STATISTICAL ANALYSIS OF RAIL ELECTROMAGNETIC TESTING SIGNALS

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Summary

The statistical approach to the rail testing tasks is preserved. The rail testing signals are obtained using the magneto-dynamical selecting method on the Lviv railway track section (Ukraine). The stationary frequency ranges for signals from typical non-faulted and faulted rails are investigated. The frequency range corresponding to defects image display is established. The basis of periodically correlated random processes (PCRP) and the scope of tasks which appear in rail testing using the PCRP methods analysis are stated. The complex of defect rail signals non-stationary correlation analysis is carried out. The possibilities of using the PCRP methods for separating the defect useful signal and localizing the defects on the early stage of their growth are shown.

Key words: rail testing, periodically correlated random processes, spectral density, variance

ANALIZA STATYSTYCZNA SYGNAŁÓW DEFEKTOSKOPII SZYN TORÓW KOLEJOWYCH

Streszczenie

W pracy podano podejście statystyczne do problemu defektoskopii szyn torów kolejowych. Sygnały testowe otrzymane za pomocą metody magnetodynamicznej selekcji na odcinkach kolei Lwowskiej. Zbadano zakres częstotliwości sygnałów szyn z defektami i bez defektów w przybliżeniu stacjonarnym. Omówiono zasady stosowania teorii okresowo skorelowanych procesów losowych (OSPL) przy defektoskopii szyn kolejowych. Przeanalizowano wyniki niestacjonarnej analizy korelacyjnej sygnałów torów bez defektów. Wskazano możliwości stosowania metod statystyki OSPL dla wyodrębnienia sygnału użytecznego przy lokalizacji defektów torów we wczesnym stadium ich powstania.

Słowa kluczowe: defektoskopia, okresowo skorelowane procesy losowe, gestość widmowa, wariancja

The basic tasks of the rail testing are the finding, classification, localization of the defects and estimating the dynamics of their growth. On the basis of these task solutions, the decisions on the necessity of rail loads decreasing, defect removal or pieces of rail track section replacement are accepted. By means of existing methods of testing the decisions often are taken visually depending on testing signal outward appearance [1].

At the same time the evolution of mathematical statistical signal processing methods should allow the trends to improvement the selecting signal processing results where the same process rhythmic violation is informative.

The model of stationary random processes is the most often encountered model for describing the process stochastic changes. In the framework of this model the average process properties are described. The model of periodically correlated random process (PCRP, also known as periodically non-stationary or cyclostationary processes) is the nature unification of deterministic and stationary concepts and includes them as sample cases. The great role of periodically non-stationary model using is confirmed by modern papers in biomedical engineering, climatology, predicting theory, signal detecting and modeling.

In the framework of correlation theory the PCRP is defined as random process with periodical mean and correlation function on the parameter t [3]:

$$m(t+T)=E\xi(t)=m(t),$$
$$b(t+T,u)=E\overset{\circ}{\xi}(t)\overset{\circ}{\xi}(t+u)=b(t,u), \qquad (1)$$
$$\overset{\circ}{\xi}(t)=\xi(t)-m(t).$$

There exists a wide range of elaborated methods of PCRP correlation analysis, such as coherent, component, maximum likelihood, least squares. These methods allow to estimate the random process characteristics – the mean, correlation function and their Fourier components. The properties of real nature process are described on the basis of obtained estimates.

For using the PCRP correlation and spectra analysis methods the process apriori information, in particular the precise meaning of the correlation period and the number of mean and correlation function components must be known.

When analyzing the rails testing signal using the PCRP methods the answers to a number of questions must be obtained. In particular, it is necessary to find the precise data period, to select the processing parameters and to clarify the situation with the diagnostic parameters choosing.

The hidden periodicity search is provided on the basis of sine and cosine component functionalby the first or second order:

$$\hat{m}_l^{c,s}(\tau)=\frac{1}{\theta}\int_{-\theta}^{\theta}\xi(t)\left\{\begin{matrix}\cos l\dfrac{2\pi}{\tau}\\ \sin l\dfrac{2\pi}{\tau}\end{matrix}\right\}tdt\,, \qquad 2)$$

where l is the number of mean component, θ - the realization length, $\xi(t)$ - the exploit signal, τ - the probe period.

Functional (2) reaches its maximum under the value τ which equals the precise value of correlation period.

The processing parameters choice depends on sampling step h, the number of mean N_1 and correlation function N_2 components as shown in [4].

When the following representation holds true

$$h\le\frac{T}{2N_1+N_2+1}, \qquad (3)$$

where N_1 – the number of upper mean component and N_2 – the number of upper correlation component, the statistically qualitative processing results are obtained. So the sum N_2+2N_1 can not exceed the value $\frac{T}{h}-1$. For this reason the choice of diagnostic parameters during the analysis of real testing signals must be taken into account. The choice of diagnostic parameters must be done with regards to the tasks which arise before the investigator. Nevertheless, in any case, we must have the information about typical signal behavior in the case of defect absence.

In [5] the properties of typical non-fault rail testing signals are investigated. It is shown that the signal two mean components and four variance components are statistically significant.

Let us consider the typical rail testing signals with different structural heterogeneity. Figure 1 shows the example of testing signal with one defect.

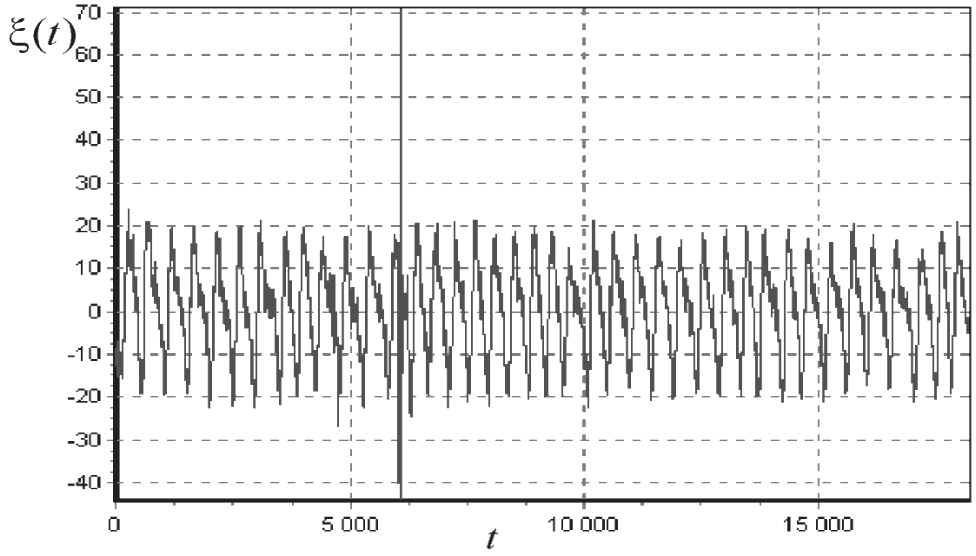

Fig. 1. Signal reflected from one fault rail

Let us carry out the analysis of this signal by means of stationary methods. The stationary correlation function can be seen in Figure 2. This correlation function has the oscillatory character with oscillation period about 500 points. The noise component is insignificant and amounts to about

1/5 of total signal capacity. The modulated oscillatory character is testifies to the narrow band of the process.

As you can see from Figure 3, the total signal capacity is situated in the low frequency range and the main spectral density peak is situated at the frequency ω=0.00219.

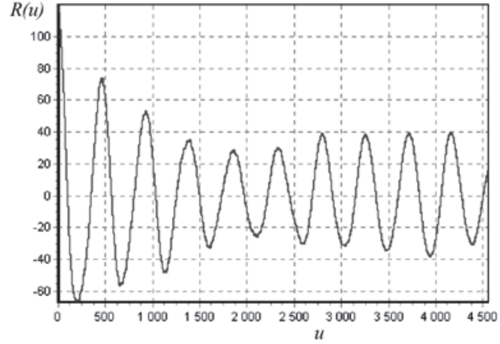

Fig. 2. Signal stationary correlation function from the fault rail

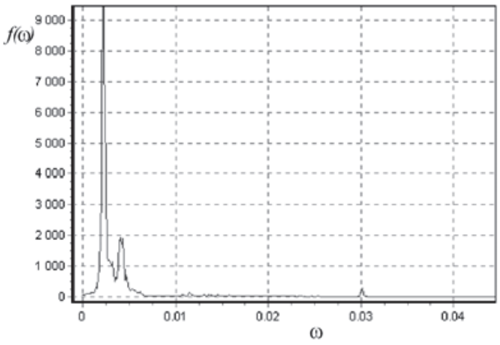

Fig.3. Fragment of signal stationary spectral density from the one-fault rail

The main signal frequencies ω=0.00219 and multiple frequency ω=0.00438 contain the information about non-fault rail [5], that is, the information about the defect is situated in the high frequency range. The signal filtered by means of low-frequency filter to ω=0.01 is shown in Figure 4. . The signal filtered by means of high-frequency filter over ω=0.01 is shown in Figure 5.

The stationary spectral density of the high-frequency filtered signal shown in Figure 5 has the following form (see Figure 6.). The spectral density peaks at the frequency ω=0.03 and multiple frequencies are caused by testing car electromagnet power supply effects. The high-frequency signal with filtered multiple frequencies to ω=0.03 is shown in Figure 7. Thus, the main information about defect is situated in the frequency range between ω=0.01 and ω=0.03.

Let us analyze the signal shown in Figure 1 by means of periodically correlated random processes (PCRP) methods. Let us use the coherent method [3] for estimating the process non-stationary mean, variance and correlation function.

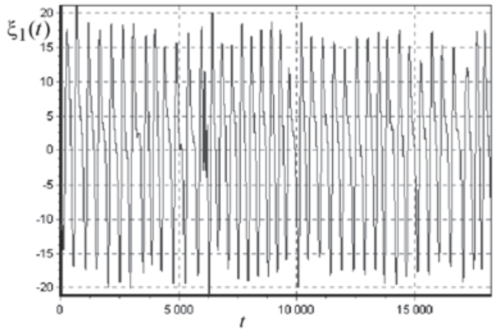

Fig.4. The low-frequency filtered signal

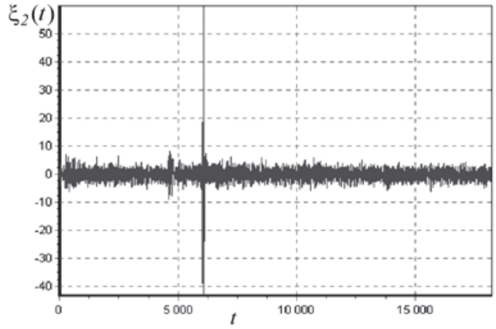

Fig.5. The high-frequency filtered signal

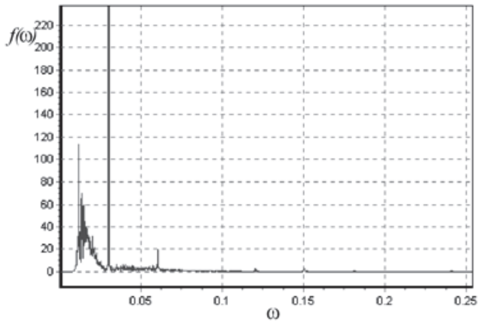

Fig.6. The stationary spectral density of high-frequency filtered signal

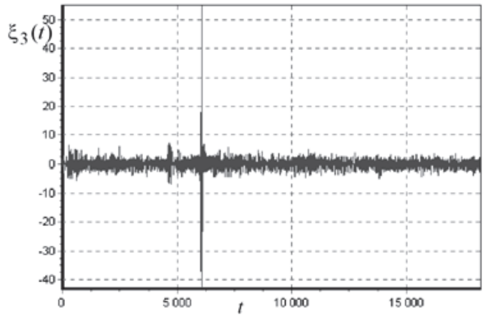

Fig.7. The high-frequency signal after filtering the multiple frequency to ω=0.03

Usually the defect is shown as powered signal oscillations which are of higher frequency than regular periodical oscillations. Therefore the amplitude and number of mean components must not increase significantly (Figure 8.). But the number of significant variance components (Figure 9.) grows considerably.

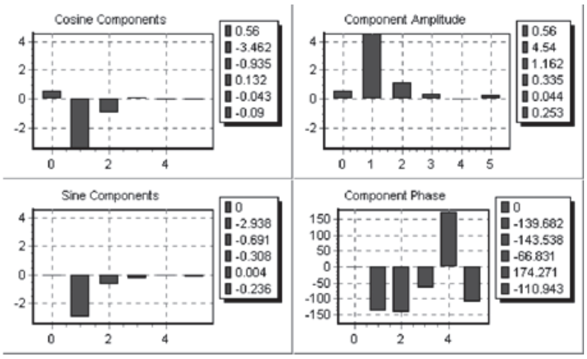

Fig.8. PCRP mean components for signal with one defect

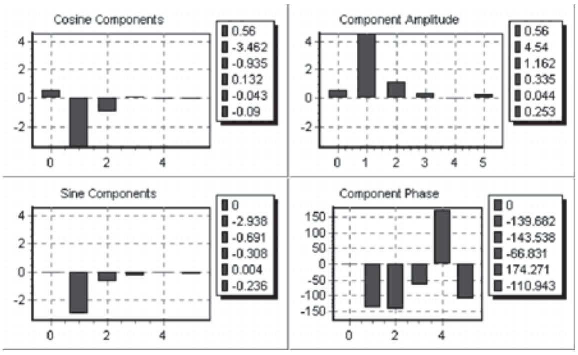

Fig.9. PCRP variance components for signal with one defect

Comparing the variance components number and amplitude for prototyped rail with non-faulted case we can indicate and sort out the defect presence or absence.

Since, the PCRP methods are sensitive for high-frequency changing in period periphery, using these methods is expedient for localization of the rail defects on the early stages of their rising.

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