DETECTION OF VIBRATION DISTURBANCES DURING THE ANALYSIS OF LONG REALISATIONS OF VIBRATION SIGNALS

Brancevich Peter

Belarusian State University of Informatics and Radioelectronics, Faculty of Computer Systems and Networks, Minsk, Belarus

Li Yibin

Shandong University, IMST, Jinan, P.R.China
email: liyibing@sdu.edu.cn

Creation of systems of proactive technical maintenance of the equipment requires conduction of a detailed study of changes in vibration condition of technical objects in the course of their use. Stationary systems of vibration control and monitoring in their work are guided by the standard criteria and signal about the appearance of emergency dangerous situations or carry out protection functions. However, the identification of the reasons for changes in technical condition of the controlled object is not their main function. Modern computer or plug-in systems allow reception of long (tens of seconds, minutes, hours, days) realizations of vibration signals which reflect vibration condition of the tested mechanism in various regimes without interruption. The visual analysis of a number of such vibration signals showed the existence of rare vibration eruptions and disturbances which are almost unidentified through the vibration signal parameters and spectral analysis. The method of processing of vibration signals is presented, based on their decomposition into periodic and noise-type components and wavelet analysis which focuses on detection of rarely created vibration eruptions and disturbances. These vibration anomalies indicate the origin of defects and their study is directed on the perfection of the means of technical diagnostics of mechanisms according to the vibration parameters.
Keywords: Vibration splash, detection, periodic, noise-like, component

1. Introduction

The technical condition of the mechanisms and units of rotary type, which is based on the rotational movement, is characterized by many parameters. Among them one of the most important are the intensity and spectral composition of vibration. And, at long continual functioning of the important technical object it is required to continuously control change of its vibratory parameters [1-4].
The standards define the rules of continuous control and monitoring of the vibratory condition of complex and expensive units (electric generators, pumping, compressors, etc.) during their operation [5]. Systems of continuous stationary monitoring allow to fix the fact of occurrence of anomalous situation on the controlled object and promptly react to it in a standard way or to implement algorithms of alarm and protection, taking into account Individual features of controlled objects [6].
However, significant changes in the average square value (RMS) of the vibrating signal, the amplitudes of individual, or group, harmonic components, detected such systems, testify to the significant development of a certain type of defect .
If the task is to create a system of proactive maintenance of equipment, there is a need for careful examination of even minor changes in the vibrational state of technical objects throughout the time

of their Exploitation. The detection of rare short-term changes in the structure of the vibratory signal and the subsequent identification of causal relationships between their appearance and the development of defects that require a certain response is of interest.

For this purpose it is expedient to analyze continuous vibrating signals reflecting the vibratory state of the object during long time intervals (hours and even days), which correspond to some cycle of regime change Operation of the equipment. This approach is consistent with the modern concept of information processing called "Big Data" [7].

2. Detecting vibration

Registration of long, continuous in time, vibrating signals is carried out by modern measuring-computational complexes and various data collectors [6, 8, 9].

Carrying out the visual and analytical analysis of the form and amplitude spectra of vibrating signals obtained during the study of rotary type mechanisms, you can notice the following. In many cases, such vibratory signals contain a periodic (or almost periodic) component consisting of harmonics multiple of the rotor speed, and the Shumopodobnuju component, as well as the rarely appearing vibrating Burst disturbances (Figure 1).

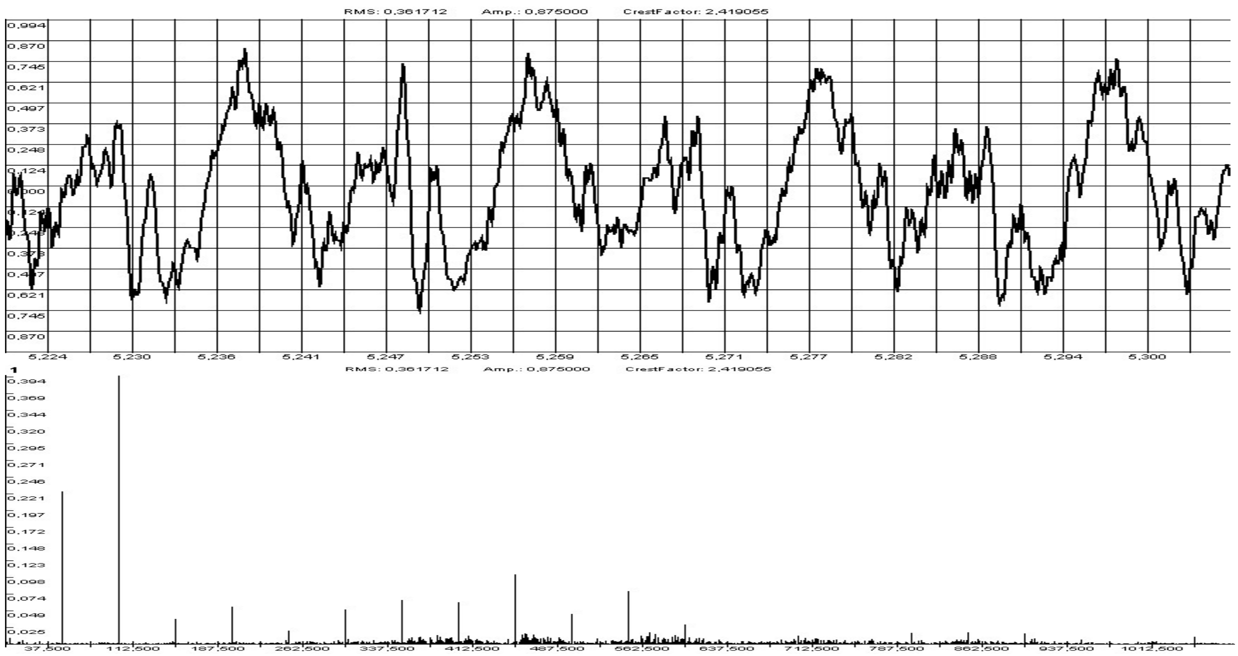

Figure 1: Vibrating signal and its amplitude spectrum.

Therefore, for the purpose of more detailed research, it is proposed to present the original vibration in the form of the sum of periodic and SHUMOPODOBNOJ components [6]:

$$x(nt_d) = p(nt_d) + s(nt_d) = \sum_{m=1}^{L} A_m \cos\left[2\pi \cdot k_m f_o \cdot nt_d - \phi_m\right] + s(nt_d), \quad (1)$$

Where is the periodic component of the vibrating signal; – Shumopodobnaja component of the vibrating signal; – Number of the discrete reference, = 0, 1, 2,.....; – Sampling interval; – The speed of the rotor or the drive shaft (reverse frequency); – The multiplicity – th harmonic, included in the periodical component, relative; ,, – amplitude, frequency, initial phase – th harmonic; ; is the number of harmonics selected for the periodic component of the vibration.

The multiplicity of harmonics, which are part of the periodic component of vibration, is determined taking into account the parameters of bearings, gears, gearbox scheme of the controlled node and its other design features and can be as an integral and fractional. If the frequency is known exactly, the amplitude and the initial phase-th harmonic are easily calculated by means of discrete Fourier transform, and the number of discrete conversion points is selected so that the analysis interval is multiple of its period (within Sampling capabilities):

$$N_m = round\left(l\frac{t_m}{t_d}\right), \quad \textbf{(2)}$$

Where is the number of periods of frequency component, such that it is less than or equal to the size of the array used to calculate the amplitude spectrum of the signal:

$$l = \mathrm{int}\left(N\frac{t_d}{t_m}\right), \quad (3)$$

where – the period – th harmonica; is a rounding operation.
When the frequency is known, the periodic component of the signal is calculated by the formula of the first approximation expression (1), and the Shumopodobnaja component is as follows:

$$s(nt_d) = x(nt_d) - p(nt_d)\,. \quad \textbf{(4)}$$

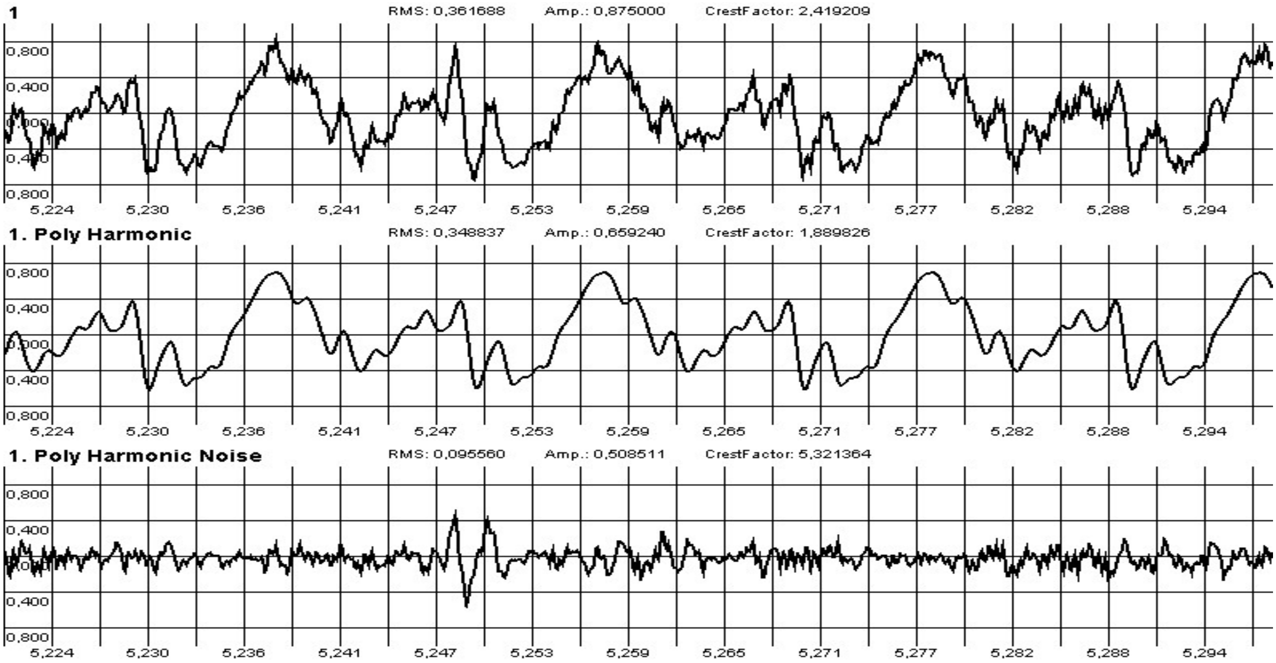

Figure 2: The decomposition of the vibration signal into a periodic and noise-like components.

Figure 2 shows the decomposition of the previously shown vibrational signal into periodic and noise-like components.

However, in practice the exact value is not always known. Traditional spectral analysis makes it possible to accurately calculate the parameters of the first and other circulating frequency components only if their frequencies are multiples of the fundamental frequency of the spectral analysis. While carrying out studies of the vibrational state of real objects, such a multiplicity can not be achieved quite often. A consequence of this is the blurring of the amplitude of the circulating frequency component along adjacent spectral lines and the problem of determining its frequency. In such cases, good results are obtained by applying the method of calculating the expressed spectral component on the basis of the values of the neighboring spectral components.

Assume that the analyzed signal has a harmonic component with a frequency such that

$$i \cdot \Delta f < f_x < (i+1) \cdot \Delta f \tag{5}$$

After calculating the amplitude spectrum, using the time interval for analyzing the rectangular time window, some values of the amplitudes of the spectral components corresponding to the frequencies and will be obtained, respectively, and.

If we denote $$\varsigma = (i+1) \cdot \Delta f - f_x, \tag{6}$$

a is the true value of the amplitude of the harmonic component with frequency, then, taking into account the fact that the representation in the frequency domain of a rectangular time window is described by the expression:

$$X(f) = \frac{\sin(\pi f T)}{\pi f}, \tag{7}$$

moreover, u can be expressed in terms of the relations:

$$A_i = \frac{A_x}{T} \cdot \frac{\sin[\pi(\Delta f - \varsigma)T]}{\pi(\Delta f - \varsigma)} = \frac{A_x}{T} \cdot \frac{\sin\left[\pi\left(1 - \varsigma/\Delta f\right)\right]}{\pi(\Delta f - \varsigma)}; \tag{8}$$

$$A_{i+1} = \frac{A_x}{T} \cdot \frac{\sin(\pi \varsigma T)}{\pi \varsigma} = \frac{A_x}{T} \cdot \frac{\sin\left(\frac{\pi \varsigma}{\Delta f}\right)}{\pi \varsigma}. \tag{9}$$

Performing the transformations over expressions (8) and (9), we define the value.

$$\varsigma = \frac{\Delta f}{1 + \frac{A_{i+1}}{A_i}} = \frac{A_i}{A_i + A_{i+1}} \Delta f. \tag{10}$$

After that the frequency value is calculated:.

$$f_x = (i+1) \cdot \Delta f - \varsigma = \left(i + \frac{A_{i+1}}{A_i + A_{i+1}}\right) \cdot \Delta f, \tag{11}$$

and the amplitude of the harmonic component:

$$A_x = A_{i+1} \cdot \frac{\pi \frac{\varsigma}{\Delta f}}{\sin\left(\pi \frac{\varsigma}{\Delta f}\right)}. \tag{12}$$

This method can be used to study the vibrational state of mechanisms with rotational motion to determine the amplitudes and frequencies of the spectral components of vibration that are multiples of the rotor's rotational frequency. These spectral components are quite pronounced on the continuous spectrum, and high accuracy of determining their parameters is achieved even if their frequencies are not multiples of the frequency resolution of the spectral analysis

After dividing the vibration signal into polyharmonic and noise-like components, the parameters of each of them are analyzed. It is logical that the changes in the parameters of the periodic component are a consequence of a sufficiently significant change in the technical state of the object, while local changes in the noise-like component are manifestations of emerging defects.

The processing of a large volume of vibrational signals obtained in the study of turbines and generators confirms the hypothesis that rare anomalous vibrational bursts are observed on the noise-like component [10]. An illustration of this is figure 2, a vibrational splash is clearly visible here.

To better isolate the disturbing bursts, in a number of cases it is expedient to first perform a wavelet transform with a noise-like component [11]. Figure 3 shows the results of such processing of a noise-like wavelet with a "Mexican hat" type wavelet.

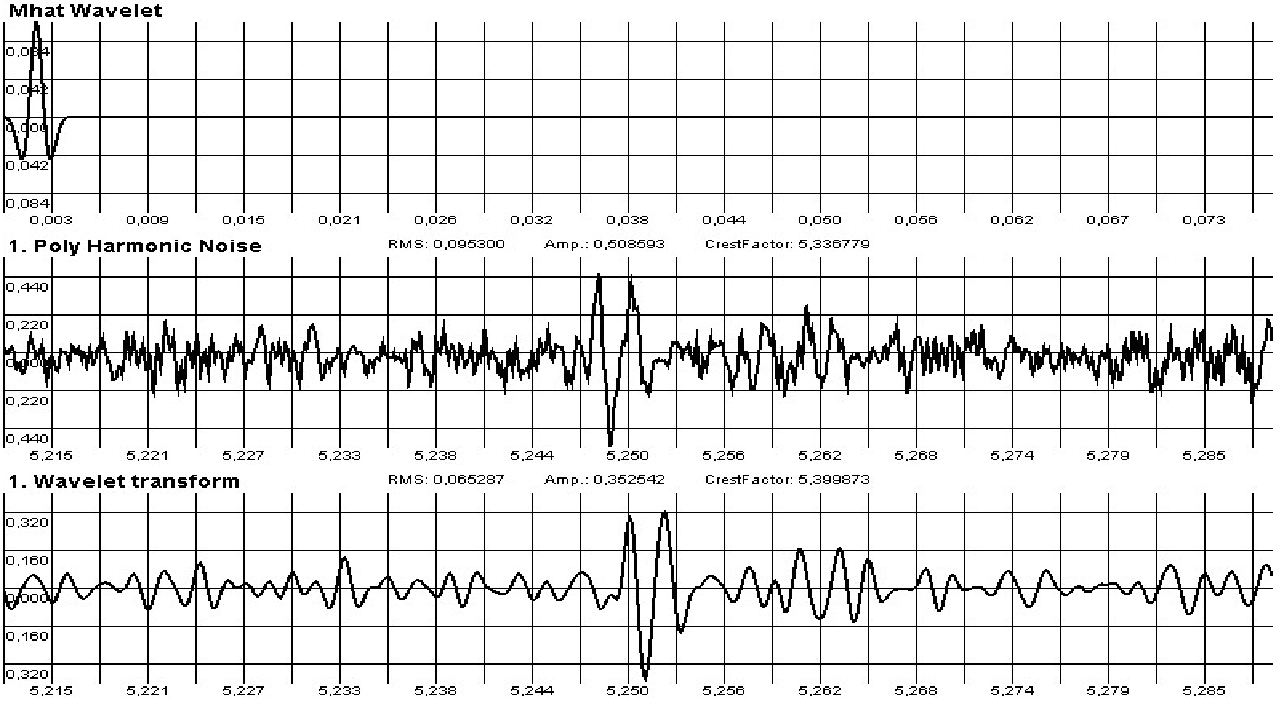

Figure 3: Wavelet processing of a noise-like component.

3. Processing vibrating signals with a changing fundamental frequency

This method of processing vibration signals should be used in cases where it is required to divide the investigated signal into components (1), but the signal is registered with the time-varying rotational speed of the controlled object. In this case, the range of the change in the rotational speed (circulating frequency) is generally known.

The following method of processing a vibration signal is proposed.

1. For the study, a segment of time realization is chosen (= 4096, 8192, 16384, 32768 discrete points, the higher the rate of change of frequency, the less points are taken).

2. At the beginning of the segment of the time realization under study, a fast Fourier transform (FFT) is performed on a shorter interval, в = 1024 or 2048 discrete points, and the amplitude spectrum is calculated.

3. The amplitude spectrum is analyzed in the sub-range of permissible change in the circulating frequency and in 5-7 sub-ranges, the values of the boundaries of which have a corresponding multiplicity with respect to the changes in the circulating frequency.

4. A harmonic is selected in one of these sub-bands (preferably the first one), the maximum in amplitude, and the multiplicity of this sub-band is determined with respect to the sub-band of the reverse frequency.

5. The formulas (11) - (12) are applied and the parameters of the chosen harmonic are determined - its frequency and amplitude.

6. If a harmonic was selected from the first sub-band, then its frequency is taken as the initial for the studied segment of the time realization of the size. Otherwise, where is the multiplicity of the sub-

band in which the frequency was determined, the sub-band of the reverse frequency (in general, this is a real number).

7. At the end of the segment of the time realization under study, at the interval of 1024 or 2048 samples the actions described above are performed (points 2-6) and the final turnaround frequency is found.

8. The amplitudes of the quasiharmonic components of the signal with varying frequencies are calculated:

$$C_{k*} = \frac{2}{L}\sum_{n=0}^{L-1} x(n)\cdot\cos\left(\frac{2\pi\cdot z_k\left(m+n\cdot\Delta m\right)\cdot n}{L}\right). \quad (13)$$

$$S_{k*} = \frac{2}{L}\sum_{n=0}^{L-1} x(n)\cdot\sin\left(\frac{2\pi\cdot z_k\left(m+n\cdot\Delta m\right)\cdot n}{L}\right). \quad (14)$$

where is the multiplicity of the -th quasiharmonic component, in the simplest case these are integer values, but there may be real values; - the number of the harmonic, which is part of the quasiperiodic component.

$$\Delta F = \frac{1}{t_S L}; \quad m_{beg} = \frac{f_{beg}}{\Delta F}; \quad m_{end} = \frac{f_{end}}{\Delta F}; \quad m = m_{beg} - \Delta m\frac{N}{2}; \quad \Delta m = \frac{m_{beg}-m_{end}}{L-N}. \quad (15)$$

where - frequency resolution in the analysis for a long time implementation; ,, are real numbers; - the sampling interval specified when the vibration signal is input; - the number of harmonics of the multiple leading frequency, which are used to determine the quasi-periodic component of the vibration signal.

9. The quasi-periodic component of the vibration signal is calculated:

$$p_*\left(n\right) = \sum_{k=1\div K}\left(C_{k*}\cos\left(\frac{2\pi z_k\left(m+n\cdot\Delta m\right)n}{L}\right) + S_{k*}\sin\left(\frac{2\pi z_k\left(m+n\cdot\Delta m\right)n}{L}\right)\right), \quad (16)$$

where is the discrete reference number, = 0,1,2, ...,.

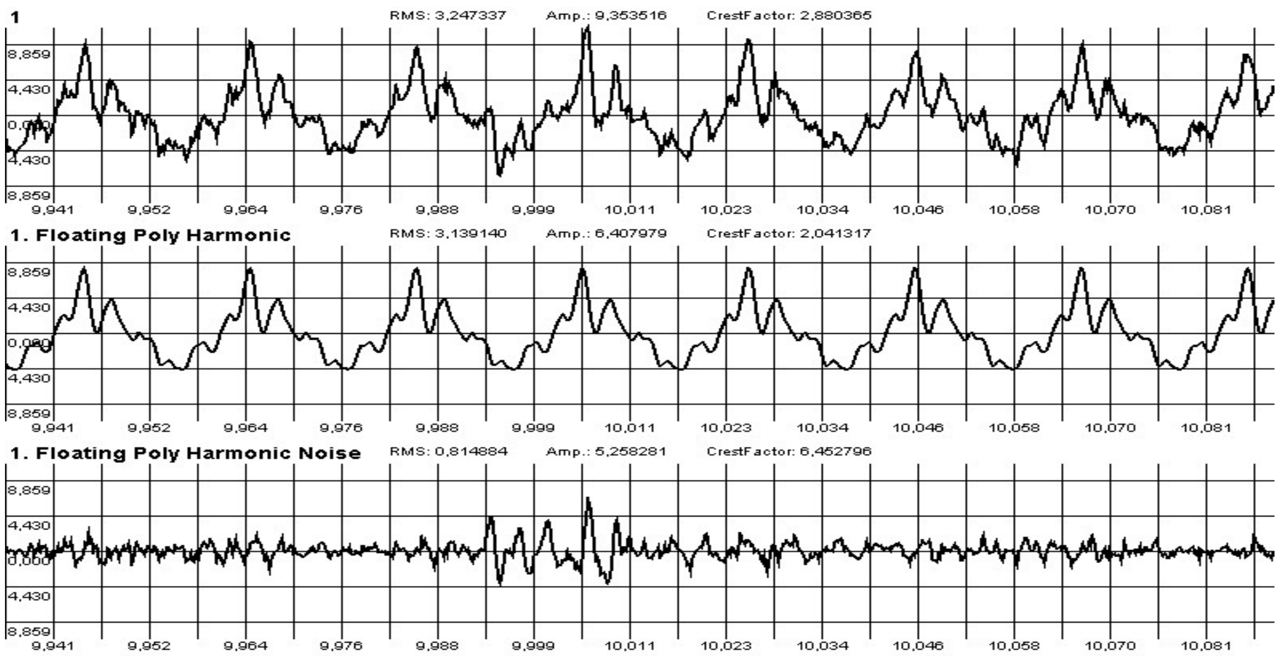

Figure 4: The decomposition of a vibration signal with a varying circulating frequency on the periodic and noise-like components.

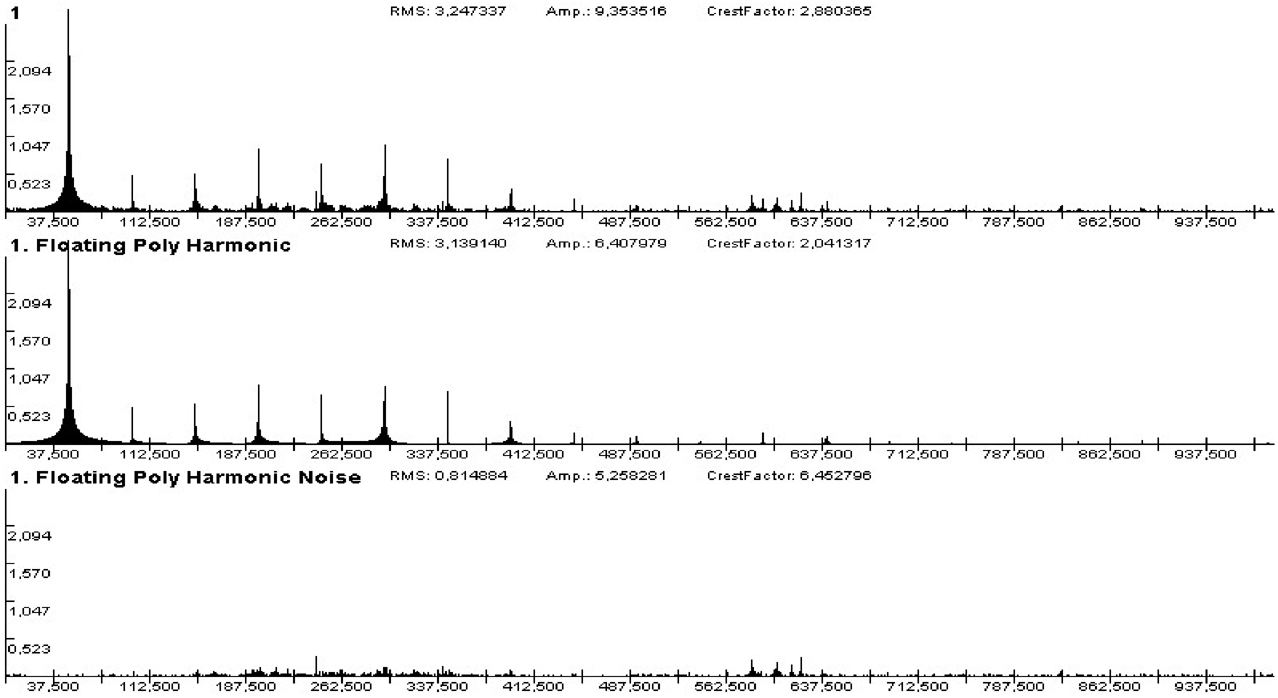

Figure 5: Amplitude spectra of a vibrating signal with a varying circulating frequency, its periodic and noise-like components

10. The noise-like component is calculated as the difference between the original signal and the quasiperiodic component:

$$s(n) = x(n) - p_*(n) \quad (17)$$

Figures 4, 5, as an example, show the initial vibration signal obtained when controlling the vibrational state of the motor, with a change in the speed of the drive shaft, its quasi-periodic and noise-like components, as well as the amplitude spectra of these signals.

This example demonstrates that the proposed method makes it possible to extract multiple quasi-harmonic components from the vibrational signal, determined by the rotor speed of the technical object under study, and to identify vibrational disturbances on the noise-like component.

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