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# *DIAGNOSIS OF INDUSTRIAL GEARBOXES CONDITION BY VIBRATION ANALYSIS*

**Abstract:**
*In the article methods of vibroacoustic diagnostics of the high-power toothed gears are described. It is shown below, that properly registered and processed acoustic signal or vibration signal may serve as an explicitly interpreted source of diagnostic symptoms. The presented analyses were based on vibration signals registered during the work of the gear of a rolling stand working in Huta Katowice (Katowice Steel Plant) (presently one of the branches of Mittal Steel Poland JSC).*

**Keywords:**
*gearbox, diagnosis, vibroacoustic*

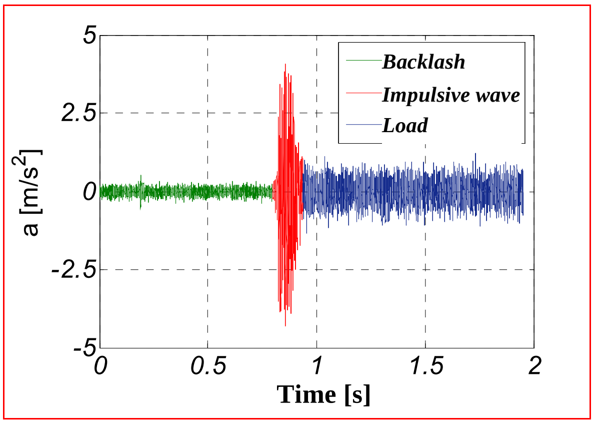
## INTRODUCTION

*Residual phenomena are inseparable phenomena during the work of a technical object, and among them there are vibrations and noise. The evaluation of the technical condition on the basis of research is known under the name of vibroacoustic diagnostics. The basis for the research on the use of vibroacoustic signals in the diagnostics of the object technical condition is the creation of symptoms measures, which will enable to define the condition precisely. Vibroacoustic diagnostics uses, as source of information about the condition of the tested object, not the static parameters, as it happens in other technical diagnostics methods, but the dynamic parameters, describing the appearance and the propagations of the vibroacoustic disturbance both in a tested object and in the outer environment [1-10]. Because of the fact that the changes in the condition of the diagnosed object may influence broadly the structure and the size of the vibroacoustic signal, the diagnostic information included in it may have a heterogeneous shape. The vibroacoustic signal includes both information required about the processes in progress in a technical object and the unnecessary information from the point of view of diagnostic aim, the, so called, information noise. A very important issue here is the right reconstruction of the information model of a given object condition, being the basis to treat it as the information carrier. In paper [2] the author points out the bigger sensitivity of the vibration signal on the changes of the object work condition of than the acoustic signal sensitivity. It is so due to the fact, that the vibration signal may be distorted only by the movement of close kinematic pairs and by the signal of other damages in that area. The acoustic signal will additionally include* *unnecessary information coming from the measuring surrounding. In paper [1] authors compared the vibration signals and the acoustic signals taking into account their damage orientation. In vibration diagnostics of the power transmission system the most often used are the vibration acceleration converters, placed in various points of the casing and the no-contact methods used to measure the perpendicular vibration speeds of the rotating shafts. The use of no-contact measurement method of vibrations decreases the amount of information noise included in the measured signal. It results directly from the shortening of the signal path generated by the appearing damage.*

## RESEARCH OBJECT

*Tests were conducted on 10 single-stage and double stage gears with additional meshing of the roll cage [3,7]. In the power transmission system of the cages the asynchronous engines with the power of 200 [kW] were applied. The rotational speeds of the input shafts are constant for each gear and are included in the range from 380 to 800 [rotation/minute]. In the course of research the measurements of vibration accelerations in three directions were conducted and the impulse signals were registered, consistent with the rotations of the input shaft which served for synchronic averaging. The measurements of the gearbox vibrations were conducted during idle running and with a load during rolling. Diagnostic signals were processed in the Matlab-Simulink environment. The applied measurement method enabled the synchronic averaging of the vibration signals with the rotations of the input shafts. The changes of the diagnosed gearboxes condition have significant influence on the structure of the vibroacoustic signal. The example registered courses of the vibration accelerations in time of idle running and under load, for two different consumption conditions are presented in fig. 1.*

*The registered vibroacoustic signals should be processed with the use of proper signal measures so that they would serve as symptoms showing the intensity or advancement of the consumption. The right signal processing in time domain and/or frequency domain enable the definition of the level and type of the carrying signal modulation, which will finally enable the diagnosis of the technical condition of the object. One of the methods is the statistic analysis of the signal received after preliminary processing in frequency domain.*



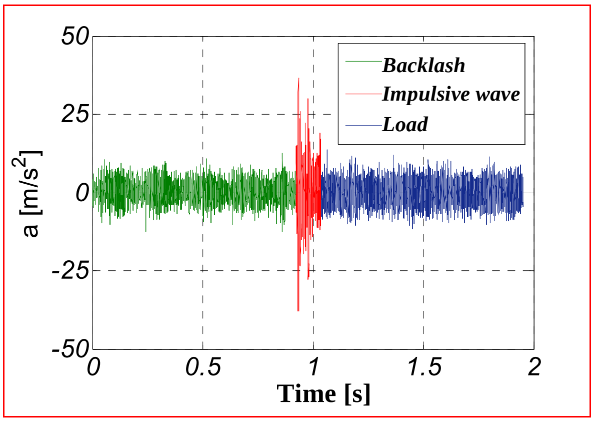




*Fig. 1 Registered vibration signals of toothed gears of the rolling stand drives, a – gear in general good dynamic condition (cage k4), b – gear classified for repair (cage k12)*

## VIBROACOUSTIC SIGNALS ANALYSIS METHODS

*In the vibroacoustic diagnosis of the technical objects lots of various signal analysis methods are used. The vibroacoustic signal, registered from a technical object includes in it information significant from the point of view of the analysed phenomenon and the unnecessary information, distorting the readability of the diagnostic information included in the signal [4,6,10]. Noise component comes from the side phenomena accompanying the object functioning and from the measuring system. In order to get the carrying signal, including the maximum amount of useful information, the synchronous averaging and signal filtration are used as preliminary analyses in the diagnostics of the power transmission systems.*

*Synchronous averaging eliminates the random component from the signal. It is based on marking the medium signal in time corresponding with the given number of periods. In diagnostics of the toothed gears the averaging with rotation period of pinion and wheel is used, and the period of tooth connection cycle repetition. A very important stage in this method is the precise synchronisation of the reference signal with the angular position of the diagnosed rotating elements. Filters are comfortable and simple tools used for elimination of noise constituents included in some frequency bands. It should be remembered, however, that each decision concerning the use of filters must be justified with the predominance of the benefits of their use over the information distortion, which is to be used in diagnosis of the technical object condition. An important problem here is the choice of the right filter and its accommodation to the defined diagnostics requirements [5]. A particularly interesting, commonly and successfully used filtration method was proposed for the first time in paper [9]. It helps to find the wide-band vibration signal modulation caused by the impulse stimulation, which is a situation that is observed by appearance of a local damage of gear teeth. In this paper it was proposed to remove those bands from the spectrum which include the rotation constituents of the wheel shafts and their harmonics ($i \cdot f_o$), as well as frequency constituents and their harmonics ($i \cdot f_z$). Later application of the reverse Fourier transform IFFT helps in getting the signal in time domain, known as the residual signal r(t). In literature one can also find the residual signal, defined as a filtration result based on removal of only meshing frequency constituents and their harmonics. Another commonly used filtration method is the one which leads to the achievement of time signal, known as the differential signal d(t). Such signal is received similarly to the residual signal, but the removed bands around the meshing frequency and their harmonics are wider and include the sidebands connected with the rotational frequencies of the toothed wheels.*

*After the application of preliminary methods of vibroacoustic signal preparation for diagnostic purposes (averaging, filtration), the next stages, serving to improve the extraction of the useful features, are the signal analysis methods in time domain, frequency, time-frequency, time-scale, frequency- frequency.*

## *ANALYSIS OF SIGNAL ENVELOPE*

*The damages appearing in the power transmission system influence the change of parameters describing the shape of vibroacoustic signal, and in case of appearance of amplitude modulation, describing the changes in envelope parameters. As the author states in [8], this dependence may be the basis to define a set of diagnostic parameters built on the basis of both the signal and its envelope. Signal amplitude modulation may be caused by modulating phenomena in the form of impacts of elements in bearings, gears and clutches. The extraction of the diagnostic information from a signal modulated in such a way enables the application of amplitude demodulation that is the use of the signal envelope:*

$$x_{obw}(t) = \sqrt{x^2(t) + x^2_{Hilbert}(t)} \qquad (1)$$

*where:*

$x_{obw}(t)$ *– vibroacoustic signal envelope,*

$x(t)$ *– tested vibroacoustic signal,*

$x_{Hilbert}(t)$ *– vibroacoustic signal after the application of Hilbert transform.*

*Time signal after application of the Hilbert transform is displaced 90° in phase in respect of the tested time signal. It enables marking the constituent amplitude of variables without the necessity to find the current phase of the tested time signal.*

## *SPECTRAL ANALYSIS*

*Each moving part of the technical object generates by movement the vibroacoustic processes included in a given frequency band. The analysis of the frequency composition of those processes can be used in diagnosis processes of the object condition. The representation of the time signal in frequency domain is achieved by the application of Fourier transform:*

$$X(f) = \int_{-\infty}^{+\infty} x(t) \cdot e^{-j2\pi ft}\, dt \qquad (2)$$

*In literature, the most common algorithm is the Fast Fourier Transform (FFT), which enables to mark the spectrum in a fast and computationally easy way. The stages of the damage development cause the modulation of the bands around the given carrier frequencies, and at the same time they change the frequency structure quality of the signal. Depending on the damage type the change in frequency structure differ. In literature one can find given frequency bands characteristic for given damage type, that is:*

- *0,4 $f_o$ to 3 $f_o$ – backlash in shaft bearing mounting or rotor bearing mounting, instability of the oil film, unbalancing, axial backlash of the shaft and its lack of co-linearity,*
- *several to over a dozen $f_o$ – damages in rolling bearings, defects appearing by the flow of working medium,*
- *over a dozen to several dozen $f_o$ – characteristic for machines with toothed gears,*
- *20 do 60 [kHz] – characteristic for surfaces rubbing one another in stroke pairs, rotating pairs and acoustic emission.*

*In toothed gears the development of the crack stage at the tooth base happens with the presence of changes in the modulated bands around the meshing frequency. The pitting, however, happens with the noise in wider and wider frequency band. This phenomenon is particularly visible in frequency range from 0 to $f_z$. An example picture of vibration signal spectrum of a toothed gear in rolling stand in various stages of consumption is presented in fig.2. Another method which enables the identification of the periodicity is the product spectrum. For a given frequency $f_p$ a product of their successive harmonics $i \cdot f_p$ is marked in the range of the whole spectrum $\Delta F$. The range of the given frequencies is limited to the frequencies $\frac{\Delta F}{3}$. The product spectrum is marked according to dependence:*

$$I_w(f_p) = \sqrt[N]{\prod_{i=1}^{N} G_{uu}(i \cdot f_p)} \quad for \quad f_p \in \left(0, \frac{\Delta F}{3}\right) \qquad (3)$$

*where: $G_{uu}(f)$ – power spectral density.*

*An example of product spectrum application is presented in fig. 3, achieved on the basis of vibration signal in toothed gears of rolling stand drives in rolling time. Changing in formula (3) the product sign to sum sign, and the root sign to division sign by number of sum elements, we get the formula for poly-harmonic spectrum:*

$$P_w(f_p) = \frac{1}{N}\sum_{i=1}^{N} G_{uu}(i \cdot f_p) \quad for \quad f_p \in \left(0, \frac{\Delta F}{3}\right) \qquad (4)$$

*Poly-harmonic spectra received from a vibration signal of toothed gears in rolling stand drives in rolling time are shown in fig.4 .*

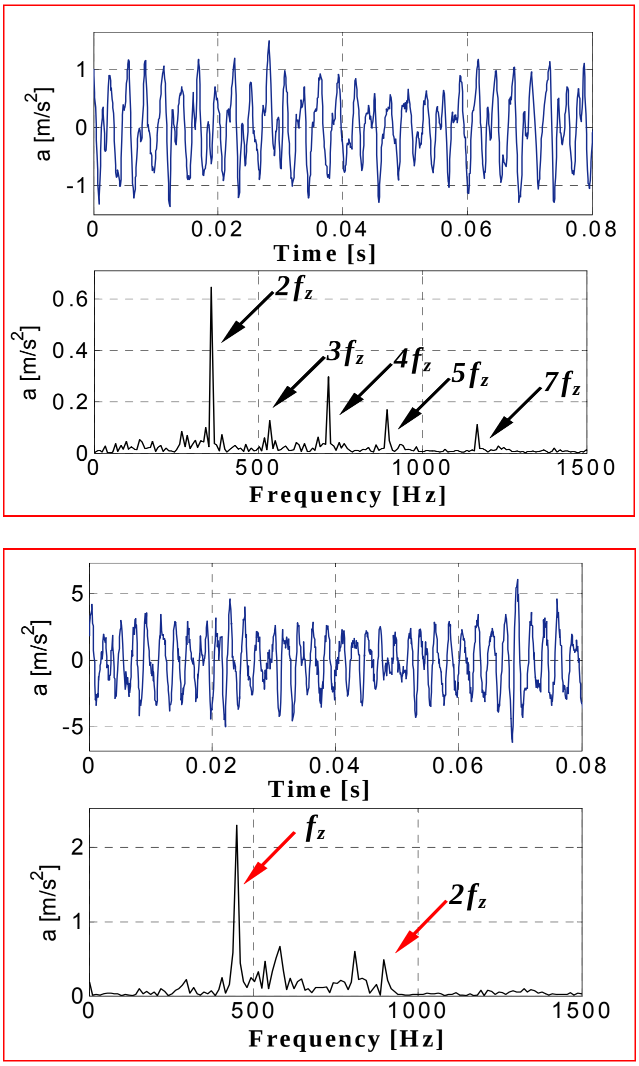



*Fig. 2 Time runs and vibration signal spectra of the toothed gears in rolling stand drives in rolling time a – gear in general good dynamic condition (cage k4), b – gear classified for repair (cage k12).*

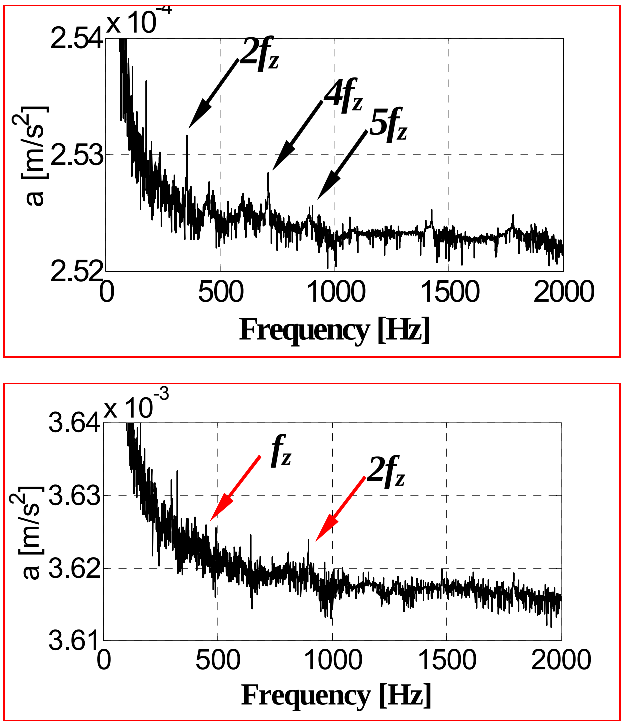



*Fig. 3 Product spectra of toothed gears vibration signals in rolling stand drives in rolling time a – gear in general good dynamic condition (cage k4), b – gear classified for repair (cage k12).*

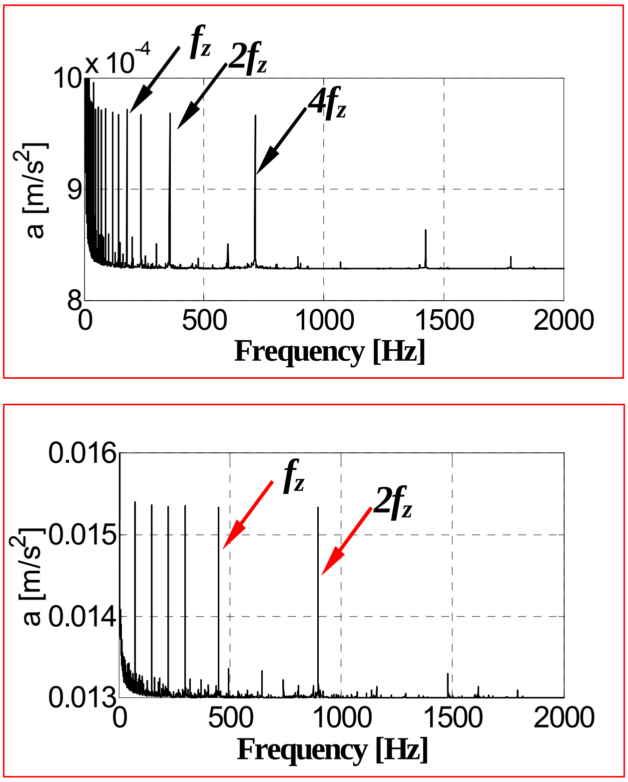



*Fig. 4 Poly-harmonic spectra of toothed gears vibration signals in rolling stand drives in rolling time a – gear in general good dynamic condition (cage k4), b – gear classified for repair (cage k12).*

## CONCLUSION

*From the number of vibroacoustic signals analysis methods applied in diagnostic practice only some are presented in this paper in reference to the analysis methods of frequency domain. Those analyses are the starting point in defining the diagnostic measures for particular diagnosed cases [1-10]. The damage descriptors of particular elements of power transmission systems built on their basis are used in forming the complete diagnostics systems. The most recently designed diagnosis systems work according to methods of artificial intelligence [3,5].*

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