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APPLICATION OF THE WAVELET ANALYSIS TO INSPECTION OF COMPACT ROPES USING A HIGH-EFFICIENCY DEVICE

ANALIZA FALKOWA EFEKTYWNYM NARZĘDZIEM DIAGNOSTYKI LIN KOMPAKTOWANYCH

This study explores the potential application of the wavelet analysis to the assessment of the working condition of compact ropes (qualitative assessment). The assessment procedure is a key aspect in the decision-making during the non-destructive testing. This is the first study on diagnostics of the new-design ropes, summarising the results of the analysis of signals from novel compact ropes, based on the defect models. Selection of the wavelet type and of the decomposition detail is a key element of the diagnostic procedure. A major step in the assessment procedure involves the replicas of the rope's surface. The data provided in this paper will be useful in developing new specialist equipment for magnetic inspection of compact ropes.

Keywords: magnetic inspection of wire ropes, wavelet analysis, diagnostics

W artykule przedstawiono możliwości oceny stanu technicznego (analiza jakościowa) lin kompaktowanych przy zastosowaniu analizy falkowej, która stanowi ważny element wspomagający proces decyzyjny w trakcie badań nieniszczących. Jest to pierwsza informacja związana z problematyką diagnozowania lin nowej konstrukcji. Omówiono w niej wyniki analizy sygnału zarejestrowanego na nowej linie kompaktowanej z zamodelowanymi uszkodzeniami. Dobór typu falki i wybór detalu dekompozycji niosącego informację o symptomach zużycia jak również dobór częstotliwości rejestracji jest ważnym elementem procesu diagnostycznego. Pomocnym elementem oceny stanu technicznego stały się repliki z powierzchni badanej liny. Informacje zawarte w artykule pozwolą na opracowanie nowej, specjalistycznej aparatury do badań magnetycznych lin kompaktowanych.

Słowa kluczowe: badania magnetyczne lin stalowych, analiza falkowa, diagnostyka

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1. Introduction

Ropeway installations nowadays often use compact ropes, particularly in the mining sector (Kalukiewicz & Reś, 2010; Kulinowski et al., 2011), in cable railways and other installations where high-resistance ropes are required. Compared to conventional lay ropes, compact ropes feature an improved resistance to failure with a reduced outside diameter and they are more elastic. A better contact can be maintained between the rope and the grooves in drums (Fig. 1) and sheaves. Besides, the ropes are less prone to elongation, and display a better resistance to corrosion and surface friction (Kwaśniewski, 2011).

The rope condition can be assessed by magnetic methods. However, the magnetic inspection data do not give full information about the ongoing wearing and tearing processes. Despite their obvious advantages, compact ropes require full diagnostics, involving several aspects:

- metrological issues, having relevance to the measurement equipment; which requires appropriate analysis with the Finite-Elements Method (Juraszek, 1995, 2005, 2006);
- operating conditions, taking into account the determinants of the wearing and tearing processes.

Fig. 1. Compact rope on the winder drum

2. Theoretical backgrounds of wavelet analysis

In the course of service life, the wires tend to break yet the wire ends may not form air-gaps ensuring the generation of signals that can be registered by conventional rope inspection methods. Inspection of compact ropes does not always reveal their wearing condition. Amplitudes of generated fault symptoms from broken wire are sometimes on the level of background noise (Kwaśniewski & Magalas, 2000).

Determining the current rope condition and its wear-off basing on signals from induction sensors requires diagnosticians with an extensive expertise in finding the symptoms of broken wires, abrasion or corrosion in signal contents. These elements are often blurred by the signal component associated with the rope construction. However, they can be selected through the use of the wavelet analysis of non-stationary measurement signals (Kwaśniewski, 2000; Kwaśniewski et al., 1999).

The equation defining the discrete wavelet transform (j — discrete scale value, k — discrete translation j, $k \in Z^2$) is given as (Misiti et al., 1997):

$$DWT_s(j,k) = \sum_{n \in Z} s(n) \cdot \Psi_j^*(n - 2^j k) \tag{1}$$

where:

$\Psi_j^*(n - 2^j k)$ — discrete equivalent of the continuous analysing function

$*$ — convolution of signal $s(n)$ with the analysing function

The dyadic signal transformation (Białasiewicz, 2000) $s(n)$ generates its decomposition on discrete levels of resolution, where the wavelet scale falki $a = 2^j$ corresponds to the resolution 2^{-j} and is given as:

$$DWT_s(j,k) = \int_{-\infty}^{+\infty} s(n) \frac{1}{\sqrt{2^j}} \Psi\left(\frac{n-b}{2^j}\right) dn \tag{2}$$

Comparing the family of analysing functions for the continuous and dyadic case yields:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}} \Psi\left(\frac{t-b}{a}\right) \equiv \Psi_{j,k}(n) = 2^{-j/2} \Psi(2^{-j} n - k) \tag{3}$$

The relationship $\Psi_{j,k}(n) = 2^{-j/2}\Psi(2^{-j} n - k)$ defines the family of analysing functions for the dyadic case. For the steady j, we get the scale $2j$. When j is changed by 1, the scale is changed two-fold.

Manipulating Eq (3) to obtain its equivalent form:

$$\Psi_{j,k}(n) = 2^{-j/2}\Psi(2^{-j}(n - 2^j k)) \tag{4}$$

and distinguishing $\Psi_{j0}(n) = 2^{-j/2}\Psi(2^{-j} n)$ as the basic wavelet for the predetermined level of the scale paremeter j, we get: $\Psi_{j,k} = \Psi_{j0}(n - 2^j k)$, which means that $2j$ becomes a step with which the basic wavelet $\Psi_{j0}(n)$ is shifted on the predetermined scale level j. The subsequent powers of 2 determine the sampling on the scale axis. The discrete wavelet analysis of the signal $s(n) \in L^2$ involves finding the discrete wavelet transforms, being the inner products of the signal s and the sequence of the function $\Psi_{j,k}$. These products are referred to as wavelet coefficients.

Two parameters: j and k allow us to capture the specific features of the signal. The parameter k allows for capturing the time moment in which to analyse the signal whilst the parameter j allows for selecting the scale level or the frequency range to analyse the frequency spectrum of the signal. The argument k denotes the time instant $2^j k$, which implies that the quantization step within the time instant 2^j will change with the scale level j (Misiti et al., 1997). Selection of an inappropriate wavelet will give rise to nonlinear distortion of the spectrum.

The detail Dj is defined as (Białasiewicz, 2000; Misiti et al., 1997):

$$D_j(n) = \sum_{k \in Z} DWT_s(j,k) \cdot \Psi_{j,k}(n) \tag{5}$$

Assuming the scale coefficient $a = 2^j \leq 2^J$, the approximation can be defined as:

$$A_J = \sum_{j > J} D_j \tag{6}$$

The analysed signal becomes a superposition (sum) of the last approximation and all the details:

$$s(n) = A_J + \sum_{j \leq J} D_j \tag{7}$$

where

A_J — approximation of the J-th level of decomposition,
D_j — details of the j-th level of decomposition (resolution).

3. Inspection of compact ropes- results

Testing is done on a new compact rope WS6 × 36 + A_0 Z/s, 27 mm in diameter. Application of the wavelet analysis o assessment of the rope's condition requires an increase of the signal registering frequency.

Fig. 2 (top section) illustrates the registered signal with modelled rope defects, revealing no location of defects. The modelled defect has a gap of about 0.6 mm, revealed on replicas of the rope's surface (Fig. 3).

The signal shown in Fig. 2 is subjected to the wavelet analysis and the decomposition detail (d2) is selected, containing information about broken wires (Fig. 2 – bottom section). Other signal amplitudes revealed on the decomposition detail are associated with changes of the wires' surface due to rope deformation. The actual image of the detail depends on the type of applied filters (wavelet type) and the number of the decomposition levels. The calculations are performed in the Matlab environment (Mrozek & Mrozek, 1995).

4. Conclusions

Wavelet analysis of non-stationary signals is an excellent tool for locating the symptoms of compact rope wearing. However, the metrological parameters of currently used measuring equipment have to be changed, to take into account the rope magnetisation, technical parameters of the applied sensors, and the recording parameters. Besides, the staff would need a good knowledge

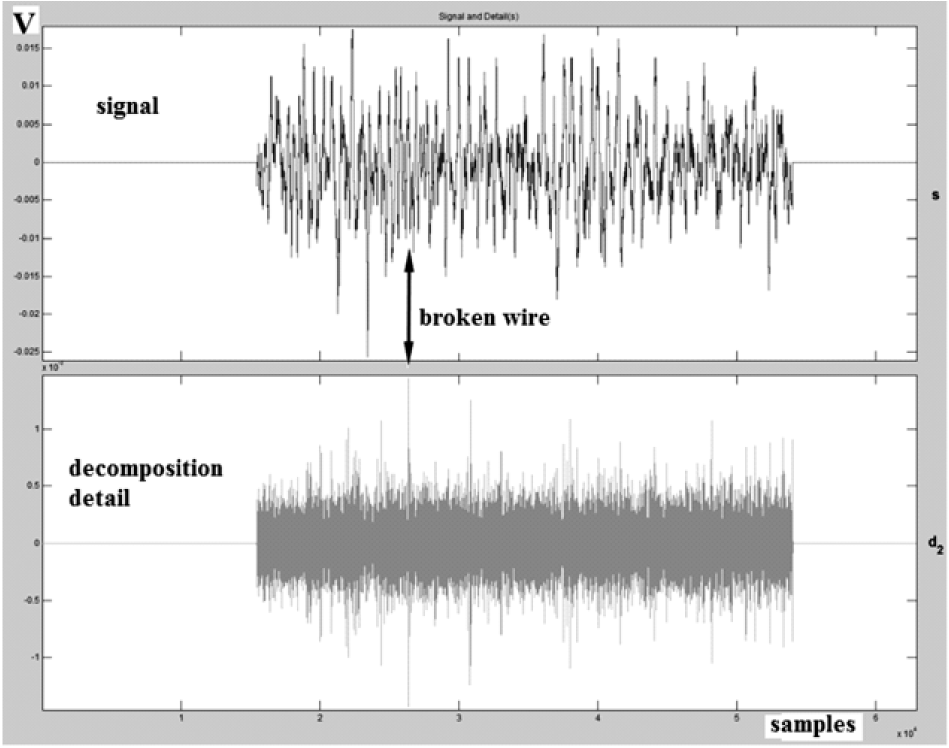

Fig. 2. Selected detail containing information about the wearing symptoms

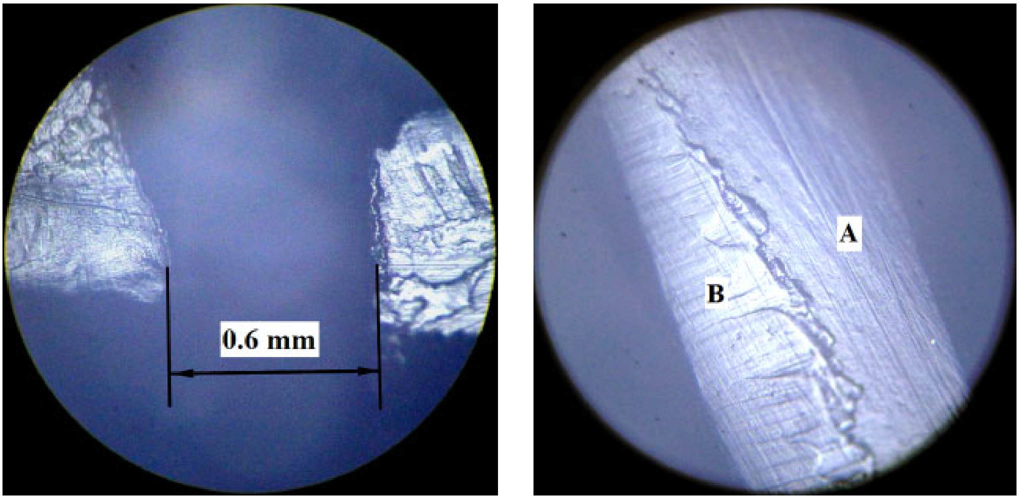

Fig. 3. Replicas from the compact rope surface (view of the gap and deformed wire surfaces;
A – flat section of the deformed wire, B – half round wire section)

of the data gathering and acquisition. Assessment of the rope's condition is facilitated by using replicas, enabling the monitoring of the rope's surface. Further research on fault detection in compact ropes is fully merited.

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