INFORMATION AND DIAGNOSTICS SYSTEMS

UDC 621.891:621.316.

Sergey F. Filonenko, D. E., Prof.
Angelika P. Stakhova, post-graduate student
Tatiana M. Kositskaya, Candidate of Engineering, Sn. Researcher

MODELLING OF ACOUSTIC EMISSION SIGNALS FOR THE CASE OF MATERIAL SURFACE LAYERS DISTRACTION IN THE PROCESS OF FRICTION

The obtained data of the resulting acoustic signals emission at the prevailing mechanism of the material surface layer wear under friction have been considered. It has been shown that the form and parameters of the acoustic emission resulting signals depend on the time of the initiation of type-I or type-II secondary structures fracture (rotation velocity of friction pair), as well as the stressed-deformed state of the materials' surface layers of friction pairs.

Розглянуто результати моделювання результуючих сигналів акустичної емісії при переважаючому механізмі нормального зношування поверхневих шарів матеріалів пар тертя. Показано, що форма та параметри результуючих сигналів акустичної емісії залежать від часу початку руйнування вторинних структур I або II типів (швидкості обертання пари тертя), а також напружено-деформованого стану поверхневих шарів матеріалів пари тертя.

Introduction

Two principal approaches – stohastical and physical – are used for the description of the acoustic emission (AE) signals [1]. In the first case, physical processes in the material structure are not considered, but the resulting signal is regarded as a sum of random pulses flow with a known shape, a random amplitude and time. The acoustic emission signals modeling in the second case is based on the account of real physical processes and of existing concepts on mechanisms of deformation and destruction of the materials [2; 3; 4].

Undoubtedly the second approach has advantages as it permits to take into account different factors, having influence on the processes of AE signals under conditions of static and dynamic forms of materials load. The resulting AE signal modeling at the wear of material surface layers, which is represented as a sum of two components has been designed in [5].

Signals, formed into random time moments at the fracture of type I secondary structures, and signals, formed into random time at the fracture of the type II secondary structures

$$U'(t) = \sum_i U_T(t - t_i) + \sum_j U_d(t - t_j), \qquad (1)$$

where

t_i, t_j is random time moments of the appearance of AE signals $U_T(t)$ and $U_d(t)$ at the fracture of the type I and II secondary structures, accordingly.

Taking into account the AE signals' models $U_T(t)$ and $U_d(t)$ at the fracture of the type I and type II secondary structures, given in the work [6], the expression (1) will be

$$U'(t) = \sum_i U_0 \delta_0 \sigma_{0e}^3 e^{4z(t-t_i)} e^{-b\sigma_{0e} e^{z(t-t_i)}} +$$

$$+ \sum_j U_{0d} \varepsilon_{0d} e^{r(t-t_j)} e^{-B\varepsilon_{0d} e^{r(t-t_j)}}, \qquad (2)$$

where

U_0 is maximum possible displacement at the fracture without dispersive by strength of the material's surface layer S_T;

$U_0 = kN_0cz$;

k is coefficient of proportionality;

N_o is quantity of elementary volume in the region of discontinuity S_T;

t is time;

δ_0 is average disturbance duration at the fracture of the elementary volume;

$$\delta_0 = \int_{t-\delta/2}^{t+\delta/2} a(\tau)d\tau;$$

$\alpha(\tau)$ is function which determines the shape of the single disturbance pulse (the same for all elementary volumes);

σ_{0e} is initial equivalent stresses in the normal wear stage;

$z = E/\xi$;

E is modulus of elasticity;

ξ is coefficient of viscosity;
c, b are distribution coefficient of the elementary volume by strength (depended on physical-mechanical characteristics of the material);
U_{0d} is amplitude of the displacement which depends on physical-mechanical material's characteristics:

$$U_{0d} = a_0 M \frac{\upsilon_d}{\ell_0} \delta_d ;$$

a_o is amplitude of the single disturbance pulse when dislocation moving (it is constant and it does not depend on the deformation);
M, B, r are constants (depend on physical and mechanical material's characteristics);
υ_d is average velocity of dislocation motion (it is considered as constant);
ℓ_o is distance between two radiation acts of the single dislocation;
δ_d is average disturbance pulse duration:

$$\delta_d = \int_{t-\delta_1/2}^{t+\delta_1/2} a_1(\tau) d\tau ;$$

$a_1(\tau)$ is function which determines the shape of the disturbance pulse (it is constant);
ε_{0d} is initial relative deformation.

The AE signals' modeling, according to (2), produced in [5], under conditions of the existence of two wear's mechanisms, permitted to determine principal mechanisms of the transformation of the resulting signals' shape and parameters depending on the change of the initial fracture time of the type I and II secondary structures, as well as stressed – deformed state of the material's surface layers.

However, the materials, surface layers' wear of which occurs in the process of friction with a prevailing mechanism of the secondary structures' fracture, can be used in friction pairs.

For example, friction pairs in terms of ceramic materials.

In our work the AE signals' modeling will be carried out at a normal wear of the friction pair with a prevailing mechanism of the materials' surface layers fracture.

It will be shown that the time of the initiation of the secondary structures fracture of both the first and the second types as well the change of the stressed – deformed state leads to the shape transformation and to the change of the resulting AE signals' parameters.

It will be also shown that similar changes are conditioned by the overlap of the formed pulse signals and their compression in time.

The results of modeling

Above – mentioned processes of the materials' surface layers' wear of the friction pair can be developed at the prevailing mechanism – the fracture of the type I secondary structures or type II secondary structures. Moreover, according to (1), the contribution of the second component is not substantial. Under such conditions, proceeded from (2), let's write expressions for the resulting AE signals as follows:

– at a prevailing mechanism of the type I secondary structures' fracture

$$U_1'(t) = \sum_j U_{0d} \varepsilon_{0d} e^{r(t-t_j)} e^{-B\varepsilon_{0d} e^{r(t-t_j)}} . \quad (3)$$

– at a prevailing mechanism of the type II secondary structures' fracture

$$U_2'(t) = \sum_i U_0 \delta_0 \sigma_{0e}^3 e^{4z(t-t_i)} e^{-b\sigma_{0e} e^{z(t-t_i)}} . \quad (4)$$

Let's carry out the resulting AE signals' modeling at the prevailing mechanism of the development of the materials' surface layers fracture at a normal wear stage, according to the expressions (2) and (3). The modeling will be carried out in two stages, taking into account the effect of two components. At the first stage, when the stresses and deformations are constant we'll investigate the effect of the initiation of the secondary structures' fracture time, which is connected directly with the velocity of the friction pair rotation, upon the shape and parameters of the resulting AE signals. At the second stage, when the time of the initiation of the secondary structures' fracture is constant, we'll investigate the effect of the change of the stressed-deformed state in the shape and parameters of the resulting AE signals. We'll perform the modeling, taking into account conditions, both at the prevailing mechanism of the type I secondary structures' fracture and at the prevailing mechanism of the type II secondary structures' fracture, according to (3) and (4).

The results of the resulting AE signals' modeling in the first stage at the prevailing mechanism of the type I secondary structures' fracture, according to (3) and the type II secondary structures' fracture, according to (4), in the stage of the normal materials' surface layers' fracture of the friction pair are shown in fig.1 and 2.

The plots are presented in the form of the relation of

$$\widetilde{U}_1(t) = \frac{U_1'(t)}{U_{\max}}$$

and

$$\widetilde{U}_2(t) = \frac{U_2'(t)}{U_{\max}}$$

in relative units. When at plotting, the time is fixed for the time of the load effect on the friction pair, which sets up a magnitude $t_{\max}$. The plots in the fig.1 are obtained in the condition of the deformation constancy and time variation of the initiation of the type I secondary structures' fracture. The plots in fig. 2 are obtained at the stresses constancy and at the time variation of the initiation of the type II secondary structures' fracture.

The modeling was carried out according to the selected plan of the consequent fracture of the secondary structures. This plan was invariable both for the type I structures and type II structures.

When the AE signals' modeling for the type I secondary structures, at the first stage, it was accepted that $\varepsilon_{0d} = 17$, but a value $B = 10$. For this, an increment of the fracture time initiation of every consequent type I structure was changed from 0,01 to 0,006 relative units with a step of the decrease equal 0,002.

When modeling of the AE signals for the type II secondary structures, at the first stage, it was accepted that $\sigma_{0e} = 17$ and $b = 10$, but the increment in time of the fracture initiation of every consequent type II structure was changed from 0,01 to 0,006 relative units with a step of decrease equal 0,002.

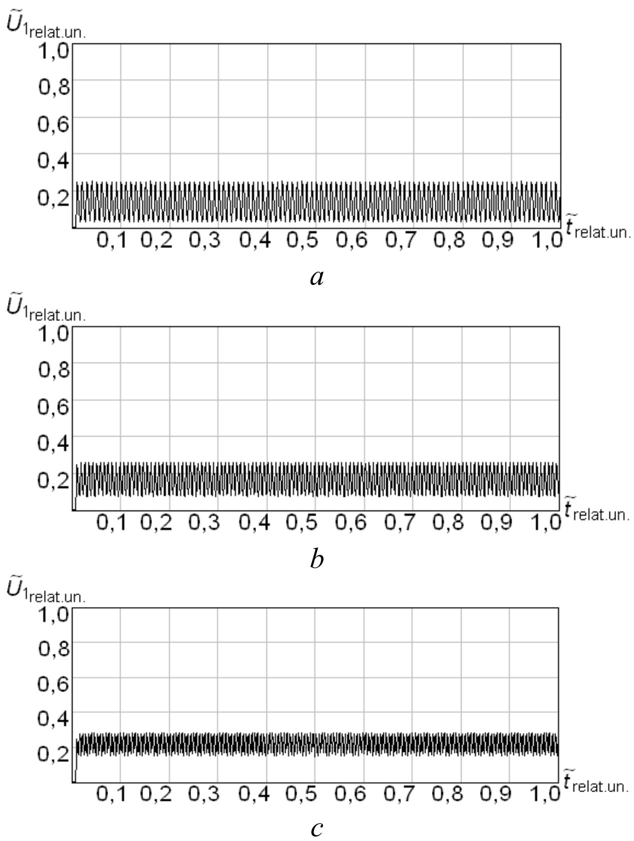


Fig. 1. The resulting AE signals at the stage of normal wear of the friction pair in the process of the type I secondary structures' fracture at the constancy of deformations and different times of the fracture' initiation ($\varepsilon_{0d} = 17$; $B = 10$; $\widetilde{U}_{relat.un.}$ is fixed value for $U_{\max}\widetilde{t}_{relat.un.}$ – a fixed value for $t_{\max}$ = const):

a – 0,01;
b – 0,008;
c – 0,006

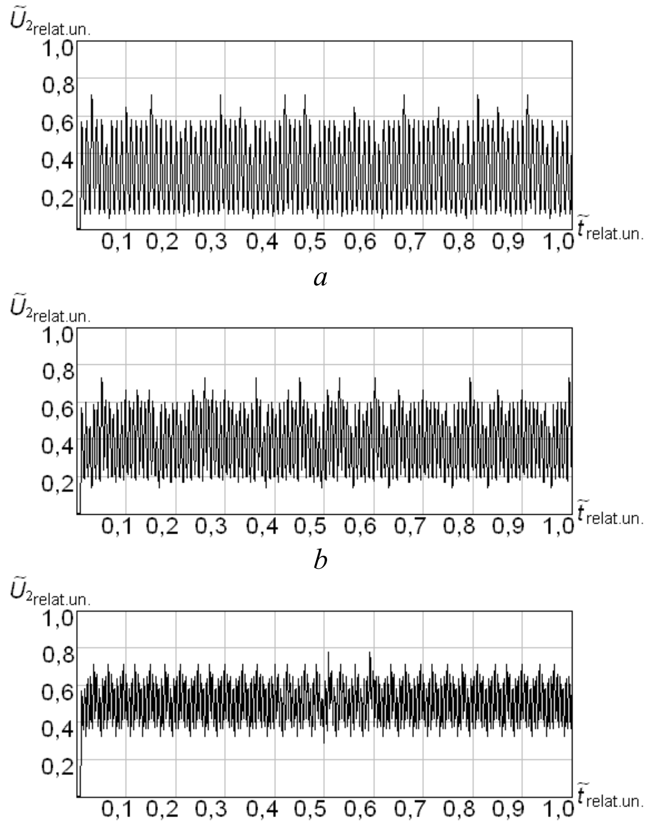


Fig. 2. The resulting AE signals at the stage of the normal wear of the friction pair at the fracture of the type II secondary structures at the constancy of stresses and different times of the fracture initiation: ($\sigma_{0e} = 17$; $b = 10$; $\widetilde{U}_{relat.un.}$ is a fixed value for $U_{\max}\widetilde{t}_{relat.un.}$ – fixed value for $t_{\max}$ = const):

a - 0,01;
b – 0,008;
c – 0,006

The results of the obtained modeling for the type I secondary structures (fig.1) point to the fact that at their consequent fracture the resulting signal represents continuous AE signal. For all this, with the decrease of the magnitude of the increment in time of the initiation of the type I secondary structures' fracture, it is observed the compression of the AE signal in time and its shape transformation. The plots (fig. 1) also show the spread decrease of the AE resulting signal's amplitude and the increase of its average value.

However, a given increase is not considerable. So, as the time interment value of the initiation of the type I secondary structures' fracture decreases from 0,01 (fig. 1, *a*) to 0,008 (fig.1, *b*), the average value of the resulting AE signal's amplitude increases in 3,3 %, but at the time increment value 0,006 (fig. 1, *c*) it increases in 18 % with respect to the time increment 0,01. Such change of the AE resulting signal's amplitude and the increase of its spread is conditioned by the following.

When modeling of the AE signals formed in the process of the plastic deformation's development [6; 7], it has been shown that their amplitude depends on the quantity of a mobile dislocation (material's volume that come into the deformation) and doesn't depend on the velocity of the deformation course. So, at the constant volume of the material, come into the plastic deformation, the AE signal's amplitude is a constant magnitude, but the change of the deformation velocity leads to the signal's compression. When modeling of the resulting AE signals, formed at a constant fracture of the type I secondary structures (fig. 1), it was supposed the volumes of the material, coming into the plastic deformation, to be invariable. It means that the amplitudes of the formed pulse signals are identical at the fracture of every secondary structures of the type I. However, as the researches showed, the increase of the resulting signal's amplitude occurs at the expense of the formed pulses' overlap in time (fig.3, *a*). The more amplitude increase, the more pulse signals' overlap (fig.3, *b*).

The decrease of the amplitude spread of the resulting signal at the decrease of the time of the type I secondary structures' fracture is also conditioned by the overlap of the formed pulse signals. Indeed, at the fracture of every type I secondary structure, the pulse signals are formed, a rear front of these signals changes according to the exponential law. If the overlap of the previous and following signals is not considerable, the lower level of the resulting signal is small (*A*, fig. 3, *a*). It leads to a big magnitude of the amplitude spread in the resulting signal.

If the overlap in time of the previous and following signals increases (the time decrease of the initiation of the type I secondary structures' fracture), the lower level of the resulting signal increases too (*B*, fig. 3, *b*).

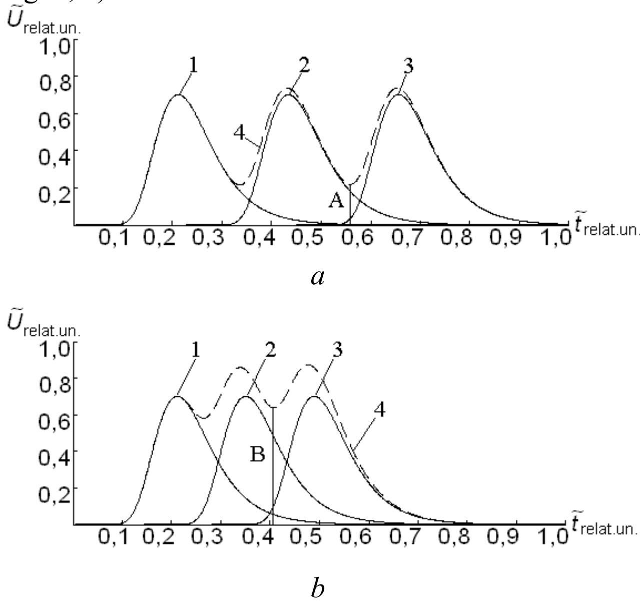


Fig. 3. Formation of the resulting AE signal at the type I secondary structures' fracture with a decrease of the time initiation of the fracture of every consequent structure:
1, *2*, *3* are pulse signals, formed at the consequent fracture of the type I secondary structures;
4 is resulting signal, which is formed

It must lead to the decrease of the spread in amplitude of the resulting signal, as we can see in the results of the modeling process (fig. 1).

From the results of the carried-out modeling for the type II secondary structures (fig. 2) one can see that the resulting AE signal also represents a continuous signal at their consequent fracture. For this, as in a previous case, the AE signal's compression in time and as well its shape's transformation are observed which a decrease of the magnitude of the increment in time of the initiation of the type II secondary structures' fracture. From the plots (fig. 2) one can see that the spread amplitude's decrease of the resulting AE signal and the increase of its average value. However, a given increase is more than the increase at the type I secondary structures' fracture. So, with the decrease of the magnitude of the increment in time of the initiation of the type-II secondary structures' fracture from 0,01 (fig.2, *a*) to 0,008 (fig.2, *b*), a mean value of the resulting AE signal's amplitude increases in 23,2 %. When the time increment's value is 0,006 (fig. 2, *c*) it increases in 65,2 % with respect to the time 0,01. Such change of the resulting AE signal's amplitude and the decrease of its spread are conditioned by the following.

When modeling of the AE signals, formed in the process of the brittle fracture development [7; 6] it was shown that at a constant area of the formed cracks, the AE signal's amplitude depends on the velocity of the cracks' increase (the magnitude of stresses). When the stress and area of the formed cracks are constant, the AE signal's amplitude is a constant magnitude, but the increases leads to the signal's compression and the increasing of its amplitude. When modeling of the resulting AE signals, formed at a consequent fracture of the type II secondary structures (fig. 2), the area of the fracture as well as an applied stress are supposed to be constant. It means that the amplitude of the formed pulse signals is identical at the fracture of every type II secondary structure. However, the increase of the mean value of the resulting signal's amplitude and the decrease of its spread's magnitude, as in a case of the type I secondary structures are conditioned by the pulses' overlap in time. When the resulting signal's modeling with analysis of the effect of the pulse signal's overlap it was obtained dependencies similar to fig.3. However, the increase of the amplitude is more considerable. This conditioned, that the signals amplitude from fracture of the type II secondary structures is more great then from fracture of the type I secondary structures. We can see it in the results of the modeling process (fig. 2).

The decrease of the amplitude spread of the resulting signal at the decrease of the time of the type II secondary structures' fracture, as soon as in the case of fracture the type II secondary structures, this is conditioned by the overlap of the formed pulse signals which leads to the increase of the lower signal's layer (fig. 3). It is observed in the modeling results (fig. 2).

At the second stage of the resulting AE signals' modeling during the secondary type I structures it was accepted that the magnitude of increment in time of the initiation of every consequent structure's fracture was constant and made 0,004 (in relative units), but the value $B = 10$. For all this, the value ε_{0d} varies from $\varepsilon_{0d} = 11$ to $\varepsilon_{0d} = 15$ (in non-dimensional quantity) with an increment step equal 2, i.e. modeling was carried out at the increase of the plastic deformation. When modeling of the second stage at the type II secondary structures' fracture, it was accepted that the time increment's magnitude at the ignition of every consequent type II structure was constant and made 0,004 (in relative units), but the value $b = 10$. For all this, the value σ_{0e} varied from $\sigma_{0e} = 11$ to $\sigma_{0e} = 15$ (in non-dimensional quantity) with an increment step, equal 2, i.e. the modeling was carried out at the increase of stresses.

At the second stage the results of the resulting AE signals modeling are shown in the form of variation's dependencies

$$\widetilde{U}_1(t) = \frac{U'_1(t)}{U_{\max}}$$

and

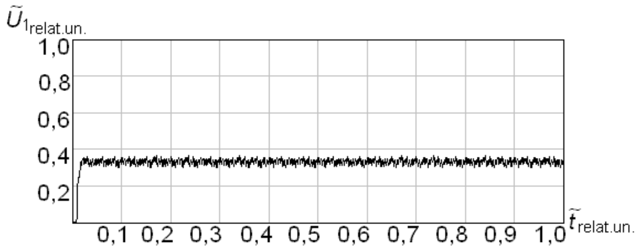
$$\widetilde{U}_2(t) = \frac{U'_2(t)}{U_{\max}}$$

in relative units (fig. 4 and 5). When plotting, the time is normalized on the time of effect of the load on a friction pair.

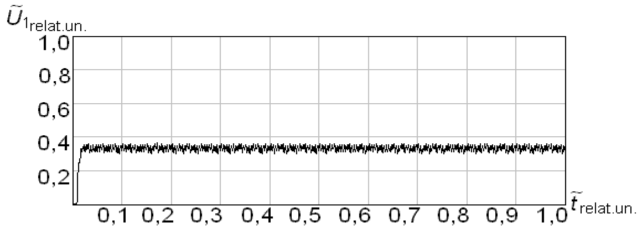
This time makes up the magnitude $t_{\max}$. The modeling, as at the first stage, was carried out according to a selected plan of a consequent fracture of the secondary structures which remained constant for both type I and type II structures.

From the results of the modeling for the secondary type I structures (fig. 4) one can see that at their consequent fracture the resulting signal represents continuous AE signal. For this, the resulting AE signals' amplitude for the taken modeling conditions, in comparison with the first stage, increased but its overshoot decreased. However, with the change of the plastic deformation's magnitude, the amplitude of the resulting AE signal changes a little enough. The result is natural and it is explained as follows.

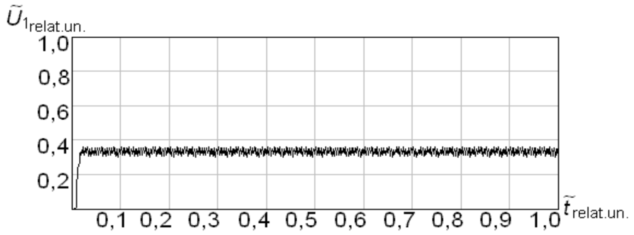
According to the data, than obtained on the first stage of the modeling, the increase of the resulting signal's amplitude and the decrease of its spread must be at the decrease of the magnitude of the time increment of the initiation of the secondary type I structures' fracture. It is observed in the resulting AE signal (fig. 4, *a*), where the magnitude of the time increment of the initiation of the secondary type I structures' fracture was taken equal 0,004. At the same time the increase of the value ε_{0d}, as shown in [6; 7], doesn't influence on the change of the pulse signals' amplitude, but leads to their stress. As it was shown by the data processing of the modeling at ε_{0d}=13, the value of the overage amplitude of the resulting AE signal with respect to ε_{0d} = 11, increased in 0,6% (fig.4, *b*) and at ε_{0d}=15 in 2 % (fig. 4, *c*).



a



b



c

Fig. 4. The resulting AE signals at the stage of the normal wear of a friction pair and at the fracture of the type I secondary structures on condition that the times of the initiation of the fracture of every consequent type I structure, in relative units, are constant and equal 0,004, and values of plastic deformation are different; $B = 10$. $\widetilde{U}_{relat.un.}$ is normalized value on $U_{\max}$ $\widetilde{t}_{relat.un.}$ - normalized value on $t_{\max} = \text{const}$:

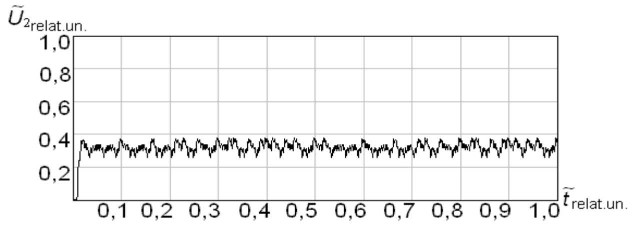
a – $\varepsilon_{0d} = 11$;

b – $\varepsilon_{0d} = 13$;

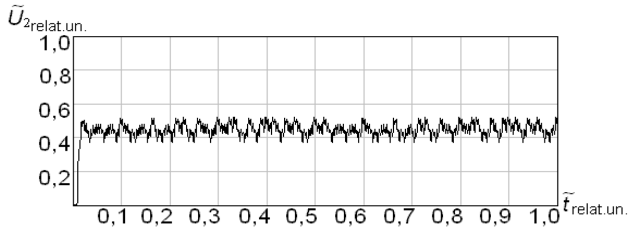
c – $\varepsilon_{0d} = 15$

For this, the amplitude spread increased in 4,4 % and 5,8%, accordingly. Such increase of the mean value of the resulting AE signal and the value of its spread is absolutely connected with the change of the temporary conditions of the pulse signal's overlap at the expense of their stress.

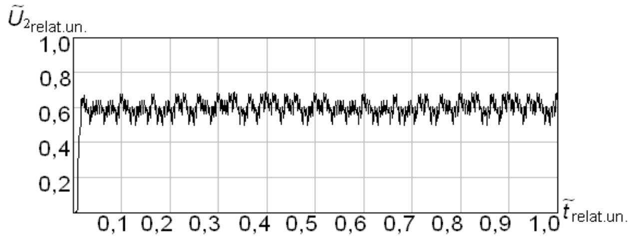
The results of the modeling at the secondary type II structures' fracture in the second stage (fig. 5) showed that the resulting AE signal represent an continuous signal at their consequent fracture. For this, at such conditions of the modeling, the resulting AE signal's amplitude increased in comparison with the first stage, but its spread decreased. However, the increase of the resulting AE signal's amplitude and the value of its spread are observed with the increase of the stress value.



a



b



c

Fig. 5. The resulting AE signals at the stage of the normal wear of a friction pair at the fracture of the type II secondary structures on condition that the times of the initiation of the fracture of every consequent type-II structure, in relative units, are constant and equal 0,004, and values of stresses are different; $B = 10$; $\widetilde{U}_{relat.un.}$ is normalized value on $U_{\max}$ $\widetilde{t}_{relat.un.}$ - normalized value on $t_{\max} = \text{const}$:

a – $\sigma_{0e} = 11$;

b – $\sigma_{0e} = 13$;

c – $\sigma_{0e} = 15$

So, when σ_{0e}= 13, the value of the mean amplitude of the resulting AE signal, with respect to σ_{0e}=11, increased in 41% (fig. 5, *b*), and when σ_{0e}= 15 – in 86 % (fig. 5, *c*).

For this, the amplitude's spread increased in 19 % and 36,7 %, accordingly. Such increase of the main value of the resulting AE signal's amplitude and the value of its spread are conditioned by the following.

According to the data obtained on the first modeling stage, the increase of the resulting signal's amplitude and the decrease of its spread must be with the decrease of the value of the time increment of the initiation of the secondary type II structures' fracture. It is observed in the resulting AE signal (fig. 5, *a*), where the value of the time increment of the initiation of the type II secondary structures' fracture was taken equal to 0,004. At the same time, the increase of the value σ_{0e}, as shown in [6; 7], leads to the increase of the pulse AE signal's amplitude and its compression in time. Such change of the pulse signals' parameters, undoubtedly, leads to the change of their temporary overlap's conditions. In the first place, it concerns to the pulse signals' compression. In accordance with fig. 3, such change of the temporary conditions of the overlap leads to the increase of the mean amplitude of the resulting signal and the increase of its spread.

Conclusion

The results of the given modeling showed that the resulting AE signals, formed at the prevailing mechanism of the normal wear of the surface layers of friction pairs, represent continuous signals. At the constant stressed-deformed state with the time decrease of the initiation of the secondary structures' fracture, the character of the resulting AE signals' shape transformation and the change of their parameters for both the type I and type II structures have common natural results. It is observed the increase of the mean amplitude of the resulting AE signal and the decrease of its spread value. However, for the type II structures the data of the change are more expressed. At the constant time of the initiation of the secondary structures' fracture with the increase of the stressed-deformed state, the character of the transformation of the resulting AE signal's shape and the change of their parameters for both type I structures and type II structures have common natural results. However, with respect to the previous conditions of the modeling, they have differences. The increase of the mean amplitude of the resulting AE signals and the increase of its spread's value are observed. For this, the data of the change for the type II structures are more expressed. The presence of similar mechanisms, as the researches showed, is conditioned by the change of it conditions of the overlap in time of the pulse AE signals, formed at the fracture of the elementary structures of types I and II. The mechanism of the shape's change and the pulse signals' parameters exert a considerable effect on given conditions at the time change of the initiation of the type I and II secondary structures fracture and stressed-deformed state of the material's surface layers of a friction pair.

References

1. *Филоненко С.Ф., Стахова А.П.* Моделирование сигналов акустической эмиссии при переходе от стадии нормального к стадии катастрофического изнашивания // Технологические системы. – 2007. – № 4 (40). – С. 41–47.

2. *Бернштейн М.Л., Займовский В.А.* Структура и механические свойства металлов. – М: Металлургия, 1970. – 472 с.

3. *Хирт Д., Лоте И.* Теория дислокаций. – М.: Атомиздат, 1972. – 600 с.

4. *Крагельский И.В. Добычин М.Н., Комбалов В.С.* Основы расчетов на трение и износ. – М.: Машиностроение, 1977. – 526 с.

5. *Babak V.P., Filonenko S.F., Stadnychenko V.M., Stakhova A.P.* The acoustic emission signals modelling at friction of materials' surface layers //Wear (London, UK). – in printing.

6. *Бабак В.П., Філоненко С.Ф., Стадниченко В.М., Стахова А.П.* Моделі сигналів акустичної емісії при руйнуванні поверхневих шарів пар тертя // Проблеми тертя та зношування. – 2007. Вип.47.– С 3–8.

7. *Бабак В.П., Филоненко С.Ф., Калита В.М.* Модели формирования сигналов акустической эмиссии при деформировании и разрушении материалов // Технологические системы. – 2002. – № 1 (12). – С. 26–34.

The editors received the article on 6 June 2008.