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BELT CONVEYOR DRIVING SYSTEM VIBRO–ACOUSTIC SEVERITY REDUCTION BY CONDITION BASED MAINTENANCE

The paper shows the need of using the condition based maintenance of belt conveyor driving systems to monitor their condition for presenting vibro–acoustic severity and preventing its effect development by replacing the rolling elements bearings, which are characterized by increased over limit backlash. It is shown that the vibro–acoustic (vibration and noise) effect/result given by a belt conveyor driving system depends of their condition. The condition of belt conveyor driving systems are the result of several factors that can be divided into four groups namely; design, production technology, operation, change o condition. The influence of mentioned four groups of factors on the vibro–acoustic severity is considered in the paper. The consideration leads to conclusion that suitable vibration parameters should be evaluate which shows the increase of a backlash in rolling elements bearings. The parameters are characterised by a load–yielding characteristic that gives relation a vibration diagnostic parameter as the function of load or function of RPM. These two characteristics are equivalently positively and negatively correlated. That means that if the load increase the vibration parameter also increase but if RPM increase the vibration parameter decrease.

1. INTRODUCTION

The vibro–acoustic (vibration and noise) effect/result of belt conveyor driving systems can cause environment severity as its condition is changing during its live. The main reason of its condition change is the increasing backlash in rolling elements bearings. The increased backlash is caused by frictional wear of the rolling elements bearings as a result of dustiness in mining environment. The most danger are fine silicon particles, which cause intensive frictional wear. The vibro–acoustic environment severity caused by increased backlash is due to bad gear cooperation,

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which cause excitation of a gearbox housing and a supporting structure on which gearboxes are fixed. The development of increasing rolling element backlash should be monitor. It should be monitor using a suitable diagnostic method. It has been developed the diagnostic method which evaluate the gear cooperation/mashing, which is the function of the rolling elements bearing backlash. The measure of the mashing quality is a new developed robust parameter, load–yielding characteristic, which is used for condition monitoring.

2. OBJECT DESCRIPTION

A belt conveyor driving system is given in Fig. 1.

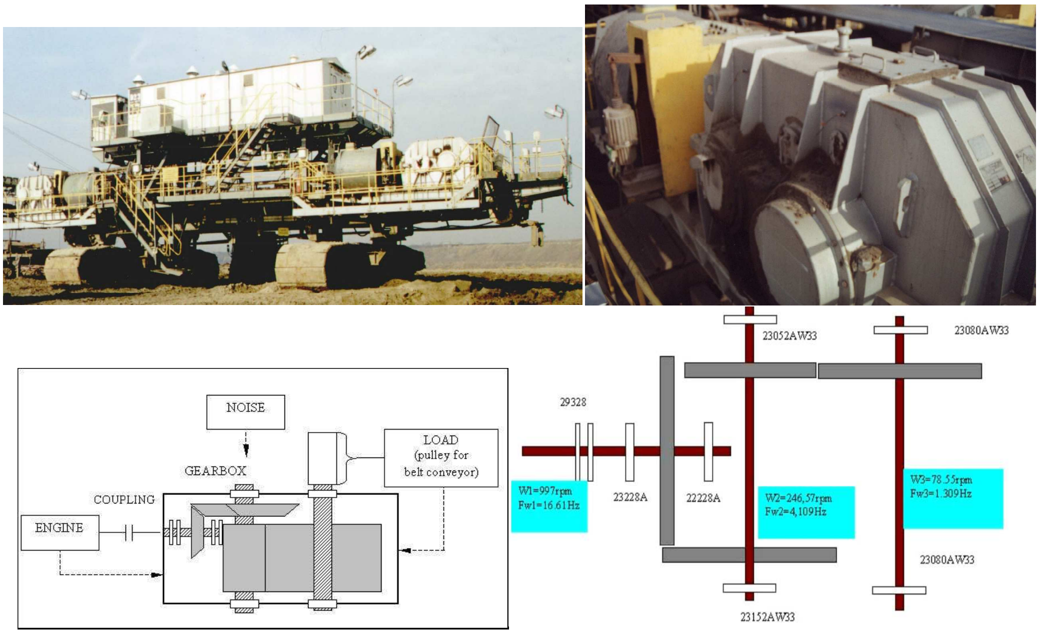


Fig. 1. Belt conveyor driving system

Fig. 1 shows the general view of the system and a view of one driving gearbox. There is also given the arrangement of the system (electric motor, gearbox and belt driving pulley drum) together with a gearbox scheme. The general view of the system shows that gearboxes (3 or 4) are supported by the steel structure, which is easy to excite to vibration, which are generated by gearboxes and electric motors. The Fig. 1 also shows steel housing of a gearbox, which is also easily to excite to vibration. The excitation comes mainly from improper gear cooperation as the result of the condition change of rolling elements bearings, which is caused by fictional wear of them as the effect of harsh environment in lignite mines. The frictional wear is mainly caused by dustiness. The gear cooperation at the condition of increased backlash in rolling elements bearings cause very intensive excitation of a gearbox housing and a supported structure given severe vibro–acoustic effect.

3. CONDITION CHANGE

The condition change of the elements of the belt conveyor driving system is described in [1]. The attention is mainly focused on local faults in roller element bearings and different faults of gearing as pitting, spalling, cracking. There is not given enough attention to frictional wear caused by harsh environment of the mine characterised mainly by dustiness. The frictional wear cause increase of inter–elements backlash, which cause improper elements cooperation. The most dangers in dust are fine particles of silicon. This increased backlash is mostly the first reason of a gearbox condition change. This change of gearbox condition is the main reason of increased vibro–acoustic severity. This increased vibro–acoustic effect is caused mainly by increased backlash in rolling elements bearings. The gearbox producers in maintenance specifications give the values of increased backlash limits for rolling elements bearings. But it is difficult to measure the backlash without a gearbox partly dismantling. In the paper will be shown that there is possible to evaluate the influence of increased backlash in rolling elements bearings to gear cooperation of teeth. In [1] there is given the proposal of the backlash assessment on the characteristic, which may be named deterministic. This static characteristic is evaluated on the measurements of vibration signal acceleration in the band 100–3000Hz. The new evaluation is now proposed that is based on statistical assessment of vibration measurements after signal processing. So some new evaluation method has been devised. The increased backlash in rolling elements bearings leads to development faults as scuffing Fig. 2, pitting, flaking Fig.4, which cover only part of a tooth line.

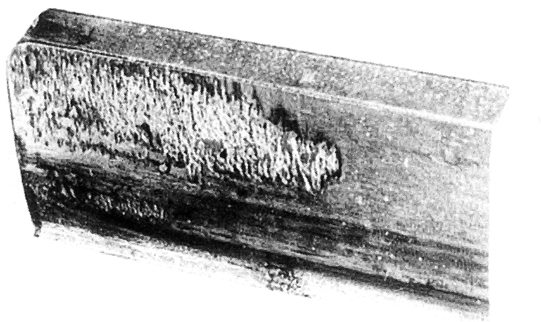


Fig. 2. Image of surface damaged by gear tooth scuffing/seizing (resulting from out-of-parallel meshing of teeth) [3]

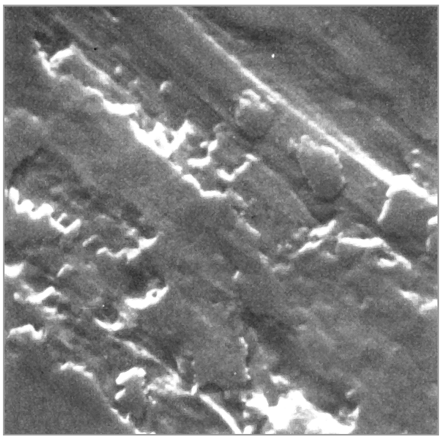


Fig. 3. Electron microscope image of surface damaged by scuffing/seizing (in its initial stage), magnification of 1000x [4]

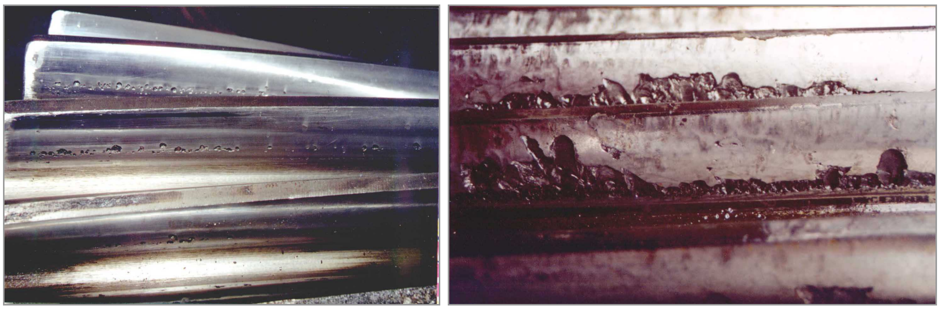


Fig. 4. Pitting and flaking on gear flanks

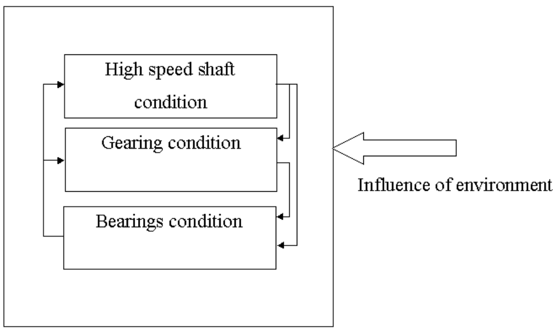


Fig. 5. Interaction of gearbox elements, influence of environment [2]

The faults of gearings, which are developed as the result of increased backlash in rolling element bearings, are given in Fig. 2–4. Fig. 2 gives the image of surface damaged by gear tooth scuffing/seizing (resulting from out-of-parallel meshing of teeth). The electron microscope image of surface damaged by scuffing/seizing (in its initial stage), magnification of 1000x is given in Fig. 3, after [4]. Pitting and flaking on gear flanks is presented in Fig. 5. The main resin of the presented faults is an increased backlash in rolling elements bearings, which may cause improper interaction of gearbox elements. The scheme describing of an interaction of gearbox elements is given in Fig. 5, after [2]

4. INVESTIGATIONS ON FACTORS INFLUENCING VIBRO–ACOUSTIC SEVERITY

According to [1] factors having influence diagnostic signals can be divided into four groups of factors, namely: design, production technology, operation, change of condition. Analysing the factors one can develop procedures for diagnostic method, which is based on vibro–acoustic effect and which is used for condition based maintenance. The factors having influence the vibro–acoustic effect are given schematically in Fig. 5, [5]. There also detail description is given.

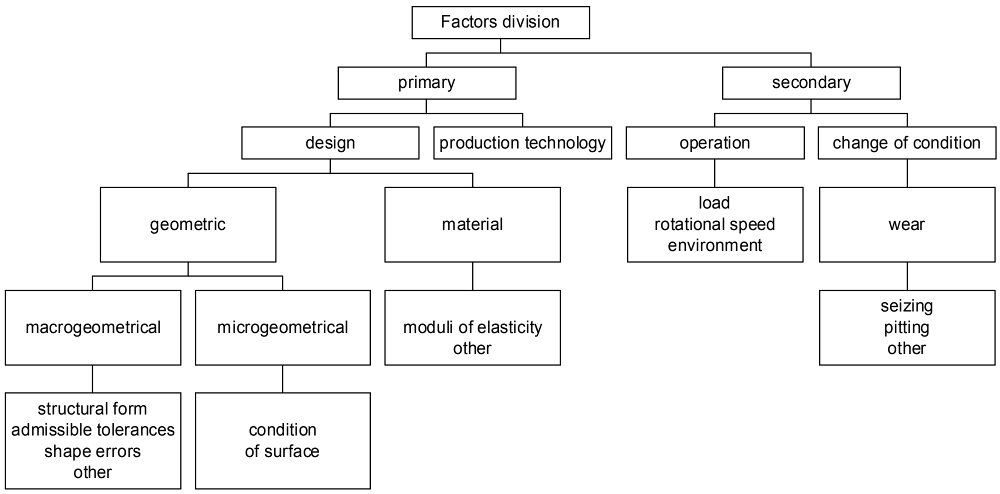


Fig. 6. Factors affecting diagnostic signal or vibro–acoustic effect

The influence of some design and condition change factors are presented in Fig. 7 where coefficient Kd as function of inter–tooth error and error mode: a – E(0.1, *e*, 0), b – E(0.5, *e*, 0), c – E(0.5, – *e*, 0), according to [1] is given. More simulation results showing influence of factors to vibro–acoustic severity is given in Fig. 8 where influence of damping coefficient is presented and which cause that vibro–acoustic severity is reduced. But generally the increase of backlash in rolling elements bearings will increase *e* value in error mode E(0.1, *e*, 0) and as the result increase of dynamic coefficient Kd that has influence on vibro–acoustic severity. More about mathematical modeling and computer simulation for investigation on influence of factors influencing diagnostic signal, vibro–acoustic severity is presented in [1] and [6, 7].

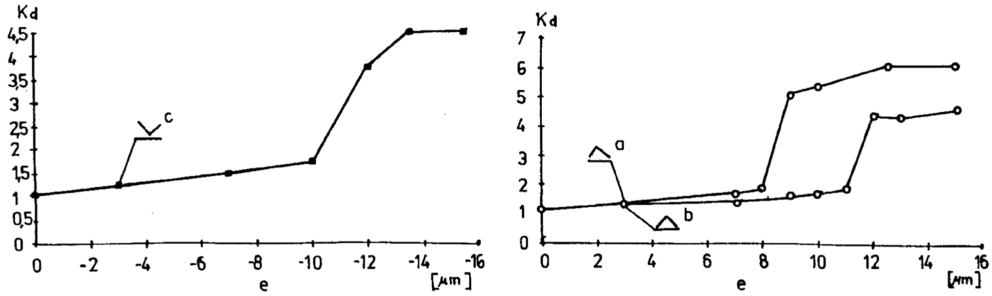


Fig. 7. Coefficient Kd as function of inter–tooth error and error mode: a – E(0.1, *e*, 0), b – E(0.5, *e*, 0), c – E(0.5, – *e*, 0), according to [1].

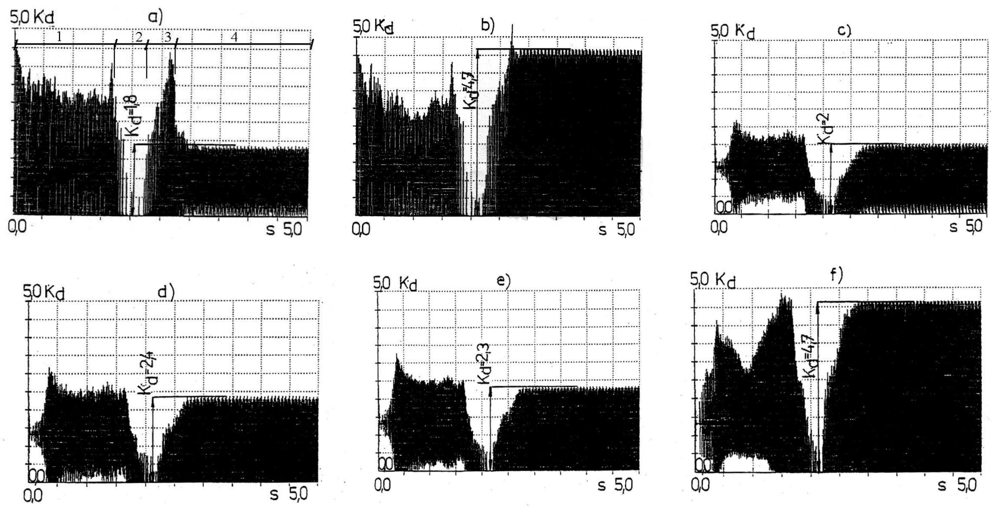


Fig. 8. a) Plot of Kd for error mode E(0.5, 12, 0.3), damping coefficient C1 = 0
b) Plot of Kd for error mode E(0.5, 15, 0.3), stiffness coefficient C1 = 0
c) Plot of Kd for error mode E(0.5, 15, 0.3), stiffness coefficient C1 = 1000
d) Plot of Kd for error mode E(0.5, 20, 0.3), stiffness coefficient C1 = 1000
e) Plot of Kd for error mode E(0.5, 20, 0.15), stiffness coefficient C1 = 1000
f) Plot of Kd for error mode E(0.1, 20, 0.3), stiffness coefficient C1 = 1000 [6]

5. DIAGNOSTICS METHODS FOR BELT CONVEYOR DRIVING SYSTEM

The simplified diagnostic method was used for double-stage gearboxes, which scheme is given in Fig. 1. The method is based on wide band signal analysis. The signal of vibration is divided into three bands. Vibration signals of accelerations and velocities are filtered in the bands 10–100 Hz, 100–3500 Hz, 3.5–10 kHz. According to [2] the following attributes have been taken for gear diagnostics:

Operating conditions of the high rotation shaft of the gear should be reflected by a wall vibration averaged velocity attribute v mm/s in frequency range (10–100 Hz).

Operating conditions of gearing should be determined by averaged values of velocity v [mm/s] and acceleration m/s^2 within the frequency range (100–3500 Hz)

Operating conditions of rolling bearings should be reflected by acceleration attribute a [m/s^2] within the frequency range (3.5–10 kHz).

The diagnostic inference algorithm leads to five classes of gear transmission condition labeled as:

- lubrication of bearings,
- motor position adjustment,
- economical replacement,
- necessary replacement,
- danger of failure.

Inferring process in the simplified diagnostic method was mostly based on premises, but factors influencing diagnostic signal were taken into consideration.

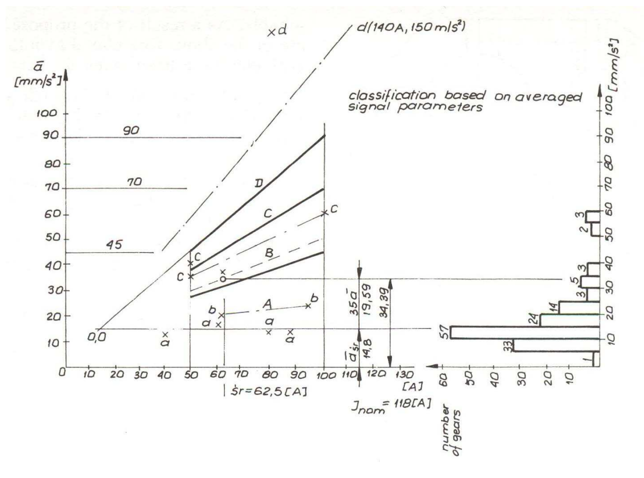


Fig. 9. Effect of load on gear transmission condition symptom value, accelerations in band 100–3500 Hz: A÷D – gear transmission classes; a÷d – gear transmission points, number of gear transmissions

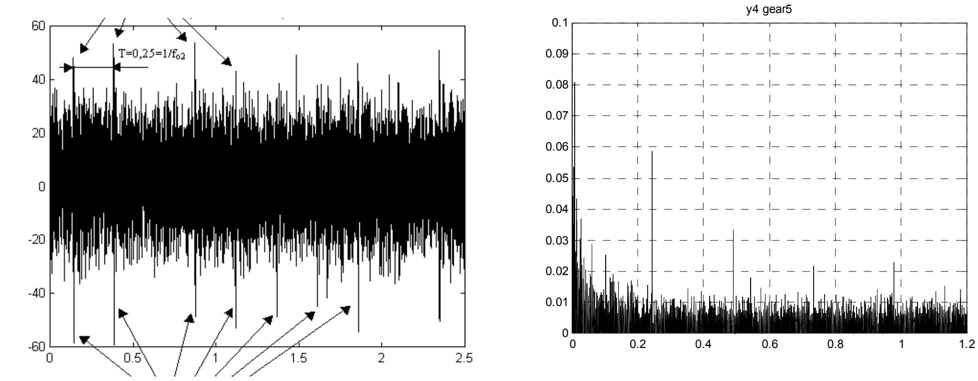
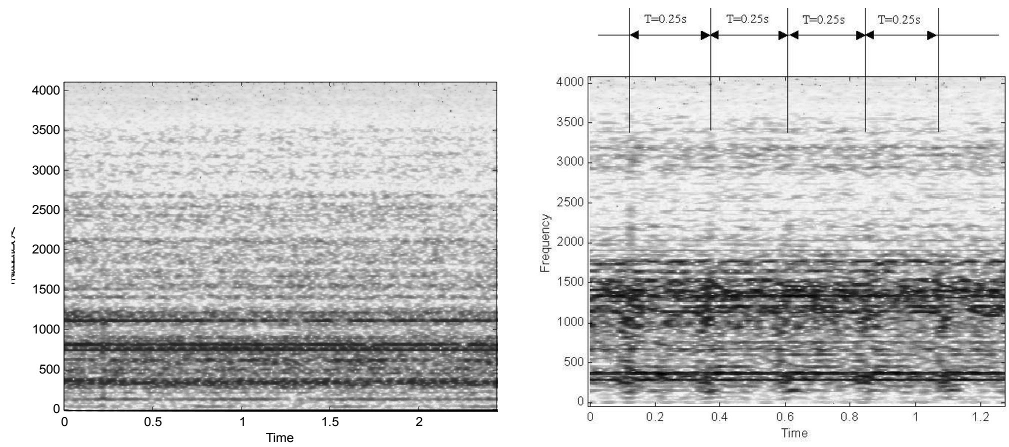


Fig. 10. Acceleration [m/s2] signal time [s] trace with series of peaks (peaks marked with arrows) and cepstrum for signal



a) b)

Fig. 11. Time-frequency [s]–[Hz] spectograms a) spectogram of signal without regular peaks b) spectogram of signal with marks equivelent regular peaks.

Fig. 9 gives the plot that gives effect of load on gear transmission condition symptom value, accelerations in band 100–3500 Hz, more details on simplified diagnostic method in [1 and 2]. Fig. 9 shows leaner relation between load and acceleration m/s^2 within the frequency range (100–3500Hz). The inclination of the relation given in Fig. 9 is the measure of influence of increased rolling elements bearings backlash. The measure of an inclination is given by formulae (1).

$$\Psi = (a_1 - a_2)/(I_1 - I_2) \quad m/(s2A) \tag{1}$$

where a_1, a_2 – value of signal acceleration in a band 100÷3500 Hz for respectively: a load of about $0.85I_n$ and $0.5I_n$; I_1, I_2 – values of electric current corresponding to the smaller and greater load, respectively, I_n nominal value of electric current in A. By (1) is expressed deterministic yielding characteristic.

For condition monitoring has been developed the advanced diagnostic method, which for this gearbox is given in papers [7] and [8]. Examples of condition monitoring assessment, using some tools for advanced diagnostic method are given in Fig. 10 and 11.

For condition monitoring faults such as distributed and local faults can be used cepstrum and for differentiation distributed faults from local fault there is a need of further signal processing to obtain a time frequency spectrogram as is given in Fig. 11. Fig. 11a) does not show a local fault, which is shown in Fig. 11b).

5. DETERMINISTIC AND STATISTICAL LOAD YIELDING CHARACTERISTICS

The formula (1) gives the deterministic load–yielding characteristic. If one wants to characterize the load yielding characteristic at the condition of varying load the statistical analysis should be developed. The investigation on finding the statistical load yielding characteristic is done on the system in which consists of bevel stage and planetary stage.

In figs 12 a) and b) one can observe the relation according to [2] but the rotation speed–vibration signal correlation is negative if the gearbox is in bad condition. The figures show that this relation holds only for a certain rotational speed range when the gearbox is loaded during operation. It follows from figs 12 a, b, c and d that the relation is mainly determined by the condition of the planetary stage. Therefore the signals from the planetary stage and the bevel stage should be separated. If one looks only at Fig. 12 d, it is difficult to explain (interpret) the obtained result. But if one takes into consideration the factors having an influence on the vibration signal, one can diagnose the condition of the two considered bevel gearboxes. Firstly, one can notice that the bevel gear (which should be at in good condition) shows a higher vibration RMS sum, but at a high load the RMS values decrease. Hence one can conclude that the bevel stage was improperly assembled. This means that the gear meshing trace is probably shifted. A proper gear meshing trace is highly important for bevel gears. If one looks carefully at the mean value curves for well and badly assembled bevel gears they have a similar shape but different parameters. It follows from the above analysis that the technology factors have an influence on the generated vibration. Therefore assembly should be treated as a technology factor. A similar situation may also occur when there are some teeth line imperfections due to the improper manufacture of the gear wheels, which is also a technology factor. If one examines the design structure of the bevel gearbox one can conclude that in the case of proper manufacture and assembly the measurement results should be represented by the curve with a lower vibration level (Fig. 12. d).

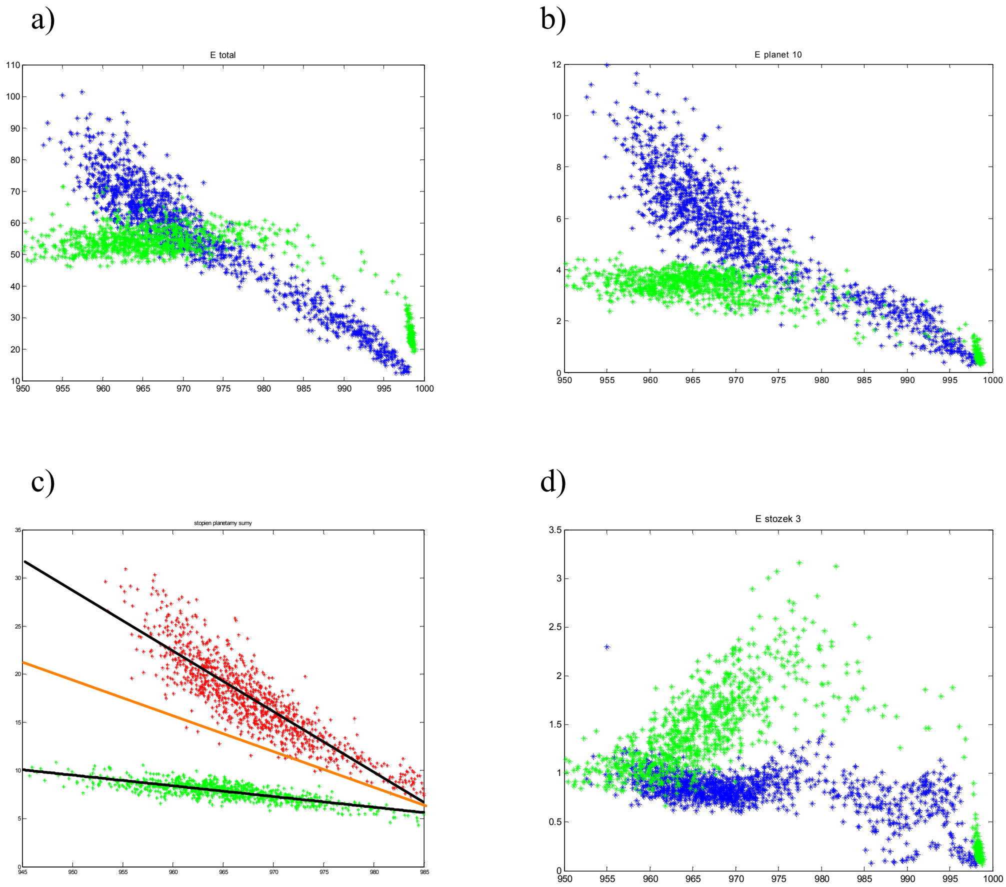


Fig. 12. Vibration signal RMS component sum versus rotational speed for:
a) planetary stage with bevel stage, b) planetary stage, c) planetary stage with restricted range of gearbox rotation, d) bevel stage.

Figure 13 shows spectrum comparing for good (green) and bad (red) object condition. One can see an increase of the vibro–acoustic severity. It is seen the increase of vibration amplitudes in the spectrum when comparing object in good and bad condition. Using the statistical load yielding characteristics one can currently evaluate the change of condition caused by increase rolling element bearings backlash. Using this type of evaluation it has been obtained robust evaluation of the gearbox condition.

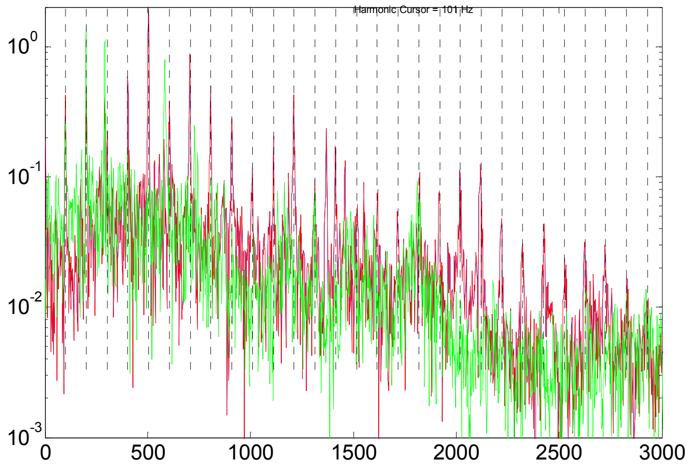


Fig. 13. Spectrum comparing for good (green) and bad (red) object condition

6. CONCLUSIONS

The statistical load–yielding characteristic is a robust condition monitoring parameter. Using this parameter it is possible to evaluate the change of a rolling elements bearing backlash. This increased backlash is mostly the first reason of a gearbox condition change. In some condition of the increased bearing backlash there is a severe vibro–acoustic effect. This effect is shown in Fig. 13 where one can see the increase of amplitude components of the vibration spectrum. These components can excite a gearbox housing and supporting structure, on which gearboxes are fitted. The gearbox at this condition not only gives the severe vibro–acoustic effect but prolonged run of gearbox cause development of faults presented in Fig. 2–4. It is a need of preventing the severe vibro–acoustic effect development by replacing the rolling elements bearings, which are characterised by increased over limit backlash. The sever vibro–acoustic effect should be evaluated by a statistical load yielding characteristic. Using the statistical load yielding characteristic one can avoid troublesome direct measurements of a rolling element bearing backlash that is connected with partly dismantling of a gearbox.

LITERATURE

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

[2] Bartelmus W.: Vibration condition monitoring of gearboxes. Machine Vibration 1992 No. 1 pp.178–189
[3] Kress D.F.: The Good Girth Guide, World Mining Equipment, Vol. 21, No. 3, 1997
[4] Barwell F.T.: Bearing Systems, Principles and Practice, Oxford University Press, 1979
[5] Bartelmus W.: Root cause analysis of vibration signals for gearbox condition monitoring. Proceedings of CM2007 Harrogate UK and BINDT Inside Journal (submitted for publication)
[6] 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
[7] 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 in internet at Dolnoslaska Digital Library)
[8] Bartelmus W.: Diagnostic information on gearbox condition for mechatronic systems. Transaction of the Institute of Measurement and Control 25,5 (2003), pp. 450–464

REDUKCJA ZAGROŻENIA WIBROAKUSTCZNEGO UKŁADÓW NAPĘDOWYCH PRZENOŚNIKOW TAŚMOWYCH PRZY UTRZYMANIU MASZYN ZALEŻNYM OD STANU TECHNICZNEGO

Praca przedstawia potrzebę wykorzystania sposobu utrzymania układów napędowych zależnego od stanu technicznego aby monitorować zagrożenie wibroakustyczne i zapobiegać rozwojowi tego zagrożenia poprzez wymianę łożysk tocznych, które charakteryzują się zwiększonym luzem. Pokazano, że zagrożenie wibroakustyczne zależy od stanu technicznego układu napędowego przenośnika taśmowego. Stan techniczny układu napędowego zależy od wielu czynników, które podzielić można na cztery grupy mianowicie: konstrukcyjne, technologiczne, eksploatacyjne, i zmiany stanu. Przedstawione rozważania prowadzą do wniosku, że odpowiednie parametry procesu wibroakustycznego powinny być wyznaczone, które wskazują na zwiększający się luz w łożyskach tocznych. Parametry te są scharakteryzowane przez charakterystykę podatności na zmianę obciążenia, która pokazuje parametr drganiowy jako funkcję obciążenia lub prędkości obrotowej [obr/min]. Te dwie charakterystyki pokazują, że te dwie wielkości są negatywnie skorelowane. To oznacza, że jeśli obciążenie rośnie, prędkość obrotowa maleje.