# APPLICATION OF WAVELET-FOURIER ANALYSIS INTO DRAWING-SHAFT REINFORCEMENT DIAGNOSTICS

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## Summary

Impulse tests are commonly encountered in the research of dynamic properties of frame constructions in their operation time. One of the most significant problem issue associated with the application of these tests is description problems and unambiguous interpretation of non-stationary measurements results.

New approach introduced by the authors involves system response-signal filtration by means of wavelet analysis and taking advantage of the information contained within the signal's energy. The article describes the application of wavelet-Fourier transformation for determining frequency spectrum from recovered impulse response. Practical usage is illustrated by the example shaft reinforcement in an underground mine.

Key words: diagnostics, wavelet-Fourier transform, non-stationary analysis.

## ZASTOSOWANIE ANALIZY FALKOWEJ-FOURIERA W DIAGNOSTYCE ZBROJENIA SZYBOWEGO

## Streszczenie

W badaniach własności dynamicznych konstrukcji kratowych w trakcie eksploatacji wykorzystuje się zazwyczaj testy impulsowe. Jednym z istotnych utrudnień ich stosowania są problemy opisu oraz jednoznacznej interpretacji niestacjonarnych wyników pomiaru.

Nowością zaproponowaną przez autorów jest filtracja sygnału odpowiedzi układu za pomocą analizy falkowej oraz wykorzystanie informacji zawartej w energii sygnału. Opisano sposób wykorzystania transformacji falkowej-Fouriera dla wyznaczenia widma częstotliwościowego ze zrekonstruowanej odpowiedzi impulsowej. Możliwości praktyczne ilustruje przykład zbrojenia szybowego kopalni podziemnej.

Słowa kluczowe: diagnostyka, transformata falkowa-Fouriera, analiza niestacjonarna.

## 1. INTRODUCTION

Shaft reinforcement is one of the elements of shaft equipment. Moving the dishes in straight-line, vertical track provides the secure vertical transportation from the surface to the mine undergrounds. The basic requirement to be controlled during exploitation is providing the appropriate construction strength to carry loads coming from moving lift dishes. At present the reinforcement wear is assessed on the basis of random thickness measurements and calculations of strength coefficients. Inference about the technical condition of the whole reinforcement exclusively on the grounds of these measurements is quite troublesome on the account of:

- incapability of testing every element (total number of several thousand),
- unknown behaviour of the reinforcement under dynamic excitation conditions,
- unknown state of joints between individual reinforcement elements whatsoever

Furthermore, these tests are time-consuming, expensive and require shutdown of all mining transportation. Under the abovementioned circumstances at the Department of Mechanics and Vibroacoustics the research had been taken for the purpose of designing the new method of shaft reinforcement diagnosing offering the possibility of wide applications in industry practice. This method makes allowance for the dynamics of reinforcement construction and relies on the testing of the behaviour of reinforcement element after being set into vibrations with impulse excitation.

Measurement of the response for the excitation and the appropriate measurement signal processing allows making conclusions about dynamic state of the reinforcement, especially about its stiffness significant for the exploitation safety. One of the problems encountered during the designing of the algorithm of dynamic properties determination was designating symptomatic vibration component for beam deflection.

## 2. IMPULSE TEST METHOD IN STEEL CONSTRUCTION INSPECTIONS

Proposed method is based on frequency characteristics' determination by means of impulse excitation (impact hammer) [1].

With respect to non-stationary measurement signal character, designating diagnostic estimates allowing for inference on technical state of examined construction calls for the need of processing simultaneously in two realms: time and frequency.

Wavelet transformation had been selected, which transforms single-dimensional into the realm designated with translation parameter *b* and scale parameter *a*, according to the formula:

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

where: s(t) – measurement signal, *Ψ*- analyzing function, *a* – transformation scale parameter, *b*- displacement parameter

Transformation cores (1) are referred to as wavelets. They constitute oscillating functions, with average value yielding zero, which, displaced in time and scaled, form function group described by the relation:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right) \quad (2)$$

Return into time-realm is processed by means of reverse transformation:

$$f(t) = \frac{1}{C_\Psi}\int_{0}^{+\infty}\int_{-\infty}^{+\infty}\tilde{f}(a,b)\frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right)db\,\frac{da}{a^2} \quad (3)$$

where: $C_\Psi$ – constant dependent on selected analyzing function

In the classic approach, frequency characteristic designation of investigated construction is defined as a relation between Fourier's transform of response signal for the excitation in the form of vibration-acceleration signal, and Fourier's transform of input signal in the form of excitation force:

$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)} \quad (4)$$

where: $H\ (j\omega)$ - frequency characteristic, $Y\ (j\omega)$ - Fourier's transform of output signal

$X\ (j\omega)$ - Fourier's transform of input signal

For non-stationary signals, their time-frequency representations [1, 3, 5] can be used, transformed to frequency realm by the formula:

$$\hat{\tilde{s}}_\Psi(a,\omega) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} s(t)\psi\left(\frac{t-b}{a}\right)dt\, e^{-j\omega b}db \quad (5)$$

and the relation between output and input signals for the implemented impulse test method is described analogically to (4):

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

$$H(\omega) = \frac{\hat{\tilde{s}}_\psi^{wyj}(a,\omega)}{\hat{\tilde{s}}_\psi^{wej}(a,\omega)} \quad (6)$$

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. DIAGNOSTIC SIGNALS ESTIMATES

Thanks to the implementation of the relation (5) it is possible to observe the alterations of dumped vibration signal and its spectrum as a construction response for an excitation.

Such an approach enables filtrating interferences and designating signal components adequate to construction wear categories [3, 6].

Function estimates for technical state categorization are based on Fourier spectrum calculated for signal's time component transferring major part of vibration energy.

$$\hat{\tilde{s}}_\Psi(a_{\max},\omega) = \int_{-\infty}^{+\infty}\tilde{s}(a_{\max},t)e^{-j\omega t}dt \quad (7)$$

where:

$\hat{\tilde{s}}_\Psi(a_{\max},\omega)$ – spectrum of signal's time component transferring major part of vibration energy,

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

Point estimates are calculated as:

- effective value of vibration signal filtered by means of wavelet analysis;
- parameters of signal's energy distribution.

## 5. PRACTICAL RESULTS

Testing of shaft reinforcement verifying the designed processing algorithm was conducted on one of the shafts at Copper Mining and Metallurgy Complex in Polkowice. The draft of the examined shaft reinforcement is presented in fig 1. The examined objects were shaft guide-rails of closed cross-section, constructed of two C140 channel bars propped up by girders at every 3 m stretch.

For comparing purposes, except dynamic-properties measurements of tested guide-rails, wall thickness measurements were carried out by ultrasonic thickness-meter of DMS 2TC type (Krautkramer).

Air-intake, two-compartment shaft was selected, with two skip devices of stiff (steel) head-guidance. Load capacity of lift dishes was 30 Mg of winning each, and moving velocity in the shaft - 20 m/s.

Shaft reinforcement examinations were conducted by means of diagnostic system composed of two parts: stationary and portable. The portable part included a digital recorder and a system conditioning the signals of excitation and element response.

Dynamic excitation was simulated by impacts of modal hammer with force detector installed. As a response signal the accelerations of construction vibration were selected.

After measurement session the data were processed by stationary part of the diagnostic system – PC class computer with software calculating package using wavelet algorithms. Draft of measurement path as well as signal analysis is shown in fig. 2 and 3.

The example results of wavelet processing of signals corresponding to different categories of steel construction wear are illustrated in fig.4 – 7. Figure 4 presents registered response signal after impulse excitation in a construction in a good technical state, of guide-rail wall thickness g=8,1mm, and the signal's wavelet transform. Figure 5 likewise, but for worn out construction of wall thickness th = 6,1 mm.

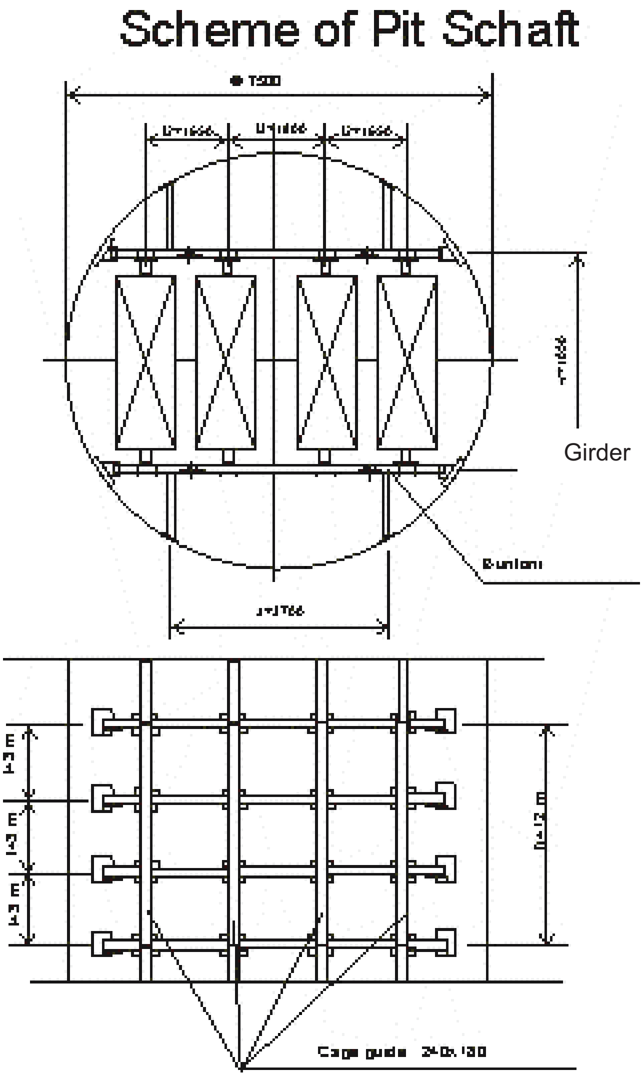

Fig. 1. Draft of examined shaft reinforcement

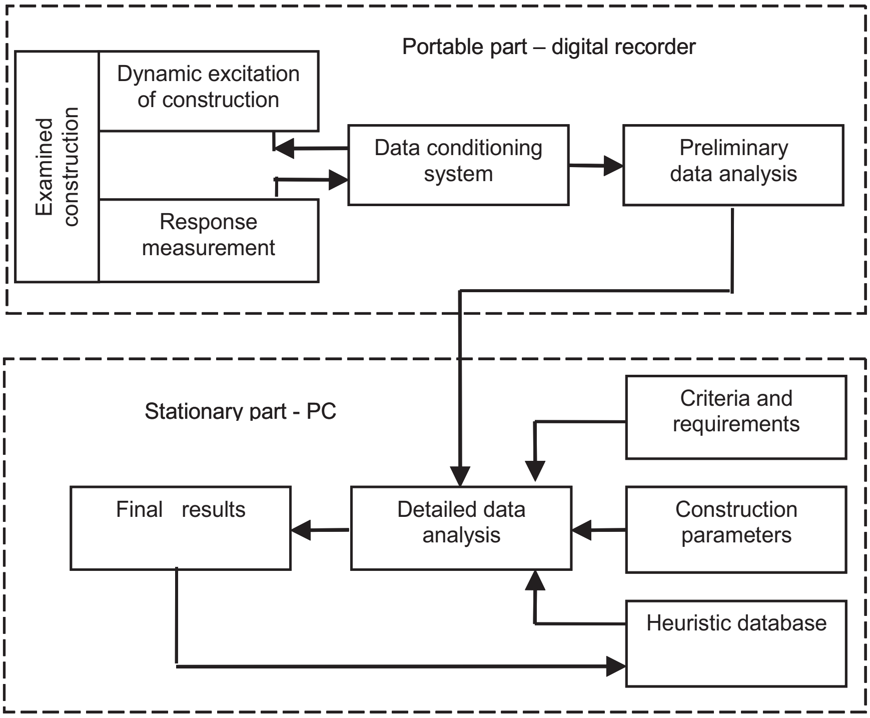

Fig. 2. Draft of acquisition system and data analysis of diagnostic signals in shaft reinforcement

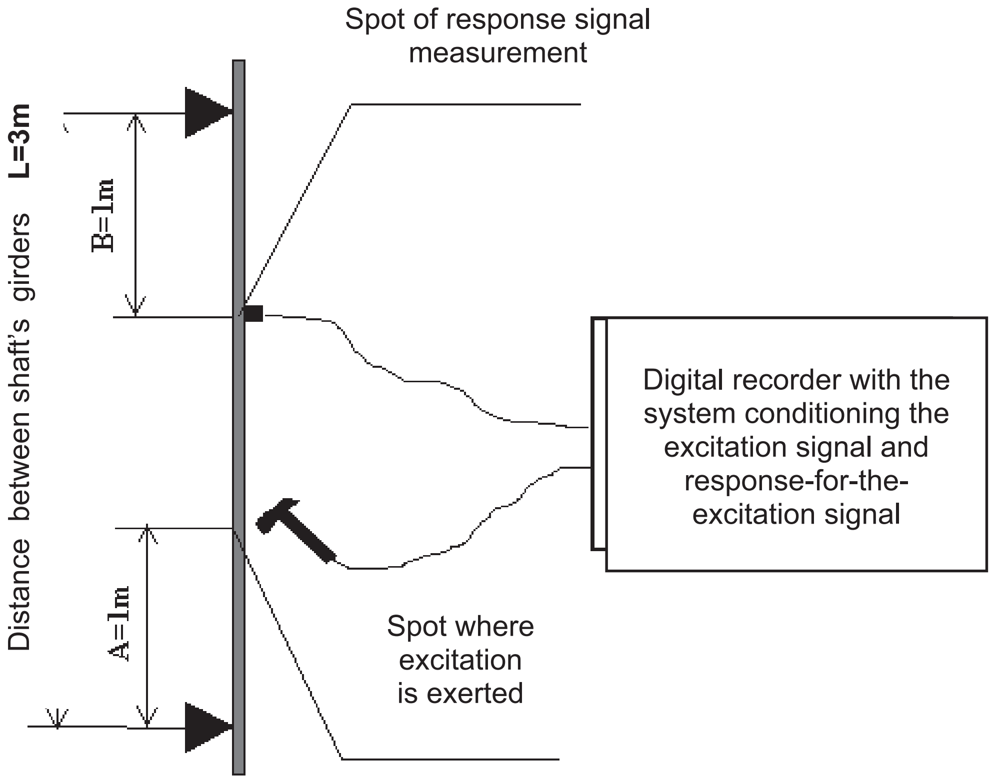

Fig. 3. Measurement path for shaft reinforcement examination by means of impulse test and wavelet signal processing

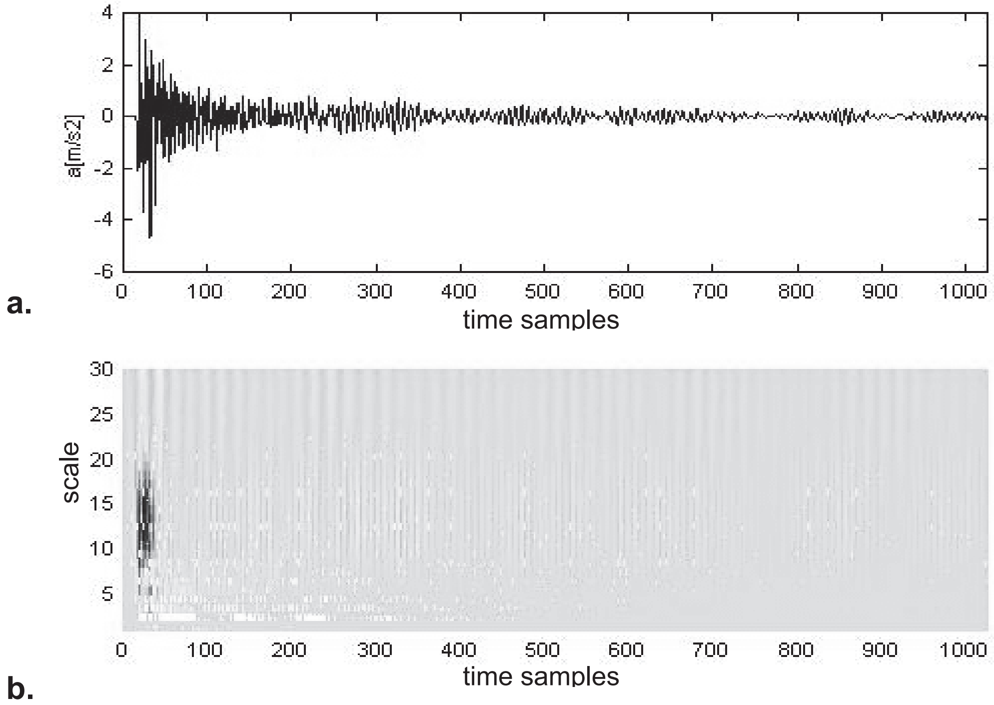

Fig. 4. Results of signal processing for the guide-rail in a good technical state
(wall thickness th. = 8,1mm)
a) response for impulse excitation,
b) wavelet transforms of response signal.

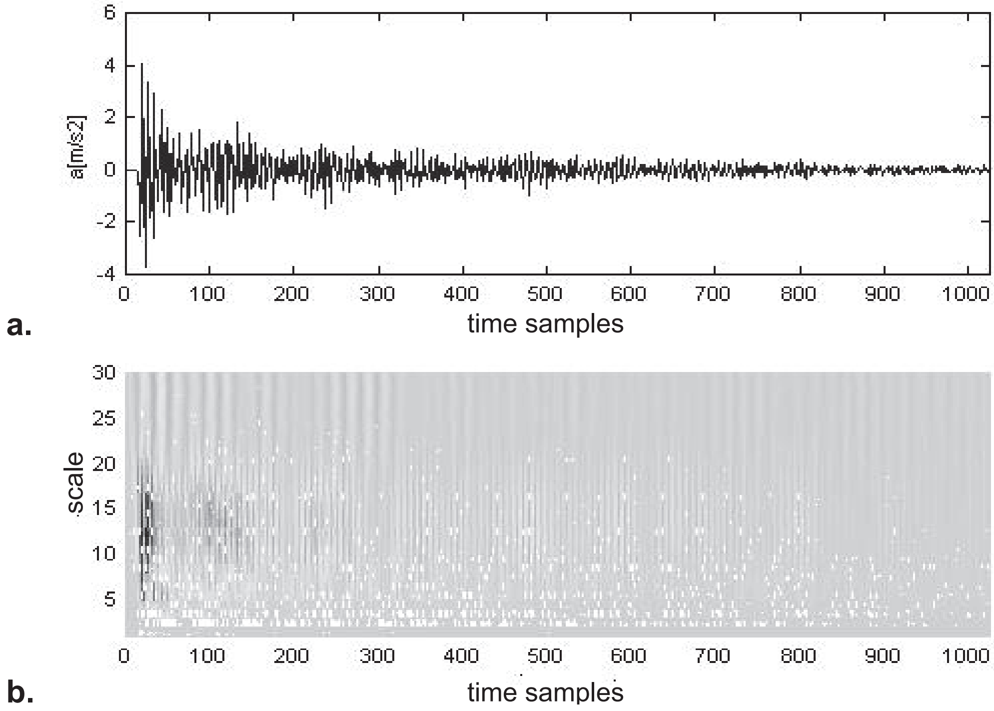

Fig. 5. Results of signal processing for the worn out guide-rail (wall thickness th. = 7,1mm)
a) response for impulse excitation,
b) wavelet transforms of response signal.

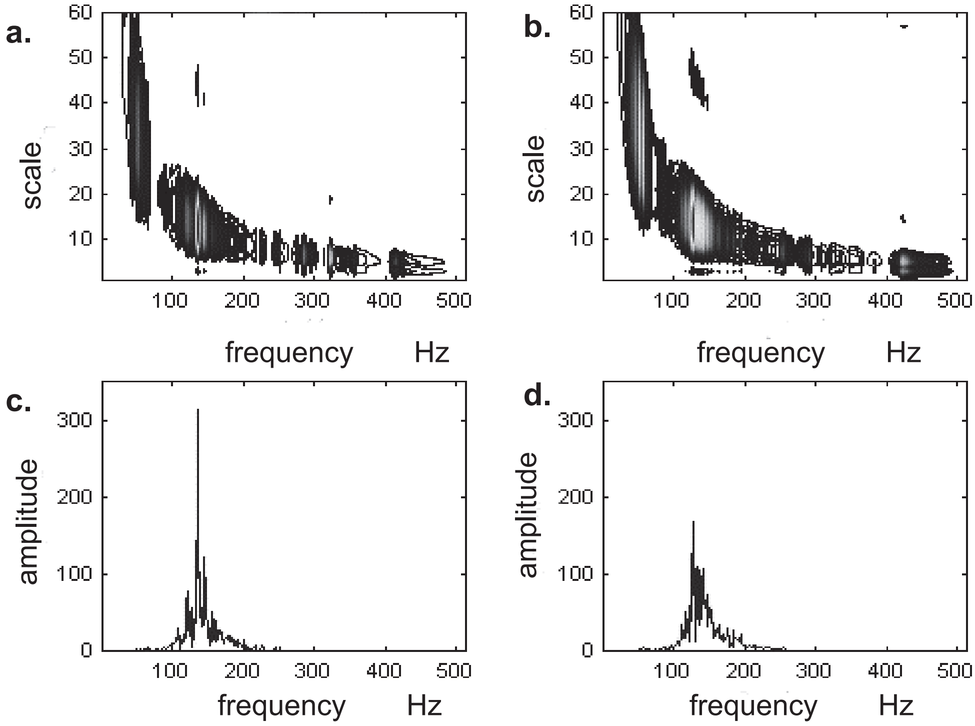

Fig. 6. Wavelet-Fourier spectra for guide-rails in various technical states
a) FFT spectrum of measurement signals for worn-out guide-rail (th .= 6,1 mm),
b) FFT spectrum of measurement signals for the good guide-rail (th. = 8,3 mm),
c) FFT spectrum of filtered signal for worn-out guide-rail (th. = 6,1 mm),
d) FFT spectrum of measurement signals for the good guide-rail (th. = 8,3 mm).

## 6. SUMMARY

By applying wavelet–Fourier transform the authors defined the functional measure of construction wear as a Fourier spectrum of wavelet transform component of the signal responsible for carrying main stream of signal's energy.

The described procedure proved effective in diagnostic identification of non-stationary processes, at least for the range and type of practical verification executed.

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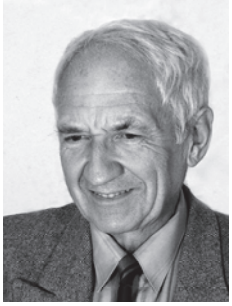
Prof. dr hab. inż. Wojciech BATKO ur.1946, absolwent Wydziału Elektrotechniki Górniczej i Hutniczej Akademii Górniczo-Hutniczej w Krakowie. Specjalista z zakresu dynamiki i wibroakustyki maszyn i związanych z nimi zagadnień: diagnostyki technicznej, budowy systemów monitorujących stan maszyn i procesów wibroakustycznych, ich układów filtracyjnych i predykcyjnych oraz doboru rozwiązań minimalizujących ich oddziaływania. Autor, bądź współautor ok.230 publikacji w czasopismach krajowych, zagranicznych oraz w materiałach konferencji krajowych i międzynarodowych, w tym 12 opracowań książkowych oraz około 300 niepublikowanych raportów z opracowań naukowo-badawczych, projektowych i ekspertyz dla przemysłu i gospodarki narodowej. Obecnie Kierownik Katedry Mechaniki i Wibroakustyki. Promotor 6 doktoratów i około 45 prac magisterskich z dziedziny diagnostyki technicznej i wibroakustyki. Członek wielu Towarzystw Naukowych, Komitetów Naukowych i Programowych szeregu konferencji krajowych i międzynarodowych oraz Rady Naukowej Faculty of Mechanical Engineering Technical University of Ostrava.



Dr hab. inż. Piotr KRZYWORZEKA, prof. AGH pracuje na tej uczelni od ukończenia studiów. Wykładał kilka lat w Algierii. Jest autorem ok. 90 publikacji, głównie o tematyce diagnostycznej, rzeczoznawcą SEP w zakresie elektroakustyki, a także członkiem PTDT od momentu jego powstania. W pracy badawczej preferuje podejście sygnałowe. Interesuje się także psychologią i filozofią. Jako środek transportu preferuje rower.

Dr inż. Andrzej MIKULSKI ur. 1964, absolwent Wydziału Maszyn Górniczych i Hutniczych Akademii Górniczo-Hutniczej w Krakowie. Specjalista z zakresu eksploatacji urządzeń transportu linowego i diagnostyki wibroakustycznej. Współautor wspólnie z Prof. W. Batko, bądź jako autor samodzielny ponad 20 publikacji w czasopismach krajowych, zagranicznych oraz w materiałach konferencji krajowych i międzynarodowych.