PROBLEMS AND SOLUTIONS IN CONDITION MONITORING AND DIAGNOSTIC OF OPEN CAST MONSTER MACHINERY DRIVING SYSTEMS

Walter BARTELMUS, Radosław ZIMROZ

Wrocław University of Technology
Diagnostics and Vibro-Acoustics Science Laboratory
Pl. Teatralny 2, Wroclaw, 50-051, Poland
Tel. (+48 71) 320 68 49, Telefax (+48 71) 344 45 12
E-mail: {walter.bartelmus, radoslaw.zimroz}@pwr.wroc.pl

Summary

In the paper is given discussion on demands connected with vibration signal analysis for condition monitoring of driving systems of monster machinery used in open cast mines. Because of external load variation which cause that the vibration signal generated by driving systems is no-stationary there is a need to use special techniques for signal analysis. The description of proper signal analysis techniques is given together with machinery description and external load characteristic. The description leads to design, production technology, operation, change of condition factors analysis [1].

Keywords: condition monitoring, mining machines, open cast mines, external load variation.

PROBLEMY I ROZWIĄZANIA W DIAGNOSTYCE UKŁADÓW NAPĘDOWYCH MASZYNOWYCH GIGANTÓW PODSTAWOWYCH GÓRNICTWA ODKRYWKOWEGO

Streszczenie

W pracy przedstawiona jest dyskusja o wymaganiach związanych z analizą drganiowego sygnału dla monitorowania układów napędowych maszynowych gigantów używanych w górnictwie odkrywkowym. Ponieważ drganiowe sygnały generowane przez układy napędowe na skutek zmienności obciążenia generują niestacjonarny sygnał istnieje potrzeba wykorzystania specjalnych technik do analizy sygnału. Przedstawiono opis niektórych maszynowych gigantów wraz z technikami analizy sygnałów i charakterystyki zmienności obciążenia. Opis prowadzi do analizy czynników konstrukcyjnych, technologicznych, eksploatacyjnych i zmiany stanu [1].

Słowa kluczowe: monitorowanie stanu, maszyny górnicze, górnictwo odkrywkowe, zmienne obciążenia.

1. INTRODUCTION

For driving of open cast machinery there are used systems which consists of electric motor, hydraulic coupling or damping mechanic coupling (in some cases both) and different type of gearboxes. Taking into consideration type of the external load, which may be classified as: varying slowly with random cycles of many minutes or a few minutes, varying quickly with cycle from less than a second to a few seconds. For driving systems of belt conveyors the length of cycle depends mainly of the length of a conveyor and from the current output of bucket wheel or chain excavators. Taking into consideration driving systems a bucket wheel load period variation depends on a bucket frequency. Another period for bucket wheel excavators is connected with the slewing of a bucket wheel. The external load of driving systems causes non-stationary vibration which is the signal for the driving system condition. This situation demands special treatment used for vibration signal analysis.

2. SOME MONSTER MACHINERY DRIVING SYSTEMS

Fig. 1 shows a driving station for belt conveyor systems with the scheme of a driving subsystem. The driving station incorporates three or four subsystems. Fig. 2 shows a bucket wheel during the operation and the scheme of bucket wheel drive with three subsystem positions. The discussed bucket wheel drive has three independent driving systems driven by three electric motors. The subsystem consists of planetary gearbox with a fixed rim z3 and three cylindrical stages of gearboxes z4 – z9. One of alternative solutions for a compact drive used for driving bucket wheels is given in Fig. 3. The system consists of a bevel gear stage and a special solution gearbox which gives possibility of driving power distribution into two ways. This possibility is given by planetary gearbox in which the sun z3 and rim z5 are rotated.

a)

b)

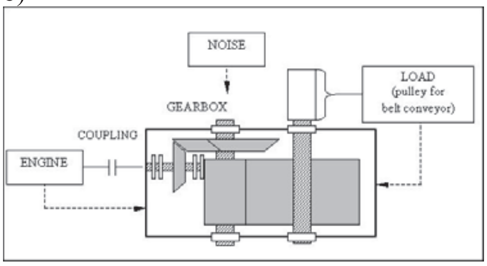
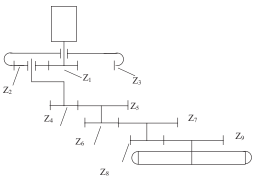


Fig. 1. a) General view of belt conveyor driving system, b) scheme of one subsystem

a)

b) c)



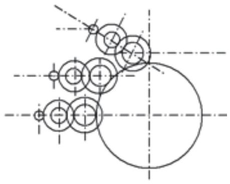


Fig. 2. a) Bucket wheel during operation
b) scheme of subsystem bucket wheel drive
c) subsystem positions

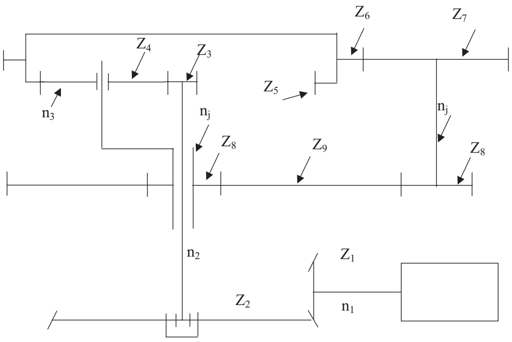
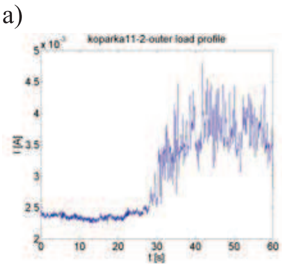


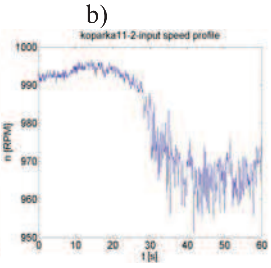
Fig. 3. Bucket wheel alternative driving system

2. EXTERNAL LOAD DESCRIPTION

The bucket wheel design which comes from digging principle is the reason of periodic variation of external load. Much longer period of load variation is connected with the boom slewing. The other operation factors influencing the load variability are connected with digging ground properties. These design and operation factors leads to external load variations and closely connected with generated vibration represented by time courses given in Fig. 4. In Fig. 4a) is given electric current consumption variation which represents directly load variation. The vibration signal variation is given in Fig. 4c). Fig. 4a) and c) show positive correlation between load and vibration. Fig. 4b) and c) shows negative correlation between load and rotation speed or between vibration and rotation speed. Detailed signal analysis can show load variations connected with bucket frequency. The vibration signal showing the value proportional to load variation is given in Fig. 10. The vibration signal procedures for load variation extraction is given in [2-4].

a) b)





c)

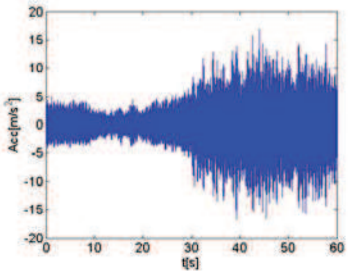


Fig. 4. a) Electric current consumption variation
b) input shaft rotation speed RPM variation
c) vibration signal variation

4. FACTORS INFLUENCING DIAGNOSTIC SIGNALS

Fig. 5 and 6 show general and detailed division of factors having influence the vibration signal. Fig. 5 shows that primary and secondary factors having influence generated vibration signal can be divided into four groups of factors. More details for further division of factors is given in Fig. 6. The detailed description of factors having influence to vibration signals is given in [1] it also well to look into publications [5 – 7] where many examples are given where different factors influencing vibration signals are considered.

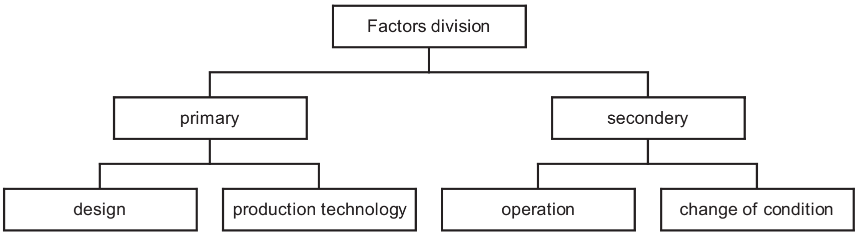


Fig. 5. General division of the factors influencing diagnostic signals

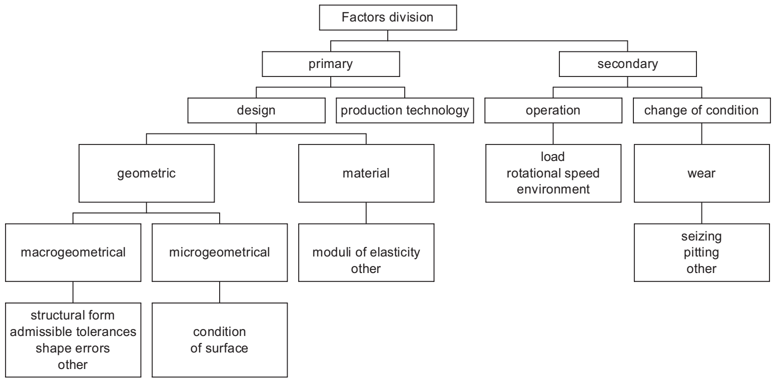


Fig. 6. More detailed division of factors influencing diagnostic signals

5. VIBRATION SIGNALS ANALYSIS

The choice of a vibration signal analysis depends of an external load variation. If the signal is constant or with the slow variation the first step for signal analysis is a spectrum analysis [6–9]. It is used for the object presented in Fig. 1. For deeper analysis are used also other techniques for signal analysis like cepstrum given in Fig. 7 and time-frequency spectrograms given in Fig. 8.

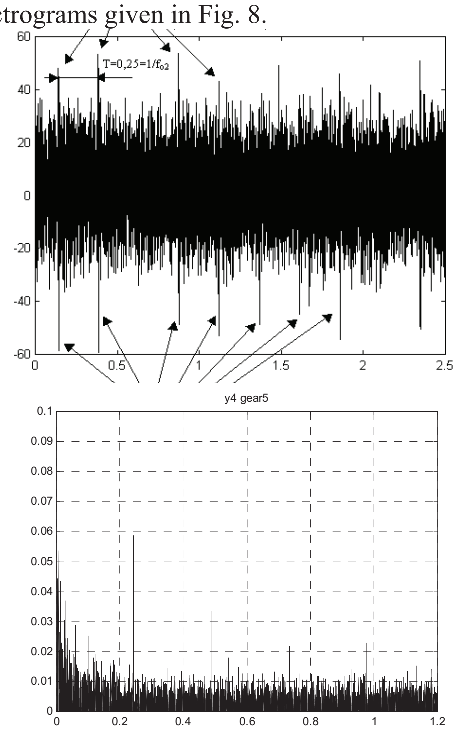


Fig. 7. Acceleration [m/s2] signal time [s] trace with series of peaks (peaks marked with arrows) and cepstrum for signal

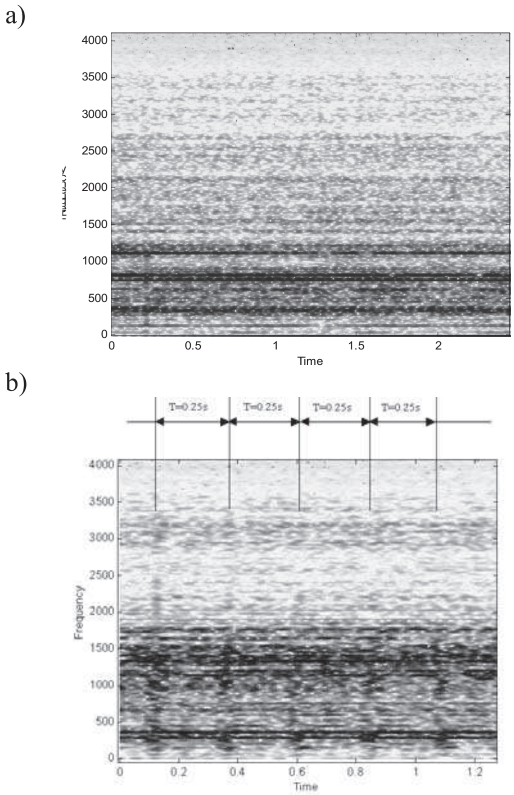


Fig. 8. Time-frequency [s]-[Hz] spectrograms
a) spectrogram of signal without regular peaks
b) spectrogram of signal with marks equivalent regular peaks

Details for these techniques of signal analysis are given in publications [6, 9].

Further analysis is connected with Fig. 9 where classification of gearing condition is given it is based on publications [7, 8]. It should be noticed that the inclination of the line separated the gear condition classes are also the measures of a gear condition.

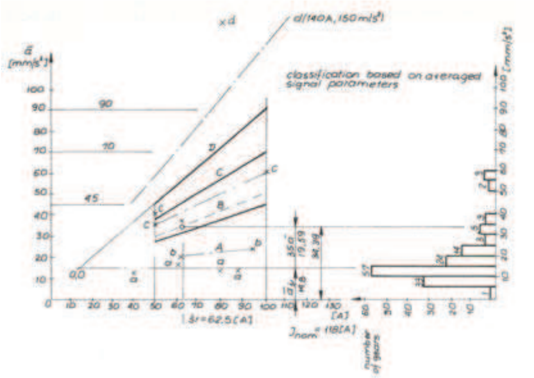


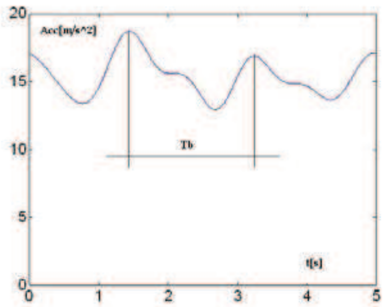
Fig. 9. Effect of load on gear transmission condition symptom value, accelerations in band 100-3500 Hz: A÷D – gear transmission classes; a÷d – gear transmission points, number of gear transmissions [7, 8]

The obtained results of signal analysis lead to identification of distributed and local faults and it is also the measure of the increase of a backlash in rolling elements bearings. More details about increase of the backlash are given for considering the case when the cycle varying load occurs.

Non-stationary vibration signal generated by some monster machinery needs special techniques for signal analysis. The signal analysis should give the background for condition evaluation and maintenance decisions. As the result of signal analysis one can expect detection of local and distributed faults and increase of elements play caused by the increased bearing backlash as result of harsh mine environment. For identification of the external load variation can be used signal demodulation techniques to obtain results as it is given in Fig. 10, [2–4] which envelopes are proportional to load variation; a) signal from gearbox before replacement b) signal from replaced gearbox. It can be seen that if the system is in bad condition it more yields under varying cyclic load as is given in Fig. 10a).

Variability of some parameter, which characterized the digging process are given in Fig. 10 to 12. In Fig. 10 and 11 are compared results of signal analysis of two gearboxes in bad and good condition. Fig.10 gives envelopes proportional to load variation: a) signal from a bad gearbox before replacement b) signal from a new replaced gearbox. Fig. 11 gives time [s] – frequency [Hz] spectrograms a) signal from a gearbox before replacement b) signal from a replaced gearbox. Fig. 10 shows the periodic variation of the signal with the bucket digging period Tb. this period is also depicted in the time-frequency spectrogram given in Fig. 11. Additionally one can noticed weak a period connected with a planetary gearbox arm/carrier rotation Ta. Fig. 12 gives more clear evaluation of the period by Wigner-Ville distribution with change in condition of the arm of the planetary gearbox: a) occurrence of distinct perturbations at the period equivalent the second harmonic of the arm rotation frequency, the gear condition before replacement of the gearbox b) occurrence of distinct perturbations at the period of the arm rotation frequency Ta for an other gearbox in a bad condition.

a)



b)

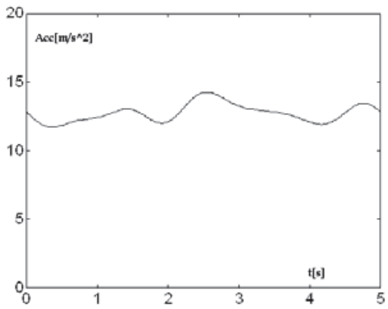
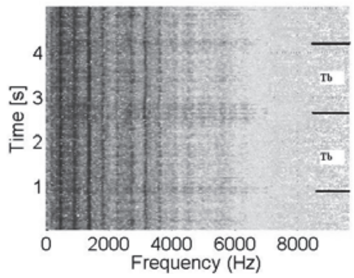


Fig. 10. Envelopes proportional to load variation: a) signal from bad gearbox before replacement – bad condition, b) signal from new replaced gearbox – good condition

a)



b)

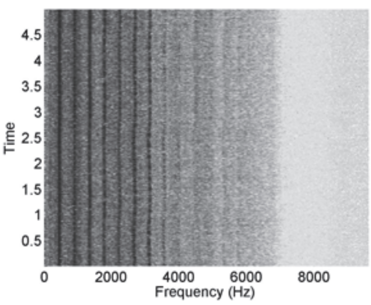
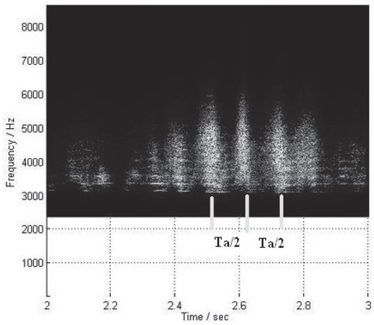


Fig. 11. Time [s] – frequency [Hz] spectrograms: a) signal from gearbox before replacement (bad condition) b) signal from replaced gearbox (good condition)

a)



b)

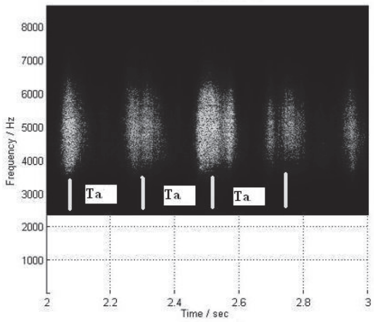


Fig. 12. Evaluation of Wigner-Ville distribution with change in condition of the arm of the planetary gearbox a) occurrence of distinct perturbations at second harmonic of the arm rotation frequency, condition before replacement of the gearbox b) occurrence of distinct perturbations at the arm rotation frequency for an other gearbox in a bad condition

Fig. 3 shows the scheme of a driving system which condition will be evaluated. It is a compact system which consists of an electric motor, one stage bevel gear (gears z1, z2), planetary gearbox with rotating sun z3 and rotating rim z5 and a planet z4. The power in the compact system is transmitted to the main gear z9 through two pinions z8 to accomplish it two gear are added z6 and z7. The variation of different parameters characterizing phenomenon of bucket wheel operation are given in Fig. 4. Fig. 4 shows in c) an input shaft rotation speed variation in RPM a) electric current consumption variation b) vibration signal variation.

Fig. 9 shows positive correlation between investigated values; Fig. 15 shows negative correlation for investigated values. The linear characteristics can be expected only for some range of an increased backlash in rolling elements bearings.

To obtain vibration parameters the signals were processed to get vibration spectrums as is given in Fig. 13. It should be stressed that the spectrums should be done for short time intervals to obtain no smeared spectrums. The intervals are equivalent to a bucket digging period Tb. The examples for the smeared and non smeared frequency component are given in Fig. 14.

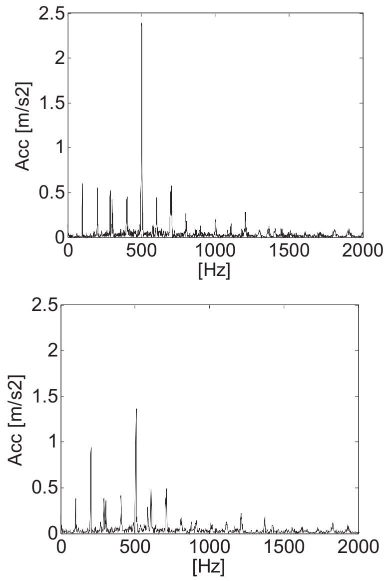
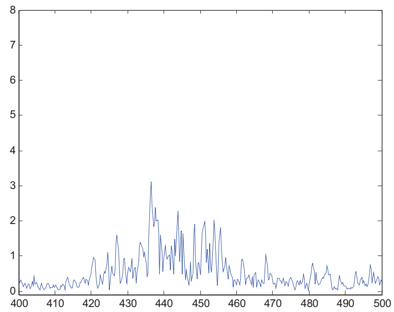


Fig. 13. Examples of short time segment frequency analysis

a)



b)

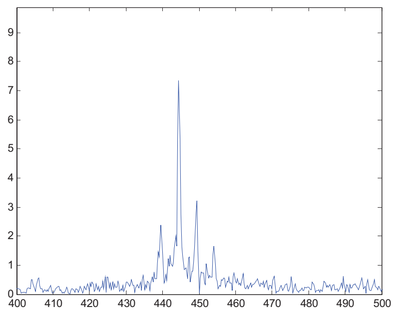


Fig.14. a) Smeared spectrum caused by frequency modulation b) non smeared spectrum

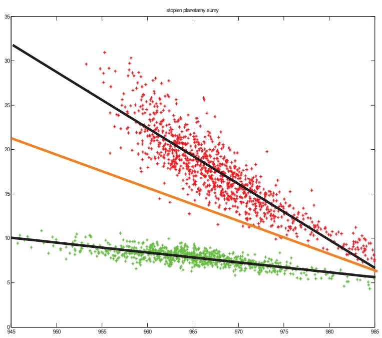


Fig. 15. Vibration signal RMS component sum versus rotational speed for planetary stage

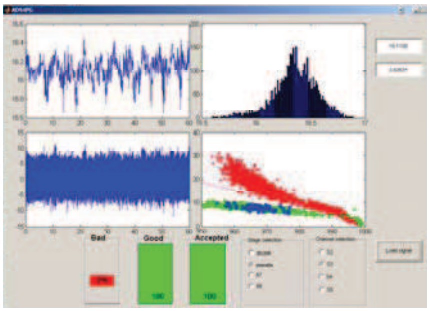


Fig. 16. Graphic interface for data analysis system

Fig. 16 shows a graphic interface for a data analysis system. In Fig. 16 one can see the course of rotation frequency variation in [Hz] as a function of time [s] (at the gearbox side of hydraulic coupling), distribution of the rotation frequency [Hz], variation of acceleration signal [m/s2] as a function of time, the plot of vibration parameters as a function of [RPM]. The plot has been obtained as the results of several vibration signals as are given in Fig. 4b) The values of parameters equivalent 60[s] period for a gearbox in good condition is given by green dots. From the vibration signal given in Fig. 4 part of the results has been automatically rejected. Into consideration are taken only spectrums, which have been obtained for a proper loaded gearbox for the distribution of the rotation frequency similar to distribution given in Fig. 16. For the data presented in the plot given in Fig. 15, which is also given in Fig. 16 the linear regression analysis has been done and obtained the equation of the external load yielding statistical characteristics in the form $y = ax + b$ for good and bad planetary gearbox.

6. CONCLUSIONS

The Paper shows the different ways of signal analysis, which have been used for condition monitoring and diagnostic for monster machines used in open cast mines. Some of the ways are connected with traditional ways of the signal analysis; these ways can be used when external load is constant or almost constant. There have been also shown new ways of signal analysis and its interpretations. These ways are suitable for the varying external load.

LITERATURE

[1] Bartelmus W.: *Root cause analysis of vibration signals for gearbox condition monitoring*. BINDT Inside Journal Vol 50 No 4 April 2008.

[2] Bartelmus W., Zimroz R.: *Influence of random varying load to vibration generated by planetary gearbox driving bucked wheel in excavators*. International Conference on COMADEM Lulea Sweden June 2006.

[3] Bartelmus W., Zimroz R.: *Bucket wheel variability identification on vibration analysis*. Proceeding of the International Symposium Mine Planning and equipment selection Torino Italy, 20-22 September 2006 pp.71-76.

[4] Bartelmus W. Zimroz R.: *Vibration condition monitoring of planetary gearbox under varying external load, Mechanical Systems and Signal Processing* (accepted for publication).

[5] Bartelmus W. *Mathematical Modelling and Computer Simulations as an Aid to Gearbox Diagnostics*. Mechanical Systems and Signal Processing 2001 Vol.15, no. 5, pp. 855-871.

[6] Bartelmus W.: *Computer-aided multistage gearbox diagnostic inference by computer simulation*. Scientific Papers of the Institute of Mining of Wroclaw University of Technology. No.100, 2002 (available on Internet at Dolnoslaska Digital Library).

[7] Bartelmus W.: *Condition monitoring of open cast mining machinery*. Oficyna Wydawnicza Politechniki Wrocławskiej Wrocław 2006 (available on the Internet at Dolnoslaska Digital Library).

[8] Bartelmus W.: *Vibration condition monitoring of gearboxes*. Machine Vibration 1992 nr1 s.178-189.

[9] Bartelmus W.: *Diagnostic information on gearbox condition for mechatronic systems*. Transaction of the Institute of Measurement and Control 25,5 (2003), pp. 450-464.

Prof. dr hab. inż. **Walter BARTELMUS.** Specjalista z zakresu eksploatacji, dynamiki i diagnostyki maszyn. Autor około 150 publikacji w tym jednej książki oraz współautor trzech monografii. Pracownik Politechniki Śląskiej (1967-1980) Instytutu Górnictwa Odkrywkowego, Wrocław (1980-1993), Politechniki Wrocławskiej (od 1994). Stypendia i wykłady: Polytechnic of Central London, Swansea University College, Southampton Institute Systems Engineering Research Center, Gunma University, Laboratoire d'Analyse des Signaux & des Processus Industrieis,. Wykłady na zaproszenia i w ramach programu Sokrates-Erasmus: Vaxjo University, Lulea University, Compiegne UTC, Cranfield University.

Radosław ZIMROZ, PhD. MSc from Faculty of Electronics (speciality -Acoustics) Wroclaw University of Technology, 1998, PhD (2002) at Mining Faculty, WUT (with honours).

Until now with Machinery Systems Group at Institute of Mining Engineering, WUT. 9 months postdoc (2004) at Cranfield University (SOE/PASE/AMAC), UK.