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Features of Noise Filtering During Acoustic Emission Testing

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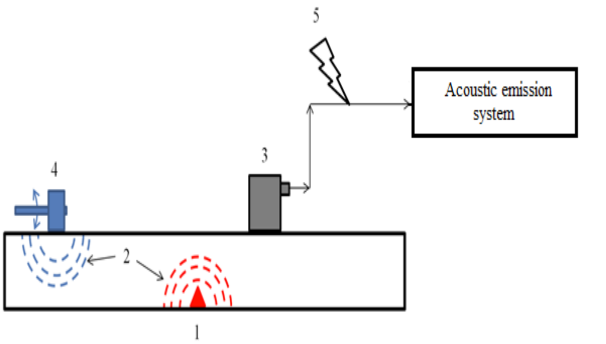
***Abstract:** This article discusses the problems of the acoustic emission method of non-destructive testing. An approach to filtering noise arising from monitoring of acoustic emission is considered. The filtering of acoustic noise is one of the key problems of the acoustic emission method, since the low noise immunity of the acoustic emission method prevents the expansion of its industrial application. The complexity of the filtering is explained by the fact that the waveform and spectrum of acoustic emission pulses change depending on the distance between the defect, which is the source of acoustic emission waves, and the sensor. In turn, the interference, as a rule, is non-stationary in nature and is determined by the type of technological process of the tested composition. This article discusses various types of noise processes, both stationary and non-stationary. The signal and noise parameters are compared, based on which recommendations are given for constructing algorithms for detecting acoustic emission pulses against a background of noise.*

***Keywords**: Acoustic emission, noise filtering, friction noise filtering*

I. INTRODUCTION

Acoustic emission is a physical phenomenon consisting in the generation of elastic waves during the destruction of a material. One of the methods of non-destructive testing is based on the phenomenon of acoustic emission (AE). AE testing scheme is shown in Fig.1.



1 – AE source, 2- AE waves, 3 – sensor, 4 – noises, 5 – electrical interference

Fig.1 Scheme of acoustic emission testing

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The defect emits AE waves that propagate through the testing structure, which is used in this case as a waveguide. AE waves are measured by a sensor mounted on the surface of the testing structure and transduce into electrical signals. Acoustic emission testing allows to assess the hazard level of defects that are sources of acoustic emission. Hazard levels are rated on a categorical scale from one (minimum danger) to four (critical danger). The defect hazard level assessment is based, as a rule, on the values of the impulse amplitudes and acoustic emission activity — the number of AE impulses emitted per second. As a rule, impulses are observed against the noise background. The most widespread sources of the acoustic noises are friction, leakages and vibration. If the noise level is comparable with the amplitudes of AE impulses, error associated with the omission of a defect becomes possible. The application of the signal filtering methods allows to reduce the risk of the defect omission.

Acoustic noise filtering is actual problem, which is considered by several researchers. Classification of acoustic emission by the nature of noise and by the complexity of filtering was proposed in a paper [1], the authors consider various methods for filtering AE impulses such as wavelet filtering and optimal Wiener filtering. Wavelet transform is an effective method for filtering AE impulses, since the noise and impulse signals caused by the activity of defects correspond to different time scales and are localized in different wavelet decomposition coefficients. The efficiency of impulse signals detection using wavelet transform is shown in [2], the examples of successful application of wavelet filtering of AE impulses is shown in [3-4]. LMS filters [5] and morphological filters [6] are also used as methods for filtering of acoustic emission signals. To filtration the impulse noises with the waveform close to AE impulses the classification methods are used. The classification approach allows us to separate noise pulses and AE pulses using discrimination in the different classes. The examples of successful application of the classification approach are described in the papers [7-8].

The aim of this paper consists in the description of various types of noises and conducting a comparative analysis of noise and AE signals in order to determine possible approaches to the filtering methods. This study is a continuation of the previous stage, the results of which are described in [9], the filtering algorithm is considered taking into account the empirical model of the AE impulse, which was previously described.

II. ACOUSTIC EMISSION IMPULSE CHARACTERIZATION

In 90% of cases, acoustic emission (AE) testing is carried out on thin-walled objects with a wall thickness of 3–40 mm. This value is comparable with the lengths of acoustic waves, which at typical operating frequencies of AE sensors 30–500 kHz lies in the range from 5 to 170 mm. In this case, the pattern of propagation of acoustic waves varies significantly compared with the simplest case of infinite volume or half-space, which makes it impossible to use simple models based on volumetric longitudinal and transverse waves. For many applications, Lamb waves are able to give the best indication of wave propagation from a source whose distance from the sensor is larger than the thickness of the material. Lamb waves exist simultaneously in two modes, symmetric and anti-symmetric which propagate independently of each other. The Lamb waves tends to dispersive propagation mode when different frequency components of the signal propagate at different speeds and for this reason are recorded by an AE sensor with a spread of tens or hundreds of microseconds [10]

Figure 2 shows the signals and their wavelet spectrograms simulating the propagation of Lamb wave zero modes A_0 and S_0 for objects with different path length with help of modal analysis [11]. Figure 2 a, b shows, that with an increase in the path length, the signal duration increases due to a larger difference in the arrival times of the A_0 and S_0 modes frequency components (fig.2 c,d) [12].

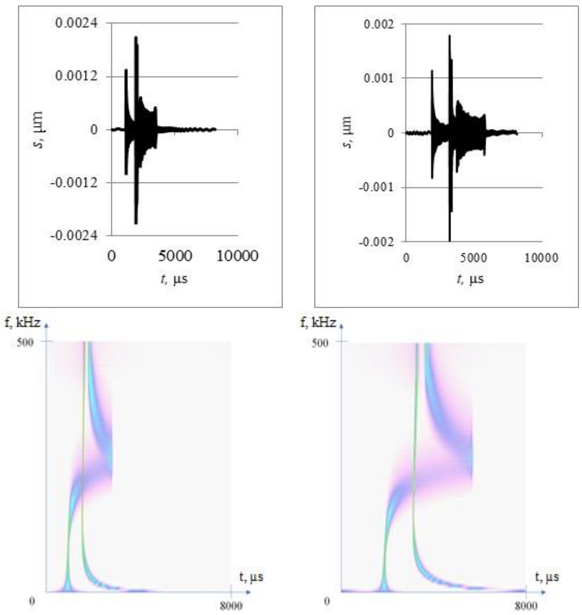


Fig.2 Model signals (a, b) and wavelet spectrograms of model signals distance 5 m; (a, c), distance 10 m (b, d)

The AE impulse waveform and spectrum strongly depend on the propagation distance. At the previous stage of the study, an empirical model of the AE impulse was proposed. The model was given by three empirical dependences – impulse amplitude vs. distance $A(l)$, rising edge angle vs. distance $RA(l)$ and frequency range vs. distance $f_{low}(l)$, $f_{up}(l)$. They are show on Fig.3 a-c.

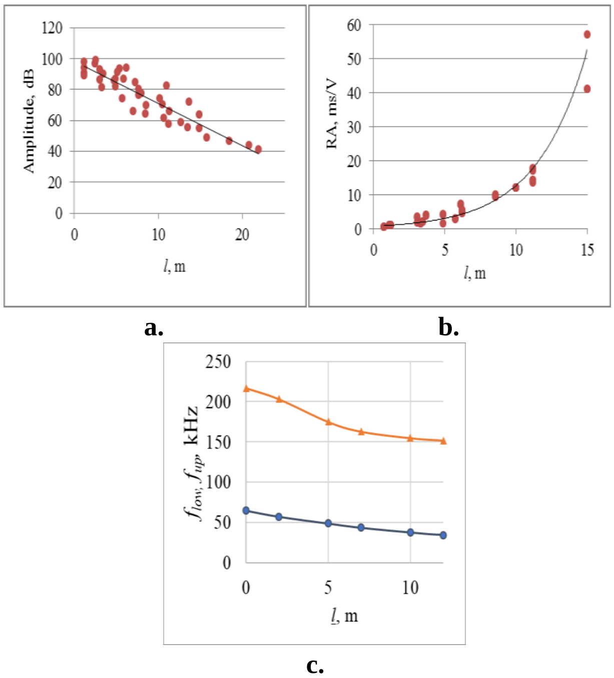


Fig.3 a. dependence A(l) b. dependence RA(l) c. dependences $f_{low}(l)$ and $f_{up}(l)$

Changing the impulse parameters with increasing distance consists in decreasing the amplitude, increasing the duration of the leading edge, and shifting the spectrum to the low-frequency range. The numerical value of impulse parameters could be approximately evaluated from the dependences fig.3 a-c.

III. DESCRIPTION OF NOISES

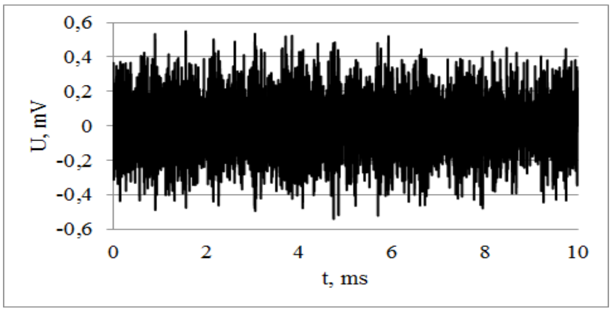
Technological noises of industrial equipment — hydrodynamic and mechanical — were considered as noise sources that were most often encountered during AE control. In total, 3 noise sources were considered: the noise of the loading device, the noise created by the outflow of liquid, the noise of friction. The main feature of these noises is that, unlike electrical noises, they have a physical nature of origin and, in time and frequency characteristics, can be similar to useful AE pulses, and mask them.

Since AE control involves loading of the object, the noise of the loading devices (Fig. 4a) is characteristic and is often encountered in practice. This noise does not significantly affect the registration of AE pulses if the primary transducer is located in close proximity to the AE source. However, as the source moves away from the transducer and the amplitudes of the useful pulses decrease, this noise can mask them, thereby reducing the reliability of the control. This type of noise is stationary.

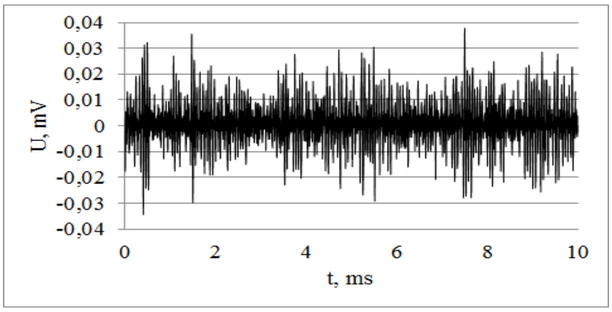
The signal corresponding to a leak (Fig. 4b) is considered not as a noise, but as a source of continuous emission, which should be detected and localized in the control process. The acoustic leakage noise is continuous emission and is stationary. Acoustic noise at the outflow of liquid or gas occurs only if the flow is turbulent in nature and can create significant difficulties in recording pulses of discrete AE corresponding to the activity of the defect.

Another source of acoustic noise accompanying the AE control process is friction. When diagnosing dynamic equipment, friction arises from the contact of rotating parts - shafts, bearing assemblies, compressor equipment; in static equipment, the source of friction can be solid particles of the product.

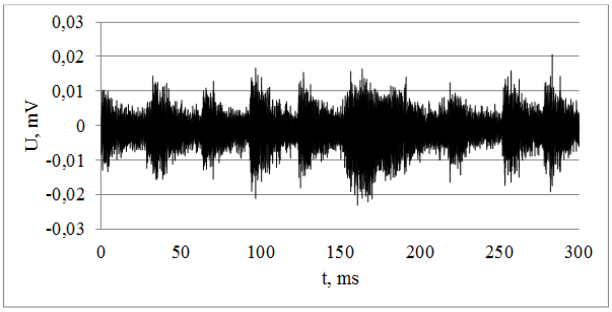
The elementary act of friction is a discrete emission. However, depending on the abrasiveness of the contacting surfaces, these pulses can occur with different repetition rates, overlapping each other. As a result, friction can give rise to both stationary and non-stationary noise processes. As an example, we consider the non-stationary process of friction, which manifests itself with low abrasiveness (Fig. 4c). The main difficulty of such noise is that the frequency range of individual pulses can significantly overlap with AE impulses from the defect.



a.



b.



c.

Fig. 4 Noises appeared during AE testing (a) noise of the loading device, (b) noise of the fluid outflow, (c) noise of the friction

Based on the change in the signals considered above in the time domain, all of them can be divided, conditionally, into two groups - stationary and non-stationary. Moreover, for each of the noise groups, their own approaches to filtering should be applied.

IV. NON-STATIONARY NOISE FILTERING

The main characteristic of the AE impulse, distinguishing it from the impulse components of noise, is a high slew rate, which can be described using the *RA* parameter $= \frac{RT}{A}$, where *RT* is the rise time of the AE signal, *A* is the signal amplitude.

Fig. 5 shows the dependences that make it possible to determine the measure of similarity between AE impulses and impulse noise components at different distances *L* between the source and sensor. The figure shows two dependences: the empirical distribution of the parameter *RA* for friction noise containing impulse components (brown graph) and the dependence of the parameter *RA*(*L*) for AE impulses calculated for different distances *L* (blue graph). For joint analysis of the graphs, the dependent variable *RA* is plotted along the abscissa axis, and the independent *L* is plotted along the ordinate axis. A joint analysis of the dependences makes it possible to determine how close the AE pulses and the pulsed noise components can be in the terms of *RA* parameter.

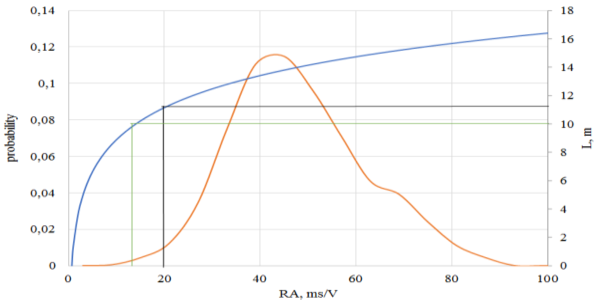


Fig. 5. Comparison of *RA* parameters of AE impulses and pulsed components of friction

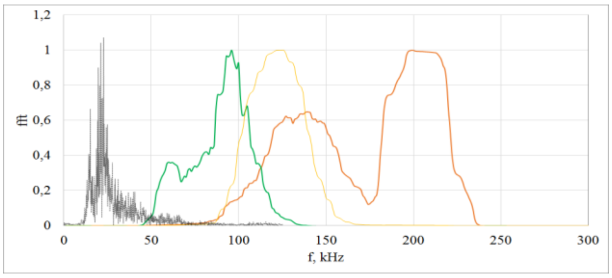
The mode of *RA* distribution for the pulsed components of friction noise corresponds to ~ 42 ms/V, the AE pulses reach such a value of *RA* at a distance of 13-15 m from the source, therefore, at a distance L between the sensors of the order of 13-15 m, the AE pulse may not be distinguishable on the background of noise. For example, if the distance between the sensors is less than 5 m, the *RA* value does not exceed 6 ms/V; this value is not characteristic of the noise process and, with a high probability, the AE impulse will significantly differ in shape from the pulse components of the friction noise.

In fig. 5 green and gray vertical lines show *RA* distribution quantiles of order $q_{0.01}$=15 ms/V and $q_{0.05}$=21 ms/V, respectively. The value *RA*= 15 ms/V is typical for AE pulses emitted at a distance of about 10 m from the sensor, 21 ms/V for a distance of 11 m. Therefore, in order for the AE pulse to be highly likely to differ in shape from the pulsed components of the friction noise, the sensors should be placed at a distance of no more than 10-11m.

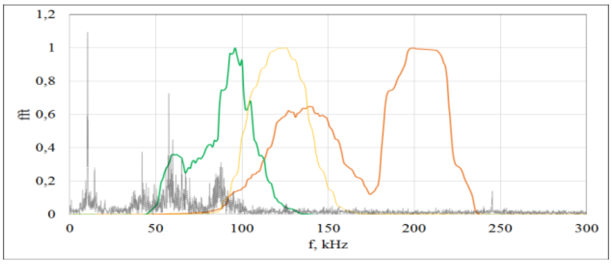
V. STATIONARY NOISE FILTERING

Stationary noise is a continuous AE in which there are no pulsed components. For stationary noise, filtering in the frequency domain is most effective, therefore, to assess the possibility of filtering noise, it is advisable to compare the spectra of AE pulses and noise in order to determine the degree of overlap for considered frequency ranges.

Figure 6 shows the spectra of various noise processes in comparison with the normalized model spectra of AE pulses at a distance of 1, 6, and 12 m averaged for different thicknesses. At a minimum distance of 1 m, the AE pulse spectrum is the most broadband, corresponds to a frequency band of 90-225 kHz, and to a lesser extent overlaps with noise spectra. The spectrum of the pulse corresponding to a distance of 6 m is localized in the frequency band of 90-150 kHz, with a distance between the source and the sensor of 12 m, the spectrum of the pulse is in the lowest frequency domain, it corresponds to the frequency band from 50 to 120 kHz. The noise spectra shown in Fig. 13 in black correspond to the noise generated by the leak (Fig. 6a) and the noise of the loading machine compressor (Fig. 6b).



a.



b.

Fig. 6 - Comparison of the spectrum of various noise processes and AE impulses corresponding to a distance of 1 m (blue), 6 m (red) and 12 m (green) (a) leakage noise, (b) loading machine noise

Since the complexity of the frequency filtering is determined by the degree of overlap of the signal and noise spectra, the most effective filtering results are expected with a smaller distance between the sensor and the AE source, which must be determined individually for each particular case.

VI. CONCLUSION

The article discusses approaches to filtering AE impulses against a various noise background using an empirical model of AE impulse. Noises appearing during the AE testing, in most cases, caused by vibration, friction, or a turbulent flow of liquids and gases.

During the filtering of stationary noises, the variability of the spectrum of the AE impulse, depending on the distance between the source and the sensor, necessitates the use of special filtering schemes aimed at extracting AE impulses with different parameters. A comparative analysis of the noise frequency spectrum and spectrum of AE impulses showed that filtering efficiency decreases with increasing distance between the defects and the sensor due to the overlapping of frequency band

Critical from the point of view of detecting low-amplitude AE impulses is the distance between the defect and the source of the order of 10-15 m.

Filtering non-stationary impulse noise, similar in waveform to AE impulses, is possible by dividing into the class of “useful signals” and “noise class”. In order for AE impulses to differ in parameters from impulse noise, the sensors must be located at a certain distance from each other.

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