WADY I ZALETY ANALIZ: CEPSTRUM, WIDMO OBWIEDNI I BISPECTRUM W DIAGNOSTYCE WIELOSTOPNIOWYCH PRZEKŁADNI ZĘBATYCH

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Streszczenie

Zastosowanie modelowania matematycznego i symulacji komputerowej zjawisk dynamicznych w przekładniach zębatych pozwala wygenerować sygnały i wykonywać na nich analizy podobnie jak dla sygnałów drganiowych z przekładni w czasie jej eksploatacji. Uzyskane sygnały poddawane są analizie w celu określenia diagnostycznych własności sygnału i relacji pomiędzy sygnałem a stanem technicznym. Stan techniczny przekładni zębatej można opisać za pomocą wielu czynników pogrupowanych następująco: czynniki konstrukcyjne, czynniki technologiczne, czynniki eksploatacyjne, zmiana stanu. Dotychczasowe publikacje autorów wykazują, że takie sformułowanie problemu prowadzi do wyodrębnienia informacji diagnostycznej zawartej w sygnale drganiowym, co pozwala ocenić stan techniczny przekładni Do oceny stanu technicznego na podstawie drga ñ można wykorzystać wiele metod analizy sygnałów. W pracy przegląd i porównanie najpopularniejszych metod stosowanych diagnostyce zorientowanej uszkodzeniowo. Podkreślono problemy z interpretacją wyników analiz cepstrum i widmo obwiedni dla sygnałów drganiowych z przekładni badanych przez autorów. Wyeksponowano zalety analizy bispektralnej w procesie identyfikacji struktury częstotliwościowej sygnału drganiowego, lokalizacji uszkodzeń (nieprawidłowa praca wałów, uszkodzenia lokalne oraz zużycie) i w wykrywaniu wczesnych faz niesprawności.

Słowa kluczowe: signal analysis, diagnostic inferring, fault detection and localisation

ADVANTAGES AND DISADVANTAGES OF USING CEPSTRUM, ENVELOPE SPECTRUM AND BISPECTRUM FOR MULTISTAGE GEARBOX DIAGNOSTIC

Summary

Using mathematical modelling and computer simulation we can generate vibration signals and made complex and complete investigation on diagnostic signal properties and on relation between vibration and gearbox condition. Many publications presented by the authors and another investigators proved that it is a truthful way. Gearbox condition should be divided into four groups of factors videlicet: design factors (DF), production technology factors (PTF), operational factors (OF) condition change factors (CCF) collectively DPTOCCF. Publications given by the authors show that using collectively DPTOCCF leads to inferring diagnostic information of gearing system condition. For signal assessment may be used signal analysis. A review and comparison of most popular vibration signal analysis method used for fault detection and localisation in gearbox condition assessment problem are presented in this paper. Some disadvantages of cepstrum and envelope spectrum methods are underlines. Bispectrum analysis is recommended for identification of signal structure (as well modulation, defect detection), fault localisation (for example unstable shaft work, local tooth failure, distributed failures) and early stage fault detection.

Keywords: signal processing, vibration analysis, diagnostic inferring, fault detection and localisation

1. INTRODUCTION

In condition monitoring of multi-stage gearboxes are used different ways of condition assessment. The most popular is to use vibration for condition inferring. Inferring on rough data does not give good results so vibration signals are properly processed. In the paper are given suitable ways of vibration signal processing used for gearbox condition monitoring.

There are stressed their advantages and disadvantages using them for fault detection.

2. ENVELOPE SPECTRA

In multi-stage gearboxes in non-linear condition of inner gear excitation there is vibration transmission between gear stages [11,2,3,7,18]. In vibration spectrum occur components as an effect of a signal modulation of a first stage gearing frequency by a second stage gearing frequency. In Fig.1 is given a signal obtained by synthetic way, which is identical as in analysed gearboxes. In Fig.2a is given signal obtained by mathematical modelling and computer simulation gained from a tuned gearbox model. In figure we see marked side-band components. Fig.2b gives us an envelope spectrum of measured vibration signal. Beside of components reviling modulation by a fast rotating shaft there seen components not having relation to any rotating gearbox component. Overlapping of side component airside from between gear stage modulation causing arising of new components.

Let's consider two meshing frequencies for first and second stage: f_{mesh1}=382Hz and f_{mesh2}=148. f_{mesh2} (and their harmonics) modulates f_{mesh1} (and their harmonics) so we obtain following frequencies: 2 left and right sidebands around f_{mesh1}(382-148=234, 382-2*148=86, 382+148=530, 382+2*148=678), 3 left sidebands around 2*f_{mesh1}(764-148=616, 764-2*148=468, 764-3*148=320). It leads to such false frequency components as 86 and 234Hz in the envelope spectra Fig.2b.

Details in the author papers [1,2,3,18]

a) b) c) d)

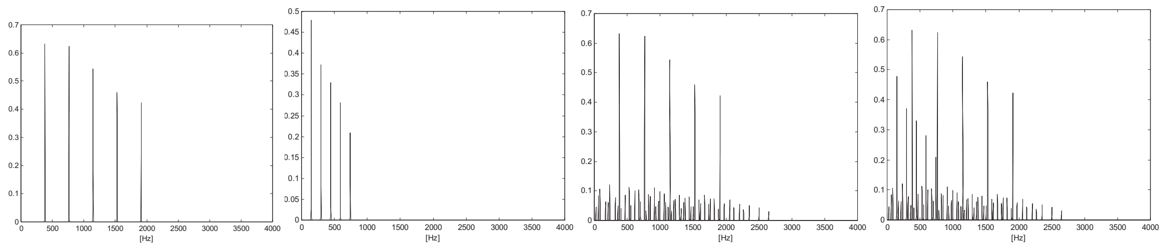

Fig.1 Linear spectrums of simulated signals a) carrying signal, b) modulating signal, c) modulated signal, d) sum of signals

a) b)

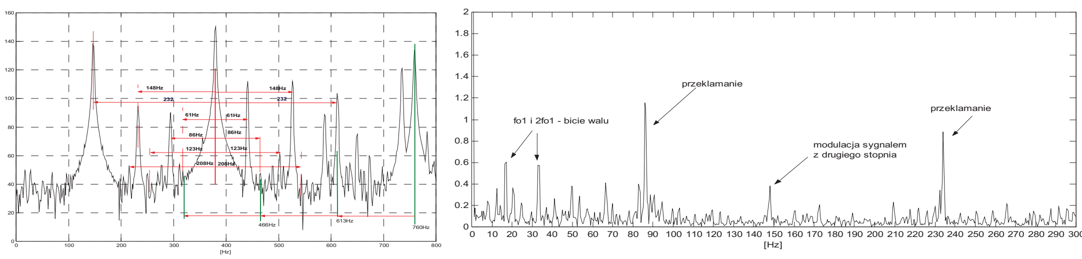

Fig 2 a) Decibel spectrum of reference signal with marked side frequencies, b) envelope spectrum of measured signal with false components 86 and 320Hz, for gearbox marked D23B

3. ENVELOPE ANALYSIS FOR CRACK DETECTION AND LOCALISATION

As it is suggested in [17] envelope analysis can be done for a signal filtrated in the band of a gearing resonance frequency. For detection of the resonance area a vibration spectrum is given in Fig.3a). It is seen in Fig.3a that the resonance area is close to the second meshing harmonic component so the signal is filtered in the band in 800 – 1200Hz. In Fig.3b one can see simulated raw signal obtained at reference gearing condition and with one tooth broken with 10% stiffness change. Fig.3b also gives a residual signal, the signal in which the meshing component is removed. The third 3b figure gives an envelope of the signal. The same analysis for measured signal is given Fig.3c. Fig.3 show us possibility of early detection of a cracked tooth.

4. CEPSTRUM ANALYSIS

Randall [15] suggested using cepstrum for vibration signal analysis for local fault detection. Examples of using cepstrum for local fault detection are given in Fig.4. The local fault causes a wide band modulation exited by impulse repeated of cycle shaft rotation. The authors showed that a wide band modulation also occurs at condition of distributed faults [1,2,3,5,18]. The same symptoms for different faults cause difficulties in proper diagnostic assessment, examine Fig.4a - b and Fig.5a – f.

a) b) c)

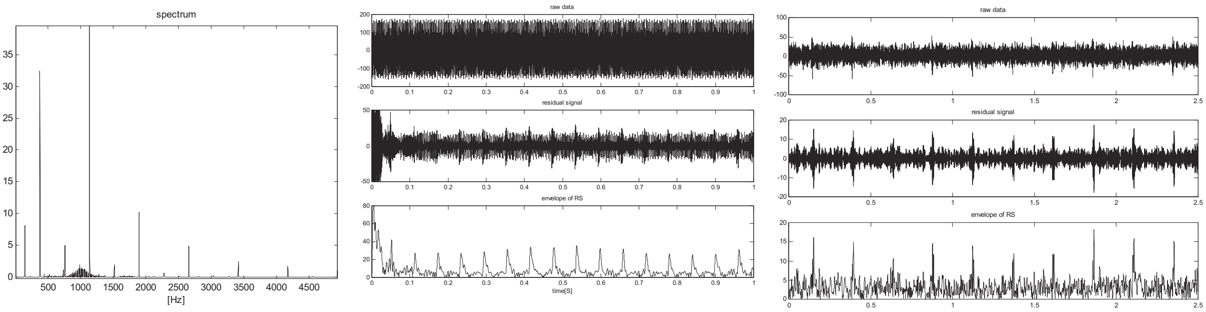

Fig 3 a,b) Model based signal analysis, a) spectra of acceleration from gearing (first-stage) - for detection resonance area, b): raw data , residual signal (RS) (without 1 and 2 stage mesh components), envelope of RS filtered at 800-1200 Hz range c)Real vibration analysis (raw data, residual signal, envelope of RS filtered at 800-1200 Hz range)

a) b) c) d)

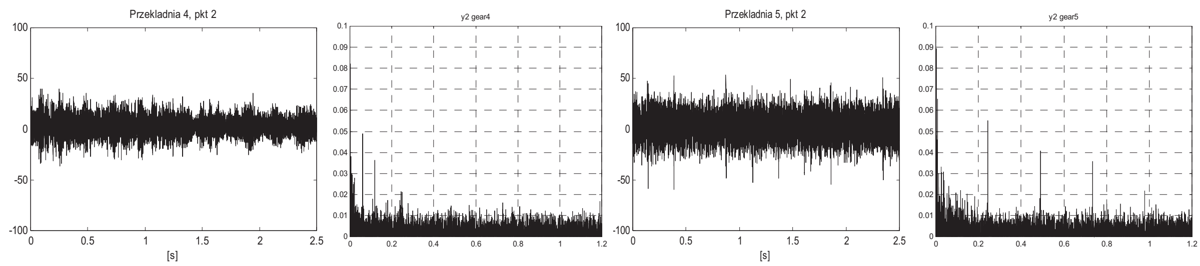

Fig.4 Time signals and their cepstrums for a gearbox in good condition (D23D_0800) and for the gearbox with a local fault (D21A_0800)

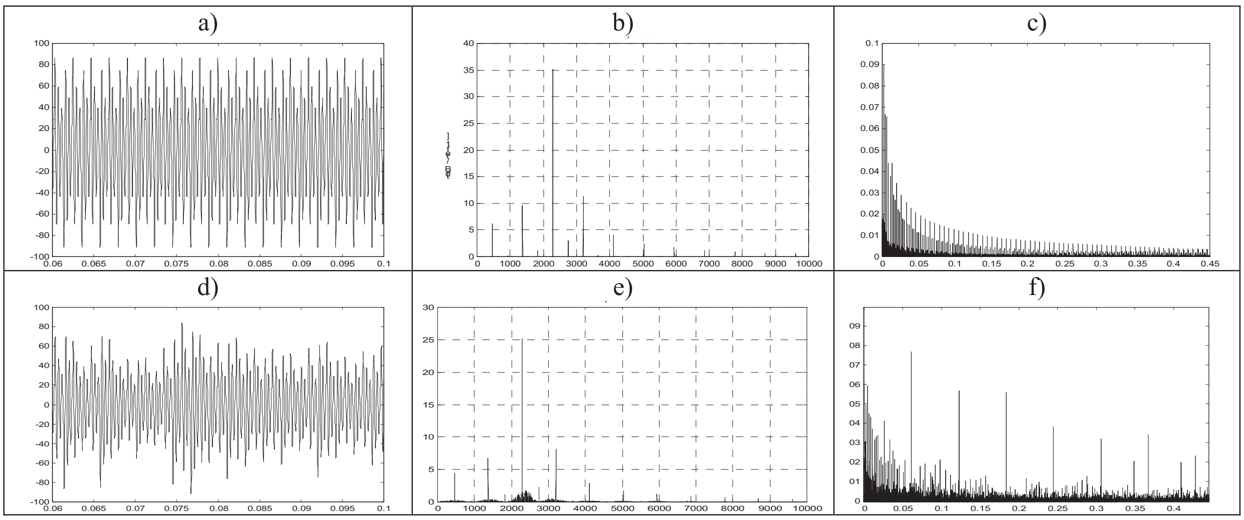

Fig.5 Simulated time signals and their spectrums and cepstrums a – c for evenly distributed faults, d – f randomly distributed faults

5. HIGHER ORDER SPECTRA.

Identification problems inclined the authors to use higher order spectra for spectral structure identification. The higher order spectra identify non-linear relations in vibration signal, as it is given in [8,9,7,13,14,1,2,18] where bispectrums are used. It may be used for assessment of interaction between gearbox stages as it is given in [18]. One of an important advantage is the possibility of early detection of faults [13,14,16,1,18].

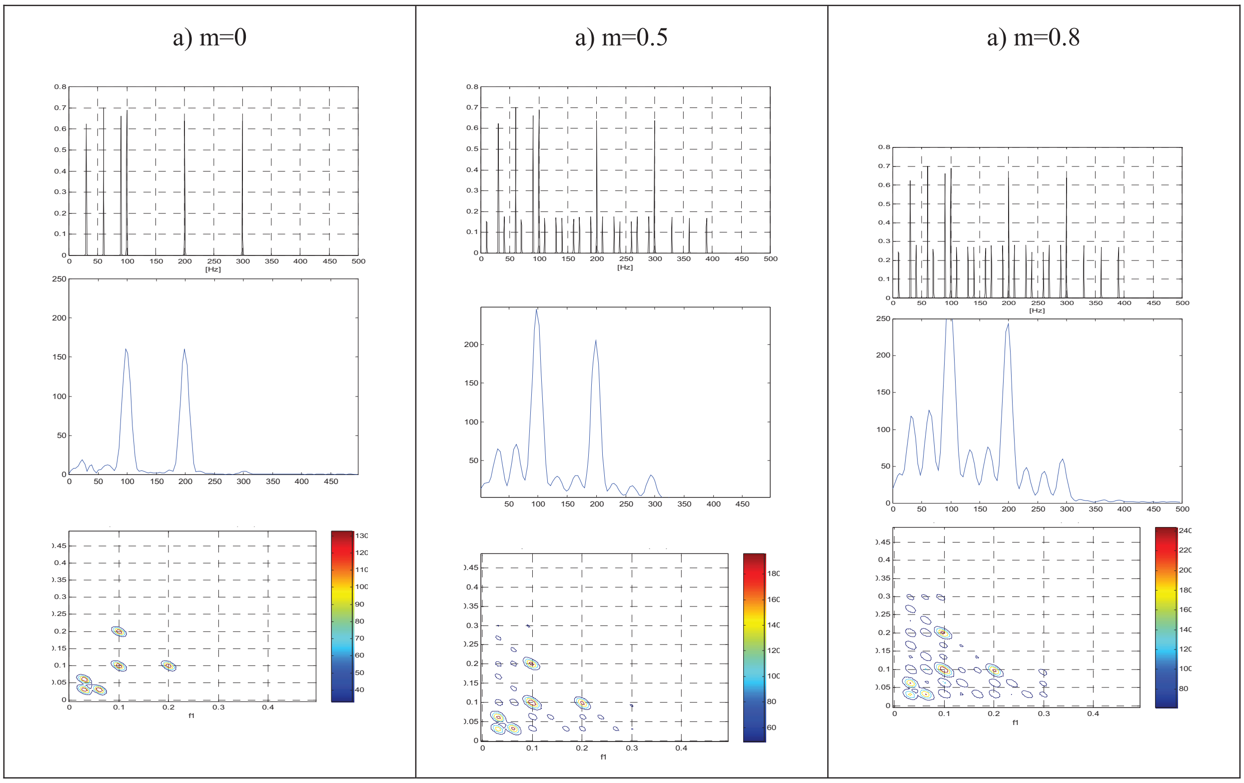

Fig.6 Spectra, bispectra and some bispectra's slices for first meshing harmonic and for three values of modulation depth m. = 0, m. = 0.5, m. = 0.8.

6. BISPECTRUM AND BICOHERENCE

As a result of bispectral analysis we obtain local peaks at co-ordinate (f_a,f_b) (Fig.7) which shows non-linearity between components f_a,f_b and the intensity of components depends of spectrum components intensity. The dependency of spectrum components intensity to the bispectral analysis gives interpretation problems. To overcome the problems normalised function is used called bicoherence. In this way we obtain information only on non-linearity.

a) b)

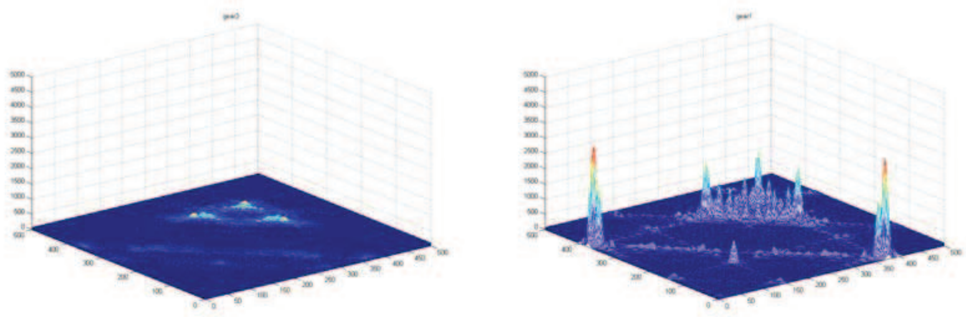

Fig.7 Bispectra, good (gearbox no3) and bad (gearbox no.1) gearbox condition comparing

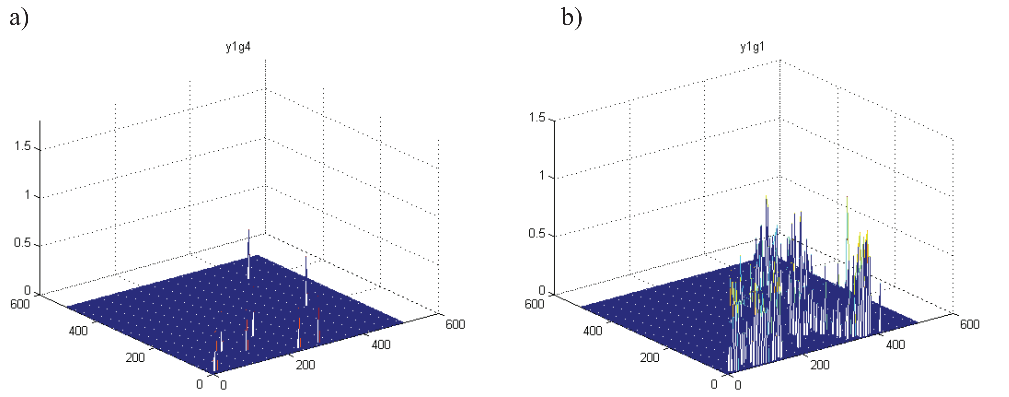

Fig.8 Bicoherence, good (gearbox no3) and bad (gearbox no.1) gearbox condition comparing

7. CONCLUSIONS

Advantages and disadvantages of some ways of signal analysis for gearbox condition assessment are given in the paper. It is postulated to use suitable signal analysis for certain fault detection. In field industry practice of unknown gearbox condition several ways of signal analysis should be used. Deed knowledge on relation DPTOCC factors and diagnostic signal gives possibility of proper signal analysis choice for certain fault detection.

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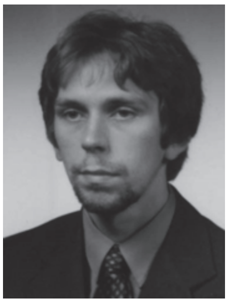

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