Abstract: In this paper analysis of defectoscopic signal using the modern digital signal processing tool - continuous wavelet transform (CWT) is described. The main criteria in the railway tracks flaws detection by CWT are proposed.

Keywords: rail head, defect, crack, CWT

1. INTRODUCTION

Diagnosis of objects technical condition ensures their safety exploitation and timely detection of defects. Especially it is important during the objects diagnosis which defects may cause significant material expenses or human casualties. Rails are the particular type of these objects.

Currently, ultrasonic and magnetic wagon-defectoscopes which complement each other are used for high-speed diagnosis of rails. In particular, magnetic defectoscopes more precisely detect transverse crack (TC) in the rail head. TC is especially dangerous because it may lead to breaking the rails under moving train.

The most important question for both magnetic and ultrasonic methods of rails high-speed control is the selection of information about defects from the signals recorded by the wagon-defectoscope. Actuality of the development methods and algorithms for computer processing of defectoscopic signals is caused by the fact that at present, the analysis of these signals is mainly based on visual expert (wagon-defectoscope operator) evaluations.
To improve the efficiency of operator's work it is necessary to automate the signal analysis for selecting patterns of such signals which are derived from dangerous defects with the highest probability.

2. TRANSVERSE CRACK IN THE RAIL HEAD AS ONE OF THE DANGEROUS DEFECTS

All defects in rails can be divided into three categories. Defects at early studies of progress, that cover 6-8% of the rail head cut included into the first category.

Defects, that cover nearly 8÷30% of the rail head cut area, should be considered as functioning defects. They are defects of the second category and rails with such defects are named as faulty.

Critical defects, which cover 30÷40% of the rail head cross-section area, belong to the third category, and rails with such defects are signed as very faulty rails.

TC in the rail head of the contact fatigue origin is the most frequent and dangerous defect. As it is shown in [2] internal longitudinal cracks, which arise in the rail head at the depth of 5÷6 mm in the area of the biggest contact tensions, are the reason of this defect appearance.

In [5] the distribution of the very dangerous rail defects discovered in Russia in 2002 is presented. From this distribution it is obvious that TC is the most widespread defect (40.75% of discovered defects). The horizontal longitudinal crack in the rail head (25.91% of defects), caused by steel contamination with big density of non-metallic inclusions extracted along rolling, is on the second place.

Next are defects arising from skidding, dents and defects caused by the welding technology violation. Especially should be mentioned defects which are related with cracks in the rail web caused by the bolt or other holes. The rest of defects are |\leq 2.5%|.

3. MAIN PROPERTIES OF THE SIGNAL FROM TRANSVERSE CRACK IN THE HIGH-SPEED MAGNETIC FLAW DETECTION

Fig. 1 shows the several shapes of signal from TC that were recorded in different parts of Lviv and South-Western Railways of Ukraine.
Precise analysis of these signal shapes leads to the following conclusions:

1. TC signal's form in the majority of cases has a three pulse structure with global negative pulse of large amplitude;
2. Signal from TC has a complex structure and amplitude of the global negative pulse depends on the crack area in relation to the area of the rail head.
3. The amplitude of the first positive pulse is rapidly growing and depends on the releasing cracks on the rail head surface.
4. The total duration of pulses with the average speed of scanning 30 - 40 km/h is 8 - 10 ms.
5. The main persistent characteristics of the signal from TC are:
   - number of pulses in the signal;
   - order of the pulses polarity;
   - pulses duration;
   - distance between the extremes of pulses;
   - pulse edges steepness;
   - absolute value of the pulses amplitude;
   - ratio of the pulse amplitudes in the group;
   - ratio of the pulse amplitudes to the signal from substrates.
6. TC signal parameters depend on:
   - speed of scanning;
   - depth of the defect;
   - defect area in relation to the rail head area;
   - crack opening size;
   - location of the sensor with respect to the magnetizing system.
4. CONTINUOUS WAVELET TRANSFORM AS ONE OF THE MODERN METHODS FOR ANALYZING SIGNALS

Common approach to the analysis of different signals $s(t)$ is their representation as a matched sum of simple components - basic functions $\psi_k(t)$ multiplied by coefficients $C_k$:

$$s(t) = \sum_k C_k \psi_k(t)$$

Since the basic functions are fixed as functions of a particular type, only the coefficients contain information about the specific signal. So, we can talk about the possibility of submitting random signals based on series with different basic functions.

For CWT basic functions $\psi_0(t)$ can be wavelets that are able to shifting along the time axis (parameter $b$) and changing in width (parameter $a$):

$$\psi(t) = a^{-1/2} \cdot \psi_0\left(\frac{t-b}{a}\right)$$

For given $a$ and $b$ function $\psi(t)$ is wavelet.

CWT is a calculation of the wavelet coefficients in the domain definition of $\mathbb{R}$:

$$C(a,b) = \int_{\mathbb{R}} s(t) \cdot a^{-1/2} \cdot \psi_0\left(\frac{t-b}{a}\right) dt$$

Although this transform is unprofitable with respect to computation time, but it allows to achieve the greatest detailing during signals analysis which is limited only by the uncertainty principle [3].

5. THE MAIN DEFECTS DETECTION CRITERIA USING THE CONTINUOUS WAVELET TRANSFORM

This research was carried out in a package Wavelet Toolbox of the computer mathematics system Matlab. The fragment of defectoscopic signal with a pattern from transverse crack in the head of rail (Fig. 2) was selected as an object of research. At the edges of this fragment signals from the rails joints are shown, and along the whole of its length - the signals from the rails substrates (similar to background noise) are also shown.
As a mother wavelet for our study was used wavelet adapted to detection signals from the transverse cracks in the rail head (Fig. 3). The process of its creation is described in [4].
Result of CWT of the aforementioned fragment is shown in the scalegram (Fig. 4) which reflects the values of wavelet coefficients in the plane of scale - samples.

As can be seen, wavelet coefficients in the defect location have a significant value. It indicates that waveforms of the mother wavelet and defect are similar and the more similarly these signals the greater wavelet coefficient values are.

Let's show this scalegram in 2D form and scale it in the region of signal from TC (Fig. 5). In this case, values of wavelet coefficients are shown by different shades of gray color. The higher values of the wavelet coefficients are, the darker they reflected on scalegram. With increasing scale (wavelet is stretched) the accuracy of the defect localization (on the samples axis) is decreased. Therefore, for better defect localization it is necessary to estimate its presence by the coefficients on the smaller scales (high frequencies). Fig. 5 shows that the CWT coefficients have a maximum value at the 2172 sample, which can be regarded as the defect placement coordinate.
In order to analyze which scale (or scales) should be chosen as a criterion of the defect presence, we need to consider the dependence of the wavelet coefficient values from the scales at the defect location (Fig. 6).

Fig. 5. Scalegram of the defectoscopic signal shown in Fig. 2 in the place of signal from TC

Fig. 6. Dependence of wavelet coefficients from scale in the location signal from the TC (2172 sample)
Fig. 6 shows that the wavelet coefficients have their maximum value in the range of scales from 8 to 21, therefore it is worth to assess the presence (or absence) of the defect by their values. Scales from 5th to 8th also can be used for this purpose, everything depends on which minimum amplitude signals we need to identify.

From the above, we can formulate the basic terms of defects detection by CWT:
- A good choice of mother wavelet for CWT.
- Selection of the optimum scales quantity (is offered in the range of 8 to 21, - for transverse cracks), by which we can judge about the presence or absence of defect with high probability.
- Optimum thresholds on the value of the wavelet coefficients for each scale.

6. CONCLUSIONS

1. The basic conditions for detection signals from defects railway by CWT are formulated.
2. Choosing of optimum thresholds on the value of the wavelet coefficients opens the possibility of involvement to this process the artificial neural networks [1].

References


NOWOCZESNA METODA PRZETWARZANIA SYGNAŁÓW NIEBEZPIECZNYCH WAD W SZYNACH KOLEJOWYCH PRZY SZYBKOŚCIOWEJ DEFEKTOSKOPII MAGNETYCZNEJ


Słowa kluczowe: główna szyna, wada, pęknięcie