Method of signal identification based on wavelet analysis.

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Abstract. The article presents the results of the development of a method for identifying the source of vibroacoustic impact on the sensitive element of the fiber-optic perimeter protection system of industrial facilities. The methodology was tested on the identification of signals from the following sources of vibroacoustic impact: impact over a certain period of time, or shaking the fence (t-impact); short-term impact type impact (δ-exposure). In the course of the work, polygon tests of the perimeter security system were conducted, a library of signals was compiled, and characteristic features of signals of various types of impact on the sensitive element of the system were identified. The main signal processing tools are the Fourier and wavelet transforms.

1. Introduction

The identification method was developed during the surveys of signals of the fiber-optic perimeter security system. This method allows you to distinguish the signals of various vibroacoustic sources. The following types of effects on the sensitive element of the system acted as vibroacoustic sources:

- Exposure over a period of time, or shaking the fence (τ-exposure);
- Short-term exposure type impact (δ-exposure).
- At the initial stage of development the technique was focused on identifying signals using the Fourier transform.

2. The Fourier transform

The Fourier transform allows you to transfer the signal from the time domain to the frequency domain, that is, to obtain the spectrum of this signal. On account the analysis of the various the spectra of signals types, it is possible to identify the frequency components characteristic of the specific vibroacoustic sources. For a discrete signal, which is a lattice function and, as a rule, defined on a finite period of time (measurement time), the Fourier transform takes the form of the so-called discrete Fourier transform:

$$ X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi j kn}{N}} $$

(1)
Figure 1 shows the $\tau$-exposure signal and figure 2 shows its Fourier spectrum. It is possible to distinguish harmonics inherent to $\tau$-exposure signals in the range of 5-40 Hz. However, the most characteristic harmonics are 6 Hz and 25 Hz, which are present in all the signals presented above.

![Figure 1. Signal of $\tau$-action](image1.png)  
![Figure 2. Fourier spectrum of $\tau$-action signal](image2.png)

Figure 3 shows us the $\delta$-exposure signal and figure 4 shows its Fourier spectrum. The harmonics lying in the range of 160-180 Hz are typical for $\delta$-exposure signals. In the low-frequency range, harmonics with an amplitude above the noise components are absent, unlike t-signal signals.

![Figure 3. Signal of $\delta$-action](image3.png)  
![Figure 4. Fourier spectrum of $\delta$-action signal](image4.png)

However, the Fourier transform provides global information about the investigated signals and does not allow considering local features of the signals (distribution of harmonics in time).

3. The wavelet transform
At the end of the last century, a new and important direction appeared in the theory and technique of processing signals, images, and time series, called the wavelet transform (WP), which is well suited for studying the structure of non-stationary (time-varying) processes. Wavelets are special functions in the form of short waves (bursts) with a zero integral value and with localization along the axis of an independent variable (t or x), capable of shifting along this axis and scaling (stretching / compression).
The wavelet transform (WT) of a one-dimensional signal is its representation in the form of a generalized series or Fourier integral over a system of basis functions:

\[ \psi_{ab}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \]  

constructed from the parent (source) wavelet \( \Psi(t) \), which has certain properties due to time-shifting operations (b) and changing the time scale (a). The multiplier \( 1/a \) ensures that the norm of these functions is independent of the scaling number \( a \).

Let's consider the result of the wavelet transformation of the previously presented signals.

For the wavelet transform of the system signals, the CWT (…) function was used in the Matlab environment. Wavelet transform implies the choice of the mother wavelet used. In preparation for the wavelet analysis, the following wavelets of various orders were considered: the Haar wavelet, the Mexican hat wavelet, the Meyer wavelet, the Morlet wavelet, and the Gaussian wavelet.

The most detailed spectrum was obtained using 8th order Gauss as the mother wavelet (Figure 5).

Figure 5. 8th-order Gaussian wavelet (ordinate axis - amplitude; abscissa axis - time in s)

The wavelet spectrum is a three-dimensional graph of the dependence of the harmonic amplitude (displayed in color) on the frequency scaling factor and time in s. It is also worth noting that you must first multiply the initial signal by the window function so that “false” harmonics do not occur at the beginning and end of the signal presence interval. As a window (weighted), the Hann function was selected with a length of 5000 samples in accordance with the length of the signals (Figure 6).

Figure 6. Hann’s window function (ordinate axis - amplitude; abscissa axis - reference number).
Figure 7 shows us the wavelet spectrum of the \( \tau \)-exposure. In this case, in the period from 2.8 s to 7 s, harmonics lying in the frequency range from 10 to 80 Hz make the greatest contribution.

![Wavelet spectrum of the \( \tau \)-exposure signal.](image1)

Figure 7. Wavelet spectrum of the \( \tau \)-exposure signal.

Figure 8. Wavelet spectrum of the \( \delta \)-exposure signal.
Figure 8 the wavelet spectrum of δ-exposure is presented. In this case, the largest contribution is made by harmonics lying in the range of 250 to 300 Hz.

Based on the obtained data, it is possible to form an algorithm for the method of identification of the signal source of the vibro-acoustic monitoring system.

τ-exposure signals are characterized by low frequencies up to 80 Hz, while δ-exposure signals are characterized by higher frequencies, ranging from 250 Hz to 300 Hz. Based on this information, an algorithm for identifying the vibroacoustic source was formed.

The algorithm consists of the following steps:

- Wavelet transformation;
- Separation of the wavelet spectrum in the region of a fixed length in time and width in frequency;
- Calculation of the average value of the harmonic amplitude in each region;
- Selecting areas with the maximum value and converting them to a two-dimensional spectrum;
- Analysis of the obtained spectrum.

The regions formed by dividing the spectrum have a time length of 0.2 s and a frequency width of 10 Hz. The grid of division of regions is presented in figure 9.

![Grid for dividing the wavelet spectrum into regions.](image-url)
After calculating the average value of harmonics amplitudes in each region, 4 regions stand out with the maximum value are allocated and the frequency coordinates of the Central points of these regions are saved. The resulting frequency values are converted to a spectrum. The next step is to analyze the spectrum. The type of vibroacoustic signal source is determined by the harmonics belonging to one of the ranges: from 0 Hz to 80 Hz (τ-impact); from 250 Hz to 300 Hz (δ-impact).

In figure 10 shows the spectra of τ-exposure and δ-exposure. Some harmonics of the spectrum of the δ-exposure signal are not included in the previously determined frequency range from 250 Hz to 300 Hz, however, Figure 10 shows us that the main contribution is made by harmonics belonging to this range.

![Graph](image)

Figure 9. The spectrum of τ-exposure signals (blue) and δ-exposure (red) obtained as a result of the processing algorithm.

As a result of all the work carried out, a methodology was identified for identifying a vibroacoustic signal source, which makes it possible to distinguish between τ-effect and δ-effect signals. This methodology can exist independently, and can be applied in conjunction with other techniques to increase reliability.

This work was supported by the Russian Foundation for Basic Research (Grant No. 18-47-860014).

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