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# INFORMATIVE PROPERTIES OF THE ENVELOPE OF THE MAGNETOELASTIC ACOUSTIC EMISSION SIGNAL

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Parameters of the envelope of the magnetoelastic acoustic emission signal are proposed to be used as informative ones. To study the properties of the envelope of the signal, the steel St.3 and nickel specimens are investigated. The signal envelopes for a number of values of the amplitude of the remagnetizing field induction are estimated by several implementations. It is shown that the shape and duration of the envelope of the magnetoelastic acoustic emission signal depends on the amplitude of the remagnetization field induction, which requires ensuring their stability when using the parameters of the envelope as informative by diagnosing ferromagnetic objects. To test the new informative parameter, uniaxial tensile stresses were applied to the nickel and steel specimens of the same size and shape (for nickel the stresses were changed from 0 to 110 MPa, for steel – to 280 MPa), the specimens were remagnetized with the outside field and the magnetoelastic acoustic emission signals were recorded. Estimates of the signals envelope for different values of the applied load are found. The dependences of duration of the magnetoelastic acoustic emission signals on the magnitude of the applied stresses, which can be used as calibration curves for diagnosing residual stresses in ferromagnetic objects of long-term operation, are constructed.

**Keywords***: magnetoelastic acoustic emission, magnetic field, envelope of the signal, residual stress.*

# ІНФОРМАТИВНІ ВЛАСТИВОСТІ ОГИНАЛЬНОЇ СИГНАЛУ МАГНЕТОПРУЖНОЇ АКУСТИЧНОЇ ЕМІСІЇ

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Запропоновано як інформативні використовувати параметри огинальної сигналу магнетопружної акустичної емісії. Оцінку огинальної знайдено за алгоритмами ковзного середнього та середньоквадратичного. Для зменшення дисперсії оцінки огинальної її усереднювали за кількістю зареєстрованих у результаті експерименту вибірок. Для вивчення інформативних властивостей огинальної сигналу виконано експериментальні дослідження на сталевому (Ст.3) та ніколовому зразках. Збуджували магнетопружну акустичну емісію синусоїдальним сигналом з частотою 9 Гц, використовуючи накладний електромагнет. За декількома реалізаціями оцінено огинальні сигналу для низки значень амплітуди індукції перемагнечувального поля. Виявлено, що форма (один пік для ніколового, два – для сталевого зразків) та тривалість огинальної сигналу магнетопружної акустичної емісії залежать від амплітуди індукції поля перемагнечення, тому слід забезпечити їх стабільність під час використання параметрів огинальної як інформативних для діагностування феромагнетних об'єктів. Для апробації нового інформативного параметра до ніколового та сталевого зразків однакових розміру та форми прикладали зусилля одновісного розтягу (для ніколу напруження змінювали від 0 до 110 МПа, для сталі – до 280 МПа), перемагнечували їх зовнішнім полем та реєстрували сигнали магнетопружної акустичної емісії. Знайдено оцінки огинальних сигналів для різних значень прикладеного навантаження. Побудовано залежності тривалості сигналів магнетопружної емісії від прикладених напружень, які можна використовувати як градуювальні криві для діагностування залишкових напружень у феромагнетних об'єктах тривалої експлуатації. Вони стійкі до низки експериментальних чинників (якості контакту перетворювача акустичної емісії з поверхнею об'єкта, його діаграми напрямленості, коефіцієнта підсилення сигналу), які впливають на амплітудні характеристики сигналу.

**Ключові слова:** с*игнал магнетопружної акустичної емісії, магнетне поле, огинальна сигналу, залишкові напруження.*

The high sensitivity of the magnetoelastic acoustic emission (MAE) signal parameters to structural changes in the material of a ferromagnetic object (plastic deformation, residual stresses, hydrogen, etc.) has been established [1–8]. This necessitated the development and implementation of the MAE method as a potentially effective means of non-destructive testing.

From the literature review it follows that, as a rule, such informative parameters of the MAE signal as the sum of the amplitudes of the signal pulses and the final count are used [8]. When interpreting the MAE signal as a pulsed random process [9, 10], one can additionally use and estimate statistical characteristics, namely, the shape, parameters, moments, and entropy of the amplitude and time distribution of a random pulse stream.

In addition to the traditional parameters of the MAE signal, an important characteristic is the envelope of the MAE signal, in particular of its shape and duration.

The estimate of the envelope by the simple moving average is found by formula [11]:

$$\hat{s}_j(k) = \frac{1}{N}\sum_{i=0}^{N-1}\left|s_j(k+i)\right| . \tag{1}$$

Here, $|s(i)|$ is the module of the *i*-th sample signal, *N* is the number of the samples signal that are averaged (width of the averaging window), $\hat{s}(k)$ is the *k*-th value of the envelope estimate.

In order to reduce the variance of the envelope estimate, it is also averaged by the number of samples M, registered as a result of the experiment:

$$\hat{s}_a(k) = \frac{1}{M}\sum_{j=1}^{M}\frac{1}{N}\sum_{i=0}^{N-1}\left|s_j(k+i)\right| . \tag{2}$$

Estimation of the envelope by the algorithm of the moving root mean square is carried out by the formula:

$$\hat{s}_j(k) = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1}s_j^2(k+i)} , \tag{3}$$

for *M* samples:

$$\hat{s}_a(k) = \frac{1}{M}\sum_{j=1}^{M}\sqrt{\frac{1}{N}\sum_{i=0}^{N-1}s_j^2(k+i)} . \tag{4}$$

Here, $s^2(i)$ is the square of the *i*-th sample signal. The variance of the estimates (2) and (4) averaged by the number of the samples *M* decreases and is equal to:

$$D_{\hat{s}_a(k)} = \frac{1}{M}D_{\hat{s}_j(k)} . \tag{5}$$

**Dependence of the shape and duration of the MAE signal on the amplitude of the remagnetization field induction**. The regularities of the process of magnetization of ferromagnetic materials are graphically represented in the form of a magnetization curve that shows the dependence of the induction *B* amplitude on the magnetic field strength *H*. Under the conditions of cyclic changes in the external magnetic field, we get a symmetric hysteresis loop. The loop for which the state of technical saturation is attained is called boundary and all other loops located inside it are called partial loops [2].

The platelike specimens of nickel and St.3 steel were made for research. Remagnetization was with the help of a sinusoidal signal with a frequency of 9 Hz by using an attached electromagnet [8] for several values of the magnetic field induction amplitude corresponding to several partial hysteresis loops.

The influence of the amplitude of the remagnetization field induction *B* on the shape and duration of the MAE signals was established. In Fig. 1 the enveloping curves of the MAE signals for nickel (*a–c*) and St.3 steel (*d–e*) specimens recorded for the ascending branch of the remagnetization loop are shown. The enveloping curves of the MAE for the nickel specimen have a single peak, the shape of which becomes narrower and increases in amplitude as the parameter *B* increases. The enveloping curves of the MAE for the steel specimen have two peaks, the amplitude of which increases with increasing *B* and they are located closer to each other due to the decrease in the duration of the MAE signals.

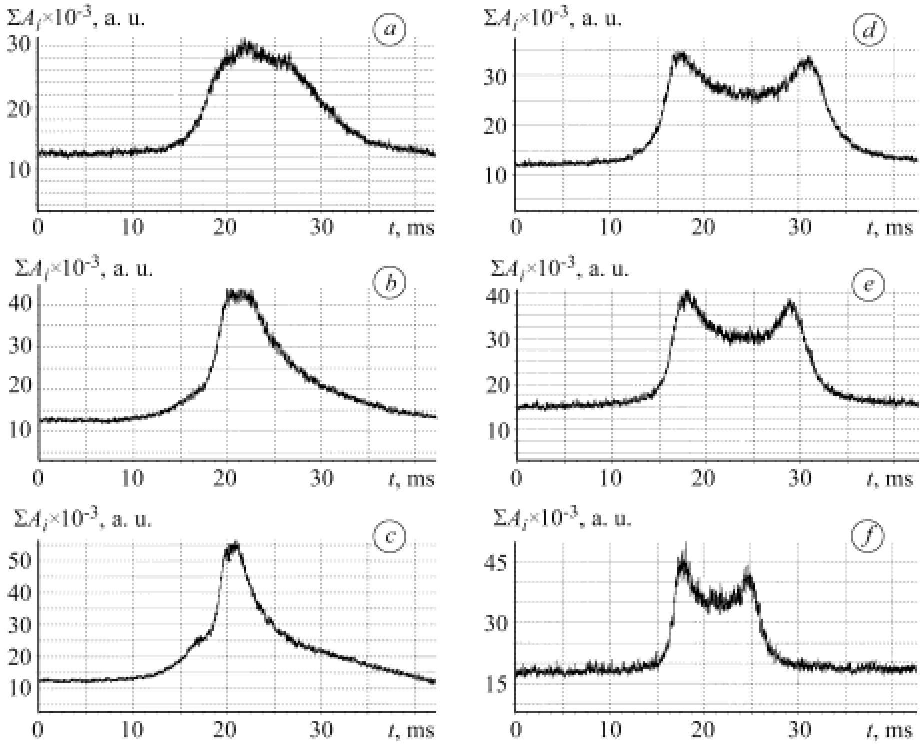


Fig 1. Enveloping curves of the MAE signals: *a–c* – nickel plate ($B$ = 0.29 T; 0.48 T; 0.60 T); *d–f* – steel plate ($B$ = 0.72 T; 1.22 T; 1.84 T).

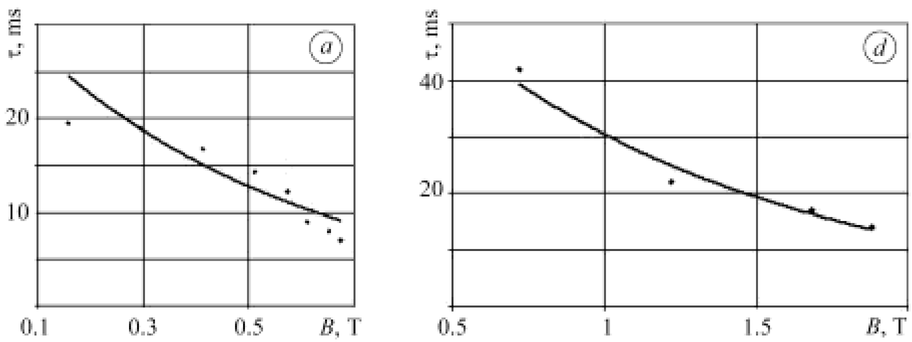


Fig 2. Dependences of the MAE signals duration τ on the amplitude of induction of the remagnetization field *B*: *a* – nickel plate; *b* – steel plate.

For nickel and steel specimens it was experimentally confirmed that the duration of magnetoelastic acoustic emission signals decreases with increasing magnitude of the remagnetization field induction (Figs. 2*a*, *b*).

It also follows from the obtained experimental results that the sum of the MAE signals amplitudes increases almost linearly with increasing amplitude of the remagnetization field induction (Figs. 3*a, b*).

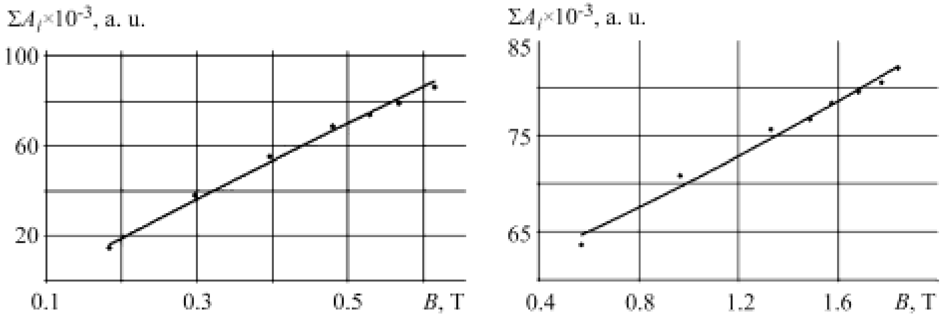


Fig 3. Dependences of the sum of amplitudes of the MAE signals on the amplitude of induction of the remagnetization field *B*: *a* – nickel plate; *b* – steel plate.

The observed behavior of the MAE signal parameters is explained by the fact that, as the amplitude of induction of the field increases, the rate of its changes in the course of the remagnetization of ferromagnetic material becomes higher and, hence, the intensity of jumps of the domain walls increases.

Based on the research results it was concluded that to ensure comparability of the results of diagnosing objects made of ferromagnetic materials by the MAE method, it is necessary to create the same conditions for each individual diagnostic experiment. In particular, it is important to ensure the constancy (stability) of the amplitude of the remagnetizing field induction.

**Estimation of the stress state of ferromagnetic materials.** The formation of a domain structure is energetically beneficial for ferromagnetic materials in the case of the absence of external magnetic fields. The boundaries between the magnetic domains are at rest, and the magnetization of the whole specimen is zero. Under the action of the applied external magnetic field, the equilibrium is disturbed, as a consequence, there is an abrupt movement of the 90°-th domain walls, which causes the appearance of the MAE signals [1–3]. The applied force load to the investigated specimen causes deformation of the crystal lattice and rearrangement of the domain structure.

The experimental platelike specimens of the same size of nickel and steel 19G were made for research. Uniaxial tensile loads were applied to the specimens (for nickel the tension σ being changed from 0 till 110 MPa, for steel – till 280 MPa), and the specimens were remagnetized with the outside field, the MAE signals being registered. According to the obtained results, the dependences of the MAE signals sum on the induction amplitude of the remagnetized field *B* are constructed (Fig. 4). When the amplitude of the magnetic field induction *B* is a constant and the applied voltages increase, one observes a decrease in the sum of the amplitudes for both samples.

The features of the envelope shape and the dependence of the MAE signal duration on the applied external load and the amplitude of the remagnetization field induction are studied (Figs. 5–7). When σ and B are increased, the change of the envelope shape is noticed (one sharp clear peak is formed in the nickel and two peaks in the steel specimens) as well as a sufficient decrease of the amplitude and the MAE signals duration.

The outside mechanic stresses, applied to the investigated ferromagnetic samples, cause the change in the magnetic structure. The magnetic-elastic energy under stresses is proportional to $\lambda\sigma\sin^2\alpha$, where $\lambda$ is the magnetostriction constant, $\alpha$ is the angle between the directions of the magnetization vector $\overrightarrow{M}$ and the applied stresses to the control object $\sigma$. The influence of these stresses causes the turning $\overrightarrow{M}$ parallel towards the direction $\sigma$ for minimizing the magnetic-elastic energy.

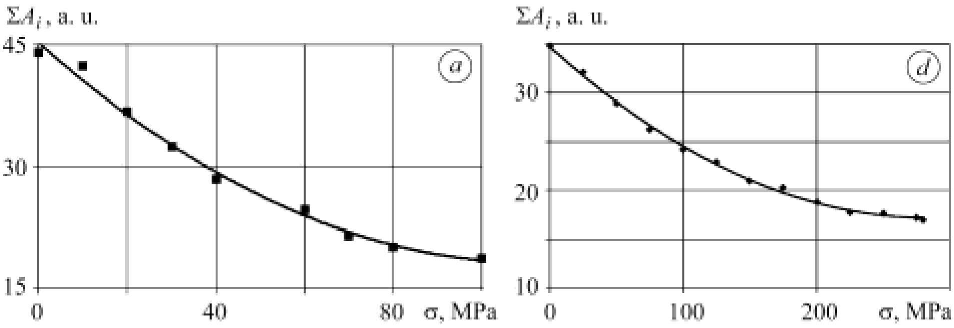


Fig 4. Dependence of amplitudes sum of the MAE signals on stresses caused by an external load: *a* – nickel plate ($B$ = 0.35 T); *b* – 19G steel plate ($B$ = 1.28 T).

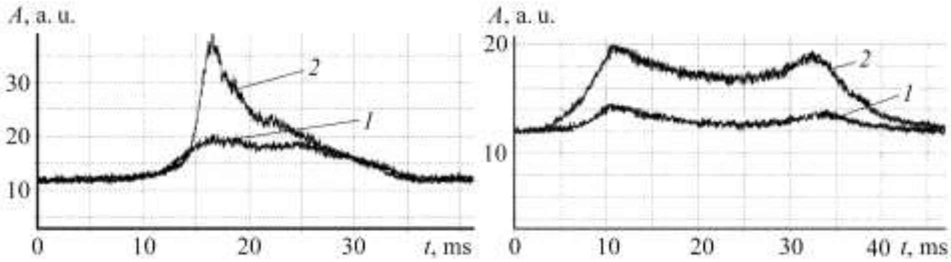


Fig 5. Features of the MAE envelope shape vs. changes of the amplitude of the magnetizing field induction $B$ and $\sigma$ = 0: *a* – nickel specimen (*1* – 0.2 T, *2* – 0.35 T); *b* – steel specimen (*1* – 1.08 T, *2* – 1.8 T).

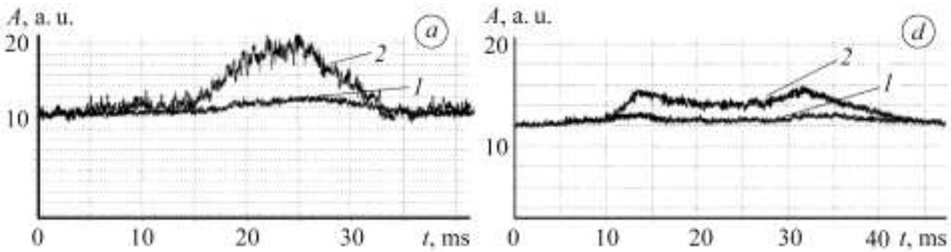


Fig 6. Features of the MAE envelope shape vs. changes of the amplitude of the magnetizing field induction $B$: *a* – nickel specimen ($\sigma$ = 110 MPa, *1* – 0.2 T, *2* – 0.35 T);
*b* – steel specimen ($\sigma$ = 175 MPa; *1* – 1.08 T, *2* – 1.8 T).

It causes the increase of the general area of the 180°-th domain walls in the material volume due to the decrease of areas of non-180°-th ones, and the decrease of the MAE signals amplitude [1]. Increase of the amplitude of the MAE signal, when the induction amplitude of the remagnetization field increases, can be explained by the improvement of intensity of the domain walls jumps.

It is obvious that the dependences of the MAE signals duration on the magnitude of the applied stresses (Fig. 7) can be used as calibration curves to diagnose residual stresses in ferromagnetic objects.

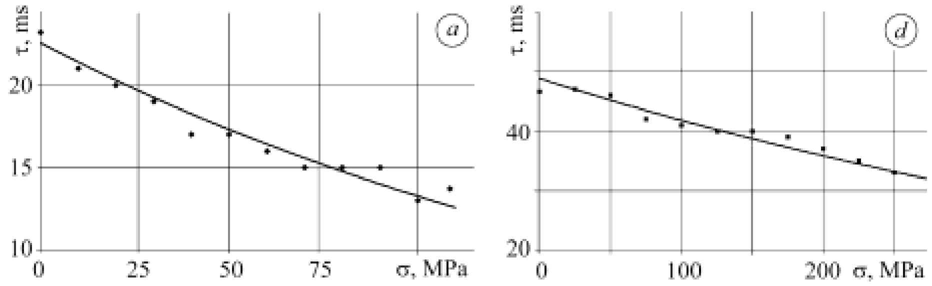


Fig 7. Dependence of the MAE signals duration on the applied stresses:
*a* – nickel specimen (*B* = 0.35 T); *b* – steel specimen (*B* = 1.8 T).

## CONCLUSIONS

The investigations shown that the MAE envelope is an important characteristic, in particular, its duration can be used as an informative parameter when diagnosing the ferromagnetic objects. Estimates of the envelope of the MAE signals for different values of the applied load were found for the platelike steel and nickel specimens subjected to tensile loading. The dependences of the MAE signal duration on the magnitude of the applied stresses, which can be used as calibration curves for diagnosing residual stresses in ferromagnetic objects of long-term operation, are constructed.


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