{Z}_{AE} = A + B\widetilde{P}, \qquad (5)$$

where $\Delta\widetilde{Z}_{AE}$ –percentage increase in average level amplitude of resulting AE signals, its standard deviation $s_{\tilde{\tilde{U}}}$ and variance $s^2_{\tilde{\tilde{U}}}$;
*A*, *B* – coefficients of approximating expression.

For the dependences of average level amplitude $\tilde{\tilde{U}}$ of resulting AE signals, as well as the percentage increase in the value of its standard deviation $s_{\tilde{\tilde{U}}}$ and variance $s^2_{\tilde{\tilde{U}}}$ the coefficients of approximation expression (5) is:
- for percentage increase of average amplitude level *A*=-73,42, B=72,86;
- for percentage increase of standard deviation of average amplitude level *A*=-15,98, B=15,84;
- for percentage increase of dispersion of average amplitude level *A*=-33,54, B=33,13. The correlation coefficients for the percentage increase of average level amplitude $\tilde{\tilde{U}}$ of the resulting AE signals, its standard deviation $s_{\tilde{\tilde{U}}}$ and variance $s^2_{\tilde{\tilde{U}}}$, respectively are:

*R*=0,9996; *R*=0,9995; *R*=0,9991.

The results of the simulations indicate that increasing of axial load on the friction pair with CM affects on amplitude parameters of resulting AE signals. There is an increase in average level amplitude of the resulting AE signals, its standard deviation and variance. However, the greatest influence of axial load is observed for average amplitude of resulting AE signal (Fig. 2).

Similar research was conducted at processing of energy resulting AE signals with growth of $\widetilde{P}$. The results showed that, like for amplitudes of the resulting AE signals, the growth of the axial load on friction unit leads to increase of the average level of energy $\tilde{\tilde{E}}$, its standard deviation $s_{\tilde{\tilde{E}}}$ and variance $s^2_{\tilde{\tilde{E}}}$.

Processing of energy parameters of resulting AE signals in the form of dependences of percentage increase of average level of energy, its standard deviation and variance with the growth of axial load $\widetilde{P}$ in relative to their initial values at $\widetilde{P}$ =1 shown in fig. 3.

Analysis of the results showed that percentage increase in average level of energy and its standard deviation, as in the case of amplitude parameters of resulting AE signals, with growth of $\widetilde{P}$ takes place linear manner. Growth of percentage increase in average energy level and its standard deviation were good described by an expression of the form

$$\Delta\widetilde{Q}_{AE} = C + D \cdot \widetilde{P} \qquad (6)$$

where *C*, *D* – coefficients of approximating expression.

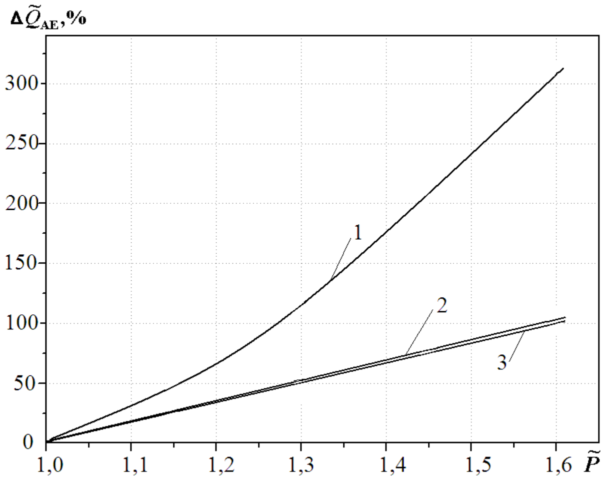



Fig. 3. Change in percentage increase of average energy level $\tilde{\tilde{E}}$ (3), its standard deviation $s_{\tilde{\tilde{E}}}$ (2) and variance $s^2_{\tilde{\tilde{E}}}$ (1)

Coefficients of approximating expression (6) for the analyzed dependencies equal to:
for percentage increase of average energy level *C*=-127,23, *D*=164,44; for percentage increase of standard deviation of the average energy level *C*=-175,79, *D*=172,68. At the same time correlation coefficients for percentage increase of average energy level $\tilde{\tilde{E}}$ and its standard deviation $s_{\tilde{\tilde{E}}}$, respectively are: *R*=0,99665; *R*=0,99802.

Dependence of percentage increase of variance of average energy level of resulting AE signals with increase of $\widetilde{P}$ is non-linear. Approximation of dependence of percentage increase $s^2_{\tilde{\tilde{E}}}$ with increase of $\widetilde{P}$ shows that it is well described by the expression

$$\Delta\widetilde{Q}_{AE} = a + b\widetilde{P} + c\widetilde{P}^2 \qquad (7)$$

where $\Delta\widetilde{Q}_{AE}$ –percentage increase in variance of average energy level;
*a*, *b*, *c* – coefficients of approximating expression.

Coefficients of approximating expression (7) for the analyzed dependence are:
*a*=215,4; b=-677,8; c=461,5.
The correlation coefficient for the percentage increase of variance of average energy level of resulting AE signals is *R*=0,99974.

Results of these studies shows that regularities of changes of energy parameters of resulting AE signals with growth of axial load are similar to the regularities of change of amplitude parameters. However, there are differences of obtained regularities. Percentage increase in average level of energy and its standard deviation with the growth of $\tilde{P}$ is almost identical (Fig. 3). This increase exceeds the percentage increase in average level of amplitude and its standard deviation.

The largest increase is observed in the variance of average energy level, which is in seven times exceed the percentage increase in average level of amplitude of the resulting AE signals. This means that in a real experiment with increasing of axial load should expect the largest increase in average level amplitude of the resulting AE signals or in variance of average energy level. However, the most sensitive parameter is the variance of average energy level of resulting AE signals.

## Conclusions

The simulations of the resulting AE signals with increasing of axial load on the friction unit with CM were conducted. Simulation results shows that increasing of axial load leads to increase of the amplitude parameters of resulting AE signals such as the average level of amplitude and its standard deviation and variance. Were obtained the regularities of change of amplitude parameters of formed AE signals. Was determined that changes in percentage increase of dependence of average amplitude level and its standard deviation and variance are the same type character and are well described by linear functions. With increasing of axial load the largest percentage increase have the average amplitude of the resulting AE signals.

The analysis of the energy parameters of acoustic radiation with increasing of axial load on the friction unit with CM was performed. Percentage increase in average level of energy and its standard deviation is also described by linear functions. Variance of average energy level increase non-linear and is well described by polynomial of second order. However, the largest percentage increase with increasing of axial load on the friction unit was observed in the variance of average energy level of resulting AE signals.

Therefore during the experimental study with increasing of axial load on the friction unit with CM largest increase should expect in the average amplitude of the resulting AE signals. Increase its standard deviation and variance is not significant. However, the largest increase should expect in the variance of average energy level of resulting AE signals. Of course, interest is the experimental study of AE signals and determining of regularities of change their parameters in case of change loading conditions of friction unit with CM.

## Література


1. Ferrer, C.; Salas, F.; Pascual, M.; Orozco, J. 2010. *Discrete acoustic emission waves during stick–slip friction between steel samples*. Tribology International. – Vol. 43, N 1: 1–6.

2. Liao, C.; Suo, S.; Wang, Y.; Huang, W.; Liu, Y. 2012. *Study on stick-slip friction of reciprocating o-ring seals using acoustic emission techniques*. Tribology transactions. – Vol. 55, N 1: 43–51.

3. Dobrzanski, L.A.; Pakuła, D.; Krizb, A.; Sokovic, M. 2006. *Tribological properties of the PVD and CVD coatings deposited onto the nitride tool ceramics.* Journal of materials processing technology.– Vol. 175: 179–185.

4. Cao, D. 2010. *Investigation of acoustic emission and surface treatment to improve tool matereals and metal forming process*. Dissertation The Degree Doctor of Philosophy in Materials Engineering. University of Dayton (Dayton, Ohio). 116 p.

6. Hong, E.; Kaplin, B.; You, T.; Suh, M., Kim, Y.S.; Choe, H. 2011. *Tribological properties of copper alloy-based composites reinforced with tungsten carbide particles*. Wear. – Vol. 270: 591–597.

7. *Рубцов В.Е.* Использование акустической эмиссии для анализа процессов изнашивания при трении скольжения / *В.Е. Рубцов, Е.А. Колубаев, А.В. Колубаев, В.Л. Попов* // Письма в ЖТФ. – 2013. – Т.39. – Вып. 4. – С. 79–86.

Rubtsov, V.E.; Kolubaev, A.V.; Popov, V.L. 2013. *The use of acoustic emission analysis for the wear in sliding friction*. Letters to ZHTF. – Vol. 4: 79–86.

8. *Бабак В.П.* Моделі сигналів акустичної емісії при руйнуванні поверхневих шарів пар тертя / В.П. Бабак, С.Ф. Філоненко, В.М.Стадниченко, А.П. Стахова // Проблеми тертя та зношування. – 2007. – № 47. – С. 5–18.

Babak, V.P.; Filonenko, S.F.; Stadnychenko, V.M.; Stakhova, A.P. 2007. *Models of acoustic emission signals in the destruction of the surface layers of friction pairs*. Problems of friction and wear. – Vol. 47: 5–18.

9. Filonenko, S.F.; Stahova, A.P.; Kositskaya, T.N. 2008. *Modeling of the acoustic emission signals for the case of material's surface layers distraction in the process of friction*. Proceedings of the National aviation university. – N 2: 24–28.

10. *Филоненко С.Ф.* Моделирование сигналов акустической эмиссии при изменении объема материала, вступившего в пластическую деформацію/ С.Ф. Филоненко, А.П. Стахова, В.Г. Кравченко //Технологические системы. – 2008. – №1 (41). – С.22–27.

Filonenko, S.F.; Stakhova, A.P.; Kravchenko, V.G. 2008. *Modeling of acoustic emission signals at the amount of material that came in plastic deformation*. Technological systems. 2008. – N 1 (41): 22–27.

11. Filonenko, S.; Kalita, V.; Kosmach, A. 2012. *Destruction of composite material by shear load and formation of acoustic radiation.* Aviation. – Vol. 16, N 1: 5–13.

12. *Філоненко С.Ф.* Вплив швидкості навантаження на амплітудні та енергетичні параметри сигналів акустичної емісії при руйнуванні композиційних матеріалів поперечною силою / С.Ф. Філоненко, О.П. Космач, Т.М.Косицька // Техологические системы. – 2012. – №1 (58). – С. 46–51.

Filonenko, S.F.; Kosmach, O.P.; Kositskaya, T.M. 2012. *Effect of loading rate on the amplitude and energy parameters of acoustic emission signals in the destruction of composite shear force*. Technological systems. – N 1(58): 46–51.

13. *Філоненко С.Ф.* Закономірності зміни часових параметрів сигналів акустичної емісії при руйнуванні композиційного матеріалу / *С.Ф. Філоненко, О.П.Космач* // Вісн. Чернігів. держ. технол. ун.–2012. – № 2(57); 114–122.

Filonenko, S.F.; Kosmach, O.P. 2012. *Laws of change of time signal parameters of acoustic emission at destruction of composite material*. Proceedings of Chernihiv state technological university. – N 2(57): 114–122.

14. *Філоненко С.Ф.* Закономірності зміни амплітудно-енергетичних параметрів сигналів акустичної емісії при зміні розмірів елементів композиційного матеріалу / *С.Ф. Філоненко, О.П.Космач* // Вісник НАУ. – 2012. – №4. – С. 66–73.

Filonenko, S.F.; Kosmach, O.P. 2012. *Laws of change in amplitude and energy parameters of acoustic emission signals at change of dimensions of the composite material*. Proceedings of National aviation university. – N 4: 66–73.

15. *Ибатуллин И.Д.* Кинетика усталостной повреждаемости и разрушения поверхностных слоев / *И.Д. Ибатуллин* // Самара: Самарский государственный технологический университет, 2008. –387 с.

Ibatullin I.D. 2008. *Kinetics of fatigue failure rate and destruction of surface layers*. Samara: Samara state technological university press. – 387 p.

16. Braun, O.M.; Manini, N.; Tosatti, E. 2008. *Role of lubricant molecular shape in microscopic friction.* Physical review. – Vol. 78: 195402-1–195402-10.

17. Braun, O.M.; Tosatti, E. 2011. *Kinetics and dynamics of frictional stick-slip in mesoscopic boundary lubrication*. Philosophical magazine. – Vol. 91: 3253–3275.

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## ЗАКОНОМЕРНОСТИ АКУСТИЧЕСКОГО ИЗЛУЧЕНИЯ ПРИ ВОЗРАСТАНИИ НАГРУЗКИ НА ПАРУ ТРЕНИЯ ИЗ КОМПОЗИЦИОННОГО МАТЕРИАЛА

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*Рассмотрены результаты моделирования акустического излучения при возрастании осевой нагрузки на пару трения из композиционного материала. Показано, что увеличение осевой нагрузки приводит к возрастанию амплитудных и энергетических параметров результирующих сигналов акустической эмиссии. Определены зависимости процентного прироста амплитудных и энергетических параметров результирующих сигналов акустической эмиссии. Описано, что при увеличении осевой нагрузки на пару трения возрастание среднего уровня амплитуды опережает возрастание его стандартного отклонения и дисперсии. Рассмотрен наиболее чувствительный параметр к увеличения осевой нагрузки на пару трения – дисперсия среднего уровня энергии результирующих сигналов акустической эмиссии.*

**Ключевые слова**: акустическая эмиссия, амплітуда, закономерность, композиционный матеріал, загрузка, параметр, прирост, сигнал, трение, уровень, энергия.

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## REGULARITY OF ACOUSTIC RADIATION AT ASCENDING LOAD ON A PAIR OF FRICTION FROM A COMPOSITE MATERIAL

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*The outcomes of simulation of acoustic radiation are reviewed at ascending thrust load on a pair of friction from a composite material. Is shown, that the increase of thrust load results in ascending amplitude and energy parameters of acoustic emission resultant signals. The relations of a percentage increment amplitude and energy parameters of acoustic emission resultant signals are determined. Is shown, that at increase of thrust load at a pair of friction the ascending of an average level of amplitude advances ascending its standard deviation and dispersions. Is determined, that most sensing parameter to increase of thrust load at a pair of friction is the dispersion of average level of energy of acoustic emission resultant signals.*
**Keywords**: acoustic emission, amplitude, composite material, energy, friction, increment, law, level, load, parameter, signal, variation.

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## ЗАКОНОМІРНОСТІ АКУСТИЧНОГО ВИПРОМІНЮВАННЯ У РАЗІ ЗРОСТАННЯ НАВАНТАЖЕННЯ НА ПАРУ ТЕРТЯ З КОМПОЗИЦІЙНОГО МАТЕРІАЛУ

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Проведено моделювання результуючих сигналів акустичної емісії, які виникають в умовах тертя поверхонь із композиційних матеріалів, а також зі зростанням навантаження, яке сприймає досліджувана пара тертя. Результати досліджень показали, що збільшення осьового навантаження приводить до зростання амплітудних параметрів результуючих сигналів акустичної емісії, таких як середнього рівня амплітуди, його стандартного відхилення і дисперсії. Отримано основні закономірності зміни амплітудних параметрів формованих сигналів. Установлено, що залежності зміни відсоткового приросту середнього рівня амплітуди, його стандартного відхилення і дисперсії мають однотипний характер, що добре описуються лінійними функціями. Результати досліджень показують, що зі зростанням осьового навантаження найбільший відсотковий приріст значень має середній рівень амплітуди результуючих сигналів акустичної емісії.

Також був проведений аналіз енергетичних параметрів акустичного випромінювання зі зростанням осьового навантаження на пару тертя із композиційного матеріалу. Результати моделювання показали, що відсотковий приріст середнього рівня енергії і його стандартного відхилення також описуються лінійними функціями. В той же час найбільший відсотковий приріст зі зростанням осьового навантаження на пару тертя спостерігається в дисперсії середнього рівня енергії результуючих сигналів акустичної емісії.

Результати досліджень показали, що під час експериментального дослідження сигналів акустичної емісії зі збільшенням осьового навантаження на пару тертя з композиційних матеріалів найбільшого зростання слід очікувати в середньому рівні амплітуди результуючих сигналів акустичної емісії. При цьому зростання його стандартного відхилення і дисперсії буде незначним. Найбільшого зростання слід очікувати і в дисперсії середнього рівня енергії сигналів акустичної емісії.

**Ключові слова**: акустична емісія, амплітуда, енергія, закономірність, композиційний матеріал, навантаження, параметр, приріст, тертя, рівень, сигнал.

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## ЗАКОНОМЕРНОСТИ АКУСТИЧЕСКОГО ИЗЛУЧЕНИЯ ПРИ ВОЗРАСТАНИИ НАГРУЗКИ НА ПАРУ ТРЕНИЯ ИЗ КОМПОЗИЦИОННОГО МАТЕРИАЛА

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Проведено моделирование результирующих сигналов акустической эмиссии, возникающих при трении поверхностей из композиционных материалов, а также при возрастании нагрузки, которую воспринимает исследуемая пара трения. Результаты исследований показали, что возрастание осевой нагрузки приводит к росту амплитудных параметров результирующих сигналов акустической эмиссии, таких как среднего уровня амплитуды, его стандартного отклонения и дисперсии. При этом были получены основные закономерности изменения амплитудных параметров формируемых сигналов. Установлено, что зависимости изменения процентного прироста среднего уровня амплитуды, его стандартного отклонения и дисперсии имеют однотипный характер, при этом хорошо описываются линейными функциями. Результаты исследований показывают, что при росте осевой нагрузки самый процентный прирост значений имеет средний уровень амплитуды результирующих сигналов акустической эмиссии.

Выполнен анализ энергетических параметров акустического излучения при росте осевой нагрузки на пару трения из композиционных материалов. Результаты моделирования показали, что процентный прирост среднего уровня энергии и ее стандартного отклонения также описываются линейными функциями. Наибольший процентный прирост с ростом осевой нагрузки на пару трения наблюдается в дисперсии среднего уровня энергии результирующих сигналов акустической эмиссии.

Результаты исследований показали, что при экспериментальном исследовании сигналов акустической эмиссии с ростом осевой нагрузки на пару трения с композиционных материалов наибольшего роста следует ожидать в среднем уровне амплитуды результирующих сигналов акустической эмиссии. При этом рост его стандартного отклонения и дисперсии будет не значительным. Наибольшего роста следует ожидать и в дисперсии среднего уровня энергии сигналов акустической эмиссии.

**Ключевые слова**: акустическая эмиссия, амплітуда, закономерность, композиционный матеріал, загрузка, параметр, прирост, сигнал, трение, уровень, энергия.

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## REGULARITY OF ACOUSTIC RADIATION AT ASCENDING LOAD ON A PAIR OF FRICTION FROM COMPOSITE MATERIAL

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In this article the simulation the results of acoustic emission signals formed by friction surfaces with composite materials at load increasing were showed. The results showed that at increase of axial load increases the amplitude of the resulting parameters of acoustic emission signals, such as the average amplitude, its standard deviation and variance. Thus were obtained the basic changes of amplitude parameters generated signals. Was determined that the variation of the percentage increase in the average amplitude, its standard deviation and variance were the same type of character, with well approximate by linear functions. The results showed that with growing of axial load the percent increase in average amplitude of the resulting acoustic emission signals.

Also, an analysis of the energy parameters of acoustic emission with increasing axial load on the friction pair with composite materials was conducted. The simulation results showed that the percentage increase in the average level of energy and its standard deviation are approximate by linear functions. At the same time the greatest percentage increase with increasing axial load on the friction pair is observed in the dispersion of the average energy of the resulting acoustic emission signals.

The results showed that at experimental study of the acoustic emission signals with increasing axial load on the friction pair with composite materials greatest growth is expected in the average amplitude of the resulting AE signals. The growth of its standard deviation and variance will be not significant. At the same time, the greatest growth is expected in the dispersion of the average energy of acoustic emission signals.

**Keywords**: acoustic emission, amplitude, composite material, energy, friction, increment, law, level, load, parameter, signal, variation.