APPLICATION OF FOURIER-WAVELET ANALYSIS IN THE DIAGNOSTICS OF PIT SHAFT REINFORCEMENT

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Abstract

Examination of the wear degree and technical condition of bar constructions in industrial practice is based mainly on measurement of the thickness of individual elements. However, in many cases, during exploitation it is necessary to investigate the dynamic properties. This can be performed through the application of the test impulse method, by generating vibrations with the use of a special hammer, and measuring construction vibrations resulting from the force. This (new) method is inexpensive and simple to apply, yet one of the main constraints of employing it are the problems of processing the measurement signals and the interpretation of the results. The paper describes the processing algorithm of signals based on Fourier-wavelet transform which allows calculation of the frequency spectrum from the measurement signal decomposed with the application of wavelet analysis. What is new, the authors propose filtering of the response signal with the application of wavelet analysis and using information contained in the signal energy.

1. INTRODUCTION

Pit shaft reinforcement is one of the elements with which the pit shaft is equipped for safe vertical transport from the mine surface underground. Its basic function is to guide extract vessels through a straight, vertical route, and the fundamental requirement controlled during exploitation is the appropriate construction resistance against loads deriving from moving extract vessels. Presently, the reinforcement wear is judged on basis of random spot checks of thickness and calculations of the sectional modulus. It is very difficult to draw conclusions as to the technical condition of the complete reinforcement exclusively on the basis of these measurements because it is impossible to examine all elements (several thousand). Also, there is lack of knowledge of the reinforcement behavior in force conditions and lack of information as to the condition of connection between particular reinforcement elements.

Additionally, this (old) method is time consuming and expensive, and requires interruption of a mine operation while being done. The above circumstances led to the research at AGH University of Science and Technology, Department of Mechanics and Vibroacoustics on the development of a new method of diagnosing pit shaft reinforcement that could be widely applied in industrial practice. The proposed method takes into account the dynamics of reinforcement construction and is based on examination of the behavior of a reinforcement element after generating vibrations through impulse force. On basis of reaction measurement to the force and appropriate processing of the measurement signal a conclusion as to the reinforcement's dynamic condition can be drawn, particularly taking into account its stiffness, as it is the key parameter to a safe exploitation. One of the problems encountered during development of the algorithm of defining the dynamic properties was the definition of the vibration component responsible for bar deflection resulting from the force.

2. IMPULSE TEST METHOD IN EXAMINING STEEL CONSTRUCTIONS

New estimation of the construction condition is based on determining partial characteristics with the application of the impulse force [1]. This is performed through generating vibrations with the use of a modal hammer, and measuring construction vibrations resulting from the force.

Due to the fact that measurement signals are non-stationary, determining measurement estimates allowing to draw conclusions as to the technical status of the examined constructions requires processing simultaneously in two areas: time and frequency. Among the available bar constructions examination processing tools, the wavelet transform has been applied, which transforms one-dimensional signal to a domain, defined by *b parameter* (time) and scale *a* (frequency) according to the formula:

$$\tilde{s}(a,b) = \int_{-\infty}^{+\infty} s(t)\frac{1}{\sqrt{a}}\Psi^*\left(\frac{t-b}{a}\right)dt \qquad (1)$$

where: s(t) – measurement signal, Ψ- wavelet, *a* – scale parameter, *b*- position parameter

The classical approach of determining frequency characteristics of the examined construction defines it as a ratio of Fourier transform response signal to the force in the form of vibration acceleration signal to Fourier transform input signal in a form of force power:

$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)} \qquad (2)$$

where: $H\ (j\omega)$ - Frequency Response Function, $Y\ (j\omega)$ - Fourier transform of the output signal, $X\ (j\omega)$ - Fourier transform of the input signal.

In tests where the measurement signals are non-stationary [1], [2] their time-frequency representations converted to the frequency field have been applied, according to the following formula[3] :

$$\hat{\tilde{s}}_{\Psi}(a,\omega) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} s(t)\psi\left(\frac{t-b}{a}\right)dt\, e^{-j\omega b}db \qquad (3)$$

and the relation of the input and the output signal for the applied impulse test method has been defined analogically to the formula (2):

$$\hat{\tilde{s}}_{\psi}^{wyj}(a,\omega) = H(\omega)\hat{\tilde{s}}_{\psi}^{wej}(a,\omega)$$

$$H(\omega) = \frac{\hat{\tilde{s}}_{\psi}^{wyj}(a,\omega)}{\hat{\tilde{s}}_{\psi}^{wej}(a,\omega)} \qquad (4)$$

where: $\hat{\tilde{s}}_{\Psi}^{wyj}(a,\omega)-$ wavelet-Fourier transform of output signal, $\hat{\tilde{s}}_{\Psi}^{wej}(a,\omega)-$ wavelet-Fourier transform of input signal

3. ESTIMATES OF DIAGNOSTIC SIGNALS

Due to the application of conversion (3) it is possible to observe the changes of a suppressed vibration signal and its spectrum as the answer of the construction to the force. This approach enables filtering of disturbances and determining the signal component adequate to the rate of wear of the examined construction [3], [4], [5].

For the purposes of decision making as to the technical condition of the examined construction, and for the needs of the developed method, functional and punctual estimates have been determined, based on the signal reply picture to the vibrations in the Fourier-wavelet field. The functional estimates are based on Fourier spectrum calculated for the signal time component transferring the main part of vibrations energy.

$$\hat{\tilde{s}}_{\Psi}(a_{\max},\omega) = \int_{-\infty}^{+\infty} \tilde{s}(a_{\max},t)e^{-j\omega t}dt \qquad (5)$$

where: $\hat{\tilde{s}}_{\Psi}(a_{\max},\omega)$ - spectrum of the signal time component carry the main part of vibration energy,

$\tilde{s}(a_{\max},t)$ - time component of the wavelet transform for scale $a_{\max}$, adequate to the signal energy maximum.

Pointwise estimates are calculated as the root-mean-square (RMS) value vibration signal filtered by means of wavelet analysis and parameters of signal energy distribution.

4. RESULTS

Examination of the pit shaft reinforcement verifying the developed processing algorithm has been carried out in one of the pit shafts in KGHM Polkowice. Sketch of the examined reinforcement is presented on Figure 1. Evaluation has been performed on closed profile pit shaft guides, made of a pair of channels bar C140 supported by girders every 3m. For the reasons of comparison, apart from dynamic properties measurements of the examined guides, thickness of walls has also been measured with the use of DMS 2TC type ultrasound thickness meter made by Krautkramer.

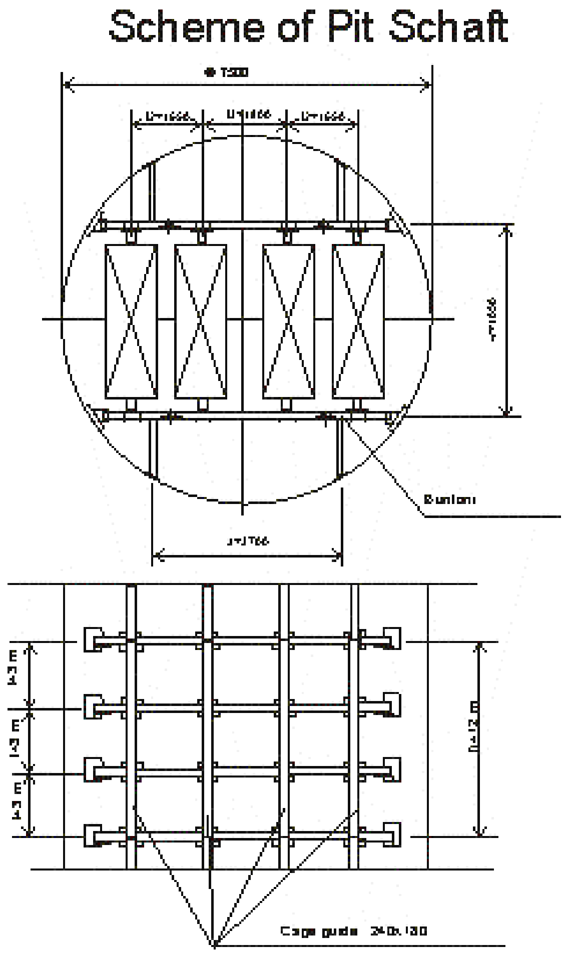

Figure. 1. Sketch of the examined pit shaft reinforcement

The examined pit shaft was a double compartment, downcast one with built-in two skip devices guided by a stiff, steel front slide. The lift of extract vessels was 30 Mg of mining each, and during production cycle the vessels move with a speed of 20 m/s. The extract machine built in on the pit shaft tower is driven by Koepe 4L-5500 devices with 2x3600kW engines for each of the extract compartments.

Examination of the pit shaft reinforcement has been performed with the application of a diagnostics system consisting of two parts: mobile and stationary. The mobile part consisted of: a digital recorder with signals conditioning system for excitation and response. The excitation was created by hitting a modal hammer with built in force sensor, whereas the response to the excitation were construction vibrations, described by acceleration signal adequate to the technical condition of the examined element. After the measurement session, the results were processed by the stationary part of the diagnostics system – a PC computer with wavelet algorithms of signal processing measurement package. The sketch of the measurement circuit together with the signal analysis has been presented on Figures 2 and 3.

Figures 4-5 present the results of the wavelet signal processing for two different statuses of the steel construction wear. Figure 4 presents the registered reply signal to the impulse force for a construction in good technical condition, with wall guide thickness g=8,3mm and its wavelet transform. Figure 5 presents similar, but for a used construction with wall thickness g=7,0 mm.

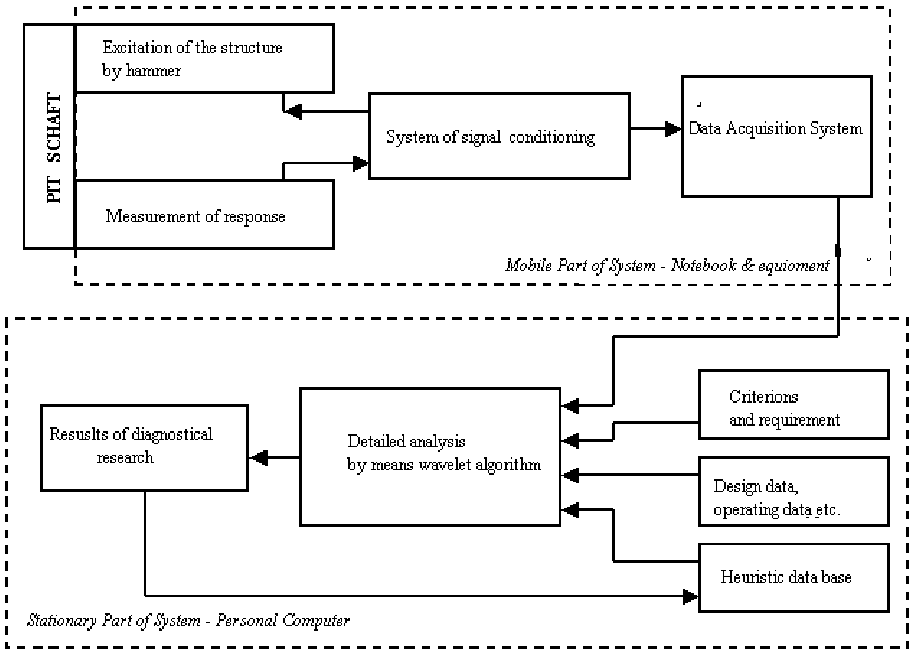

Figure 2. Sketch of diagnostics signal acquisition and analysis system for pit shaft reinforcement

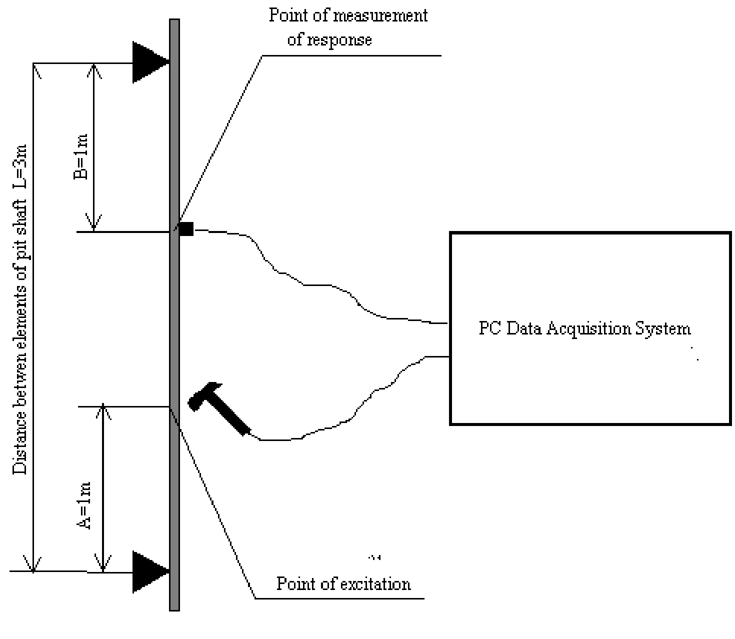

Figure 3. Sketch of measurement route for examination of pit shaft reinforcement with the use of impulse test and wavelet signal processing

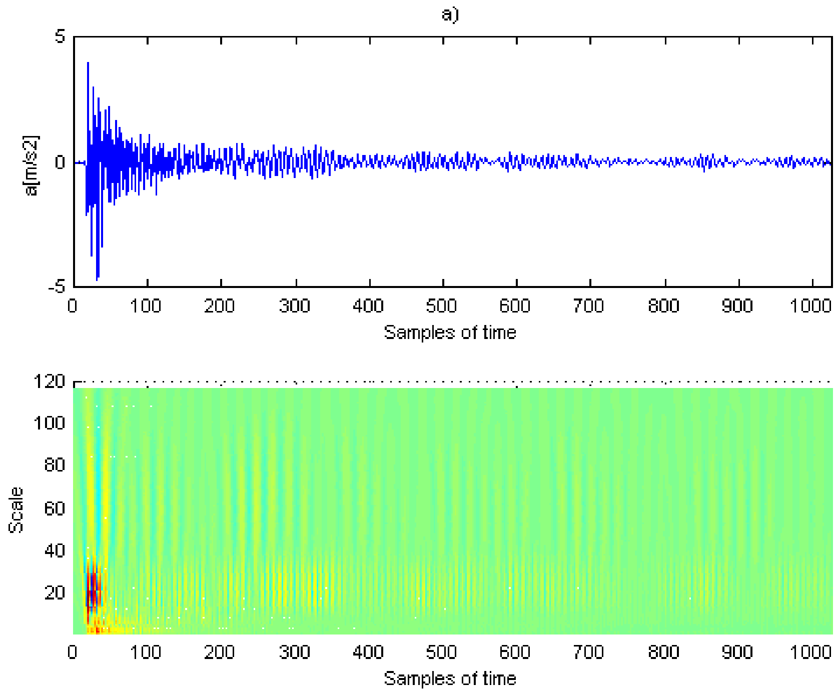

Figure 4. Results of signal processing for a guide in good technical condition (wall thickness g=8,3mm a). signal of response to excitation, b) wavelet transform of response signal

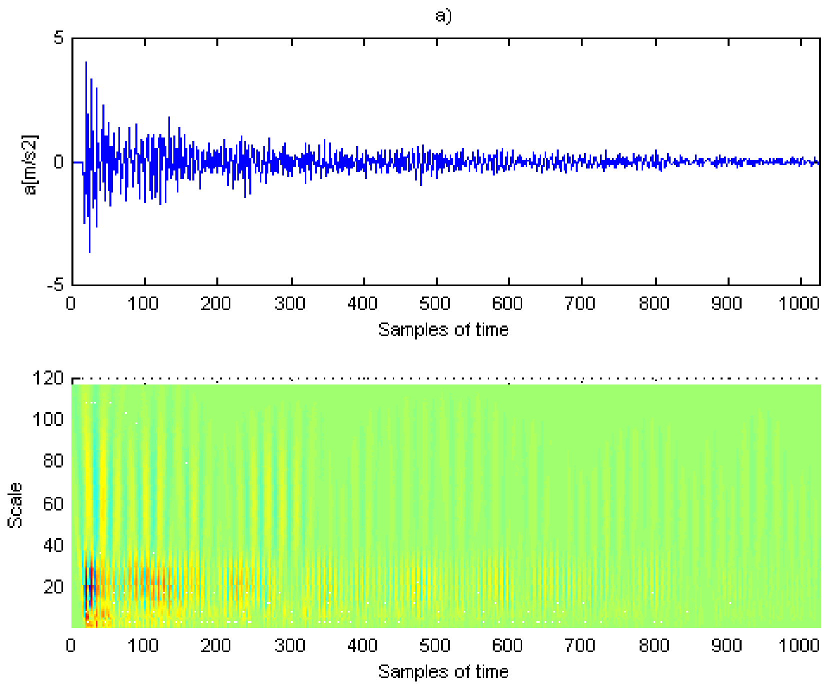

Figure 5. Results of processing for a used guide – wall thickness g=7 mm a). signal of response to excitation, b) wavelet transform of response signal

Calculated wavelet coefficients for particular signals registered during examination have been further processed according to the formula (5), and on basis of the obtained energy schedule within coordinates frequency-scale the areas with increased signal energy have been defined. This knowledge allowed to assign the scale a_g of wavelet transform adequate for functional estimates describing the wear condition of the examined guide. This, in turn, allows inverse transform for scale a_g and separation of measurement signal for component responsible for the wear. For comparison of different guide conditions, Fourier spectrum estimates of filtered signal element can be determined. Figure 6 presents Fourier spectra for two examined guides filtered by wavelet analysis.

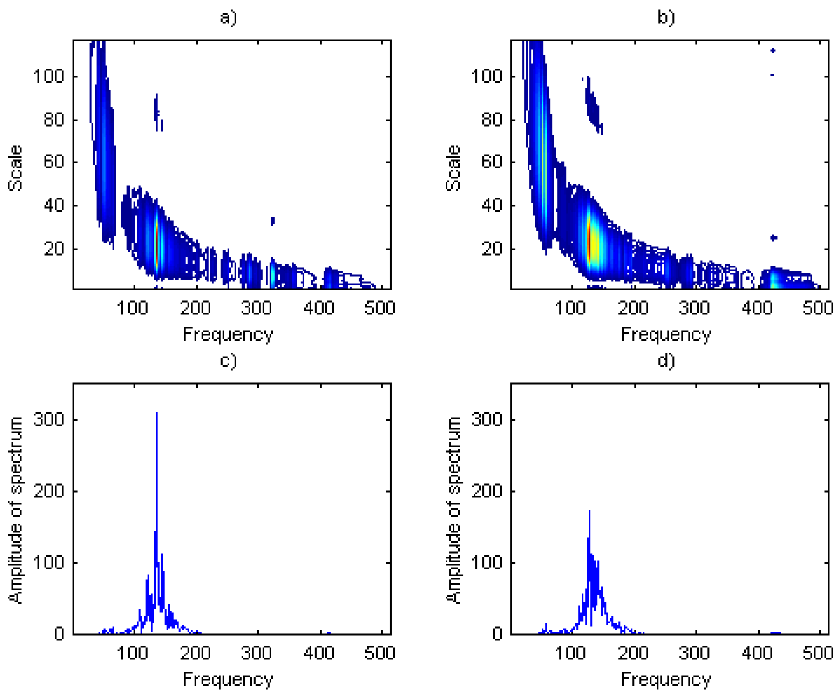

Figure 6. Fourier-wavelet spectra for guides in different technical conditions.
a). Fourier-wavelet transform of signal for a worn our guide (g=7,0 mm),
b). FFT of filtered signal for a good guide (g=8,3 mm),
c). Fourier-wavelet transform of signal for a worn our guide (g=7,0 mm),
d). FFT of filtered signal for a good guide (g=8,3 mm).

5. SUMMARY

In many cases of exploitation of devices there is a need to obtain information about construction dynamic properties. Such examination is necessary when the object is an element of human transport system or when it is under considerable force and it is difficult to estimate its influence on e.g. the stiffness of construction.

The impulse test is a convenient examination method executed by generating vibrations of the construction and measuring the reply, yet for determining estimates of the worked on signals, initial processing is necessary in order to solve the problem of the signals being non-stationary. For this purpose, the authors have proposed Fourier-wavelet transform and have defined a functional measurement of construction wear as a Fourier spectrum of a signal wavelet transform component responsible for transferring the main part of the signal energy. The new method, presented in the paper has been already applied in practice for the diagnostics of pit shaft reinforcement in underground mines.

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