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OBJECT AND OPERATION SUPPORTED MAINTENANCE FOR MINING EQUIPMENT

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Abstract: The paper aroused in answer to discussion in Mining Magazine (MM) September 2011 and July/August 2013. The paper shows that discussion given in the MM issue July/August 2013 does not fulfill expectations expressed in MM issue 2011. The presented paper is the review on maintenance that is based on condition monitoring as tool for detection of faults and failure prevention. Fault and failure are regarded as inevitable during the machine operation as the process of wear and the process of degradation. The question is, if one can influence the wear and degradation process, using condition monitoring. The paper will present technology (in reference to cited papers) which demonstrates that the use of the proper method can influence the wear and machine degradation process, using proper condition monitoring techniques and knowing scenarios of wear and degradation process, the maintenance can be rationalized. The presented paper shows possible improvements which are needed to fulfill expectations expressed in MM September 2011 and they are not taken into consideration in MM July/August 3013. These improvements can be fulfilling on the bases of object and operation supported maintenance.

Keywords: condition monitoring, characteristic frequencies, vibration, load susceptibility characteristics, mining machinery/equipment, maintenance, object support, operation support.

1. INTRODUCTION

The subject of the paper is initiated by discussion undertaken in papers (Goodbody, 2013 and Mining Magazine 2011). Wide discussion on a good maintenance management is given by a paper (Goodbody, 2013). But one may also state that the presented discussions in (Goodbody, 2013) can not fulfil the expectations given in (Mining Magazine 2011). The presented paper, which is the kind of review on the subject, gives the answer how to fulfil the expectations given in (Mining Magazine

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2011). It may be achieved by the object and operation supported maintenance. The expectations given in (Mining Magazine 2011) in chapter "Integrated predictive maintenance strategies: what can we expect in the future?" are mainly expressed by following quotations:

(1) "We receive a lot of information on on-board systems, in order to help to improve maintenance, but sometimes there are so many data that we don't know how to deal with it."

(2) "We want to introduce vibration analyses signature on excavators, maybe on trucks as well. The problem is that most of these analyses depend on steady-state operation. One has to know the speed and keep the constant movement."

(3) "The comment I have is how you deal with the data."

(4) "It's quite easy to place sensors wherever one wants on a machine and get data wherever one needs. The tough part that makes the whole process valuable is having understood what that data tell you."

Even though paper (Goodbody, 2013) gives the wide discussion on maintenance management but not give answers for all expectations expressed by upper quotations which are given in (Mining Magazine, 2011). In (Goodbody, 2013) there is mentioned on some recent positive attitude to maintenance. In the past, reactive maintenance or crisis management may have been the norm, but more recently, companies have begun to see the long-term cost benefit of maintenance and repair efforts, rather than 'run to failure and replace' Awareness of the total cost of ownership has also risen significantly, so maintenance is now being seen as a tool to improve productivity, and a lot of effort has been put into the professionalization of maintenance activities. According to (Keith Mobley, 2002) maintenance costs are major part of the total operating costs of all manufacturing or production plants. Depending on the specific industry maintenance costs represent between 15–40 per cent of costs of goods produced. Heavy industries maintenance represents up to 40 per cent of the total production costs. In this paper there are given some main problems, which ought to be taken in for improvement of mining machinery maintenance. The statement given in (Goodbody, 2013) "The primary function of the machine health-monitoring system is collecting the data and making it available" is in contrast with expectations given in (Mining Magazine 2011).

To give an answer to above quotations from (Mining Magazine, 2011) there is a need to present the following discussion. The basic statement is that mining machinery work in non-stationary operations condition, which is characterized by varying rotation speed and load that means to take operation condition into consideration. Understanding of the operation condition support equipment maintenance. The issue of machinery condition monitoring under varying load is not considered in very popular books like for example: (Keith Mobley, 2002), **(**Neville W. Sachs, P.E., 2007), **(**Hatangadi, 2005), (Gridkhor, Scheffer, 2004**).**

Vibration generated by these machines generates load depended vibration which gives load dependent diagnostic features when using: spectrum and cepstrum analysis, order tracking, cyclostationary analysis (Spectral Correlation), short time Fourier transform, Wigner-Ville distribution, crest factor and etc. get load dependent results of analysis. The order tracking analysis gives an opportunity of eliminating the varying rotation speed but the amplitude components of order tracking are still load dependent. The order analysis doesn't give solution that can fully satisfy, since it really isn't possible to assess the fault severity development which is component amplitude dependent and the time trending changes are disturbed. The identification of faults is related to the identification of occurrence frequency in Hz, which is linked to the given fault. Moreover it is a basic component and its harmonic components. The faults can be classified roughly as local or distributed. For example rolling element bearing faults of an inner or outer ring can be classified as local; gear pitting spread on gear teeth is classified as a distributed fault. In most researchers' opinion the condition monitoring should be done when the machine is at normal operation (loaded), not e.g. within the onset of operation or by ideal constant rotation speed.

Generally spoken, monitoring systems which are used for condition monitoring of machines working in non-stationary operations, should give an opportunity to identify instantaneous value of frequency and instantaneous value of load. In some cases, when the system is at normal operation, the rotation speed is linearly related to the load, therefore only load or rotation frequency is identified. Such relation occurs when machines are driven by asynchronous electric motors at the condition about rated load and within fluctuation caused by varying normal operation condition.

At the generally condition for proper machinery condition monitoring there is a need to identify instantaneous frequency and load. For these conditions of an identified frequency and load, a vibration fault feature needs to be estimated and presented in two-dimension space (vibration fault feature, load). This two-dimension characteristic is the load susceptibility characteristic (load or frequency trending) as it is given in the paper (Bartelmus, Zimroz, 2009b).

The presented paper gives new advancement on machine condition monitoring, which gives new quality in condition monitoring used for proper maintenance in comparing with (Goodbody, 2013) and (Keith Mobley, 2002), **(**Neville W. Sachs, P.E., 2007), (Hatangadi, 2005), (Gridkhor, Scheffer, 2004)**.** This new way of the object and operation supported maintenance is based on a book (Bartelmus, 2006) and papers (Bartelmus, 1992), (Bartelmus, 2009a), (Bartelmus, Zimroz, 2009a), (Bartelmus, Zimroz, 2009b) (Bartelmus, and others 2010), (Bartelmus, 2013), (Bartelmus, 2014) (Zimroz, and others 2014a). In (Bartelmus, 1992) and (Bartelmus, 2006) there is presented influence of operation conditions to the vibration feature which is RMS value of acceleration signals. Signals were received from gearboxes, which are used in open cast mines. Influence of object/design factors to vibration signals is characterized in papers (Bartelmus, 2009), (Bartelmus, Zimroz, 20011a), (Bartelmus, 2011a).

Influence of operation conditions is characterized in papers (Bartelmus, 1992), (Bartelmus, Zimroz, 2009a and b), (Bartelmus and others 2010). Influence of machine degradation processes is described in papers (Bartelmus, 2008) and (Bartelmus, Zimroz, 2009c), (Bartelmus, 2011b), (Bartelmus, 2012), (Bartelmus, 2014), by the author is also given Editorial statement (Bartelmus, 2013) in which are given new directions for the machine condition monitoring working in non stationary operation condition. The subject of non-stationary operation condition is also given in proceedings (Condition Monitoring of Machinery in Non-Stationary Operations 2012) and (Advanced Condition Monitoring of Machinery in Non-Stationary Operations 2013). It is also very valuable to study on degradation processes given in papers (Morales-Esejel, 2012), (Happian-Smith, 2001), (Stadler K), (Alben, 1985) In papers (Stefaniak and others, 2012), (Sawicki and others, 2012), (Stefaniak and others, 2014) (Zimroz and others 2014b) there is given discussion on condition monitoring for a spatially distributed mechanical system of a belt conveyor network in underground mine and novel techniques of diagnostic data processing for belt conveyor maintenance in which condition monitoring in non-stationary operation is taken into consideration. In these papers there are taken modified features in comparing with (Bartelmus, 2006).

2. BASE GROUND FOR THE OBJECT AND OPERATION SUPPORTED MAINTENANCE

The object and operation factor orientated diagnostics is based on factor analysis (Bartelmus, 2009), which has influence on vibration signals. These factors are divided into four groups namely: design (describing object), production technology, operation, and change of object conditions as it is given in Fig. 1.

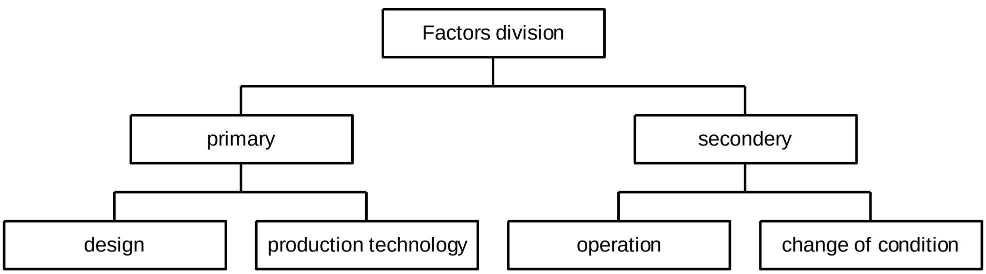


Fig. 1. Introductory division of factors influencing vibration signals

As one can see from the Fig. 1 the factors can be also classified as primary and secondary. The object and operation factors orientated diagnostic should give the solution how to make diagnostic when machines work under non-stationary operations. Such machines would include: mining and civil engineering machin-

ery/equipment, wind turbines, helicopters and so on. Many established machine condition monitoring methods are geared to stationary operations. Considering the influence of real fast varying load and rotation to generation of vibration signals there is a need to develop ways of signal analysis and take into consideration that machine is a unity of elements not a system of separated elements (bearings, gears, shafts) and not degradation of a specific element or fault, summery in (Bartelmus, 2013) (Bartelmus, 2014). The developed method should solve the problem of condition monitoring of machinery under varying operation and under the degradation process (Bartelmus, 2014). As an example, the gear tooth cracking could be a last agent in gear degradation process, and treating it as the first agent in the gear degradation process is only a special case of such process. This issue is presented in chapter 2.2.
Better understanding of machine vibration signals is connected with deeper division of factors, which have influence to vibration signals as it is given in (Bartelmus, 2012) and (Bartelmus, 2014). It obvious that more detailed division of factors influencing vibration signals better understanding of their influence to the signals gives better diagnostic that means better fault identification; understanding of fault influence to the other elements of the diagnosed system, better prognosis would be obtained. This issue is connected with (4) quotation" The tough part that makes the whole process valuable is understanding what that data is telling you"

There is a need to develop ways of signal analysis which take into consideration that machine is a unity of elements not a system of separated elements (bearings, gears, shafts, axles and so on) and not only degradation of a specific element or fault, Interaction between elements should be taken into consideration as is in Fig. 2.

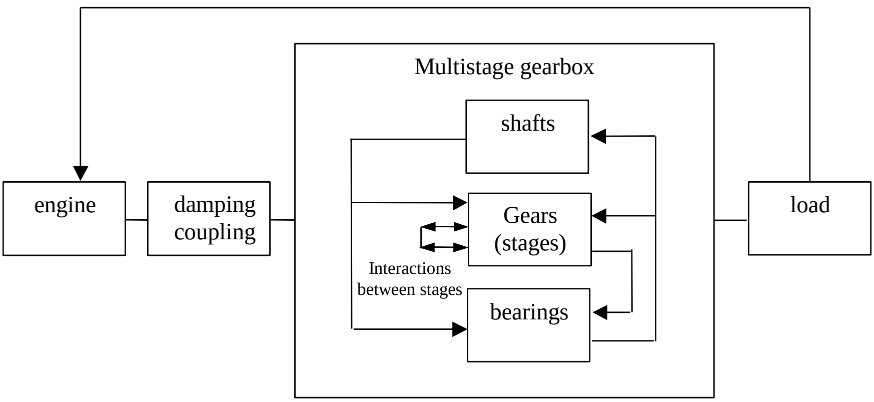


Fig. 2. Interaction between components of in gearbox and interaction of external components to the gearbox such as: electric motor, damping/ hydraulic coupling, external load

Analyzing influence of different factors, influence of mines environment should also be taken into consideration. The environment in the mine site to which mining machinery/equipment is exposed is characterized by extreme ambient temperatures, dust, water, grim, high humidity. The environment should be included into operation condition factors, which understanding supported mining equipment maintenance.

2.1. DETAILS ON OPERATION CONDITION

Till now it was mentioned several times on load variations which are connected with expectation (2) “We want to introduce vibration analyses signature on excavators, maybe on trucks as well. The problem is that most of these analyses depend on steady-state operation. One has to know the speed and keep the constant movement.”

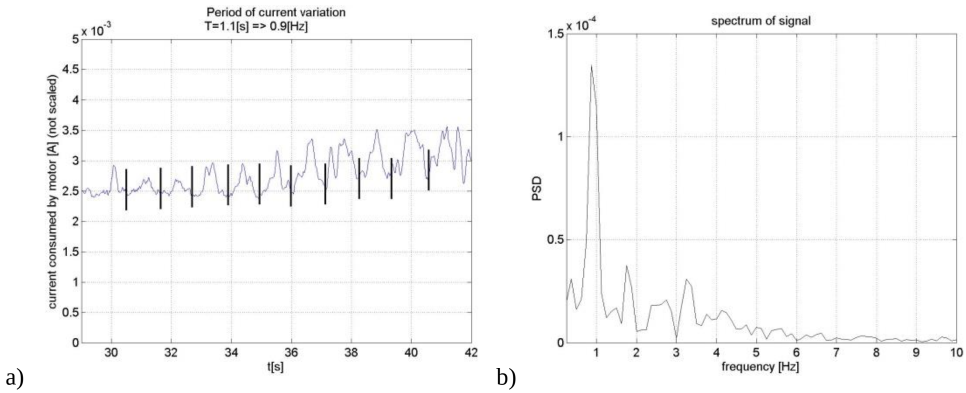


Fig. 3. a) Time fragment of electric current consumption and its spectrum b)

Fig. 3a shows time fragment of electric current consumption and its spectrum (fig. 3b). Electric current motor consumption is proportional to the transmitted load by the gearbox system. Its spectrum shows that the main component of the spectrum is about 1Hz which is equivalent to the bucket frequency of a bucked wheel excavator so the period of a load variation is only 1 s. Because of 1s period to obtain a vibration spectrum there is a need to use the shot time Fourier transformation spectrum. All procedures on vibration signal analysis is given in (Bartelmus, Zimroz, 2009b).

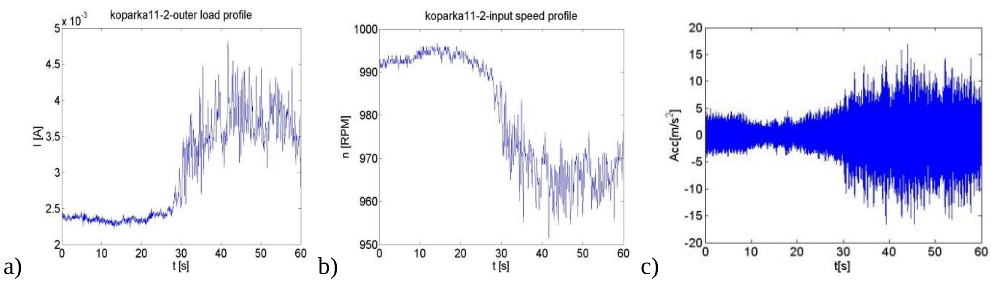


Fig. 4. Variation in: a) instantaneous electric current consumption, b) the output of hydraulic coupling rotation speed RPM, c) vibration signal.

More details on the variation in: a) instantaneous electric current consumption, b) the output of hydraulic/fluid coupling rotation speed RPM, c) vibration signal is given in Fig. 4. Fig. 4 shows that increased load represented by electric current consumption (Fig. 4a) cause decrease of rotation speed of gear system (Fig. 4b) and increase of vibration (Fig. 4c). Fig. 4 shows vibration generated by the gearbox system is load dependent and rotation speed and vibration are negatively correlated. Further relation on the relation between load and vibration and also between load and gearbox condition will presented later.

2.2. DEGRADATION PROCESS

The description of degradation process is supported by the experience described in (Bartelmus, Zimroz, 2009c) and (Bartelmus, 2014) one my try to infer the degradation process of the gear shone beneath. The chapter shows that the gear tooth cracking and brakeage could be a last agent in gear degradation process, and treating it as the first agent in the gear degradation process is only a special case of such process.

Fig. 5. Heavily effected/destructed gear teeth, and colours heat tint

Fig. 6. View of damaged gear, fatigue fracture area with beach marks, brittle fracture area

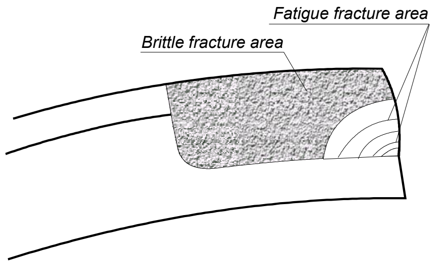


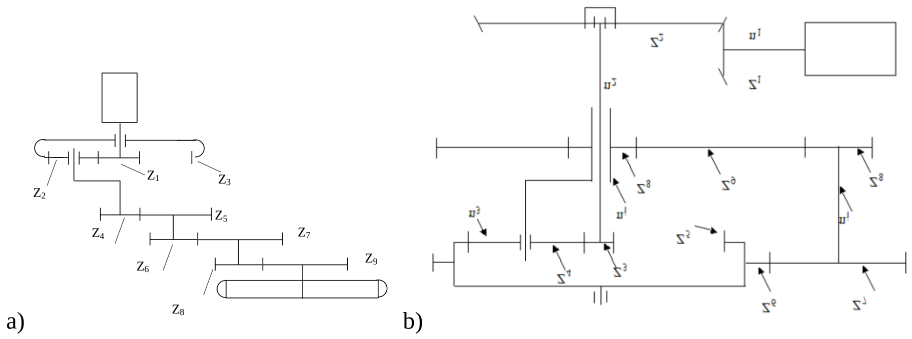
Fig. 7. Scheme of a fatigue fracture area
with beach marks and brittle fracture area

Some discussions on gearbox root cause analysis have been presented in (Bartelmus, 2008). Here a case has been reported, describing the root cause analysis (RCA) of bevel gears which shows that the reason of gear condition change is the inner gearbox shafts and gears misalignment IGSGM (Bartelmus, 2012). The RCA is based on the knowledge gained from experiment presented in the (Bartelmus, Zimroz, 2009b). The bevel gear (Fig. 5) shows developed scuffing (there is more on surface distress in (Morsles-Espejel 2012)) and a tooth gear fatigue development, and heat tints, the heat tints show that the surface bulk temperature would rise to about 250 ^{o}C. It was also inferred that the tooth breakage is the fourth cause of tooth gear degradation. The first cause is misalignment, second scuffing, third fatigue crack (details in Fig.6), fourth brittle tooth breakage. Fig. 7 shows a scheme of fatigue fracture area with beach marks and brittle fracture area. These considered case show that the main cause of gearbox failure is IGSGM. At the end it should be emphasized that primary cause of misalignment, which comes for example from misaligned motor and gearbox shaft position should be eliminated before putting system into operation, according to the technologies presented in (Wowk, 2000).

2.3. BASES FOR OBJECT SUPPORT MAINTENANCE

According to (Bartelmus, Zimroz, 2011) the gearbox systems can be divided as: compound and complex gearboxes, and multifunction gearboxes. Fig.8 a) and b) shows the schemes of complex system gearboxes which can be reduced into compound gear systems.

Fig. 8 shows two driving systems for a bucked wheel. In both systems a planetary gearbox is used. In the system presented in Fig. 8a) the planetary gearbox is characterised by standstill rim (gear z_3) and rotating sun (gear z_1). The planetary gearbox in system Fig. 8b), the rim (gear z_5) and the sun (gear z_3) are rotating. Equivalently their ratios are given in Figs 8a and 8b. In both systems there are given planetary gearboxes



$$u_p = 1 + \frac{z_3}{z_1} \qquad u_p = 1 + \frac{z_5}{z_3} + \frac{z_5 z_7}{z_3 z_6}$$

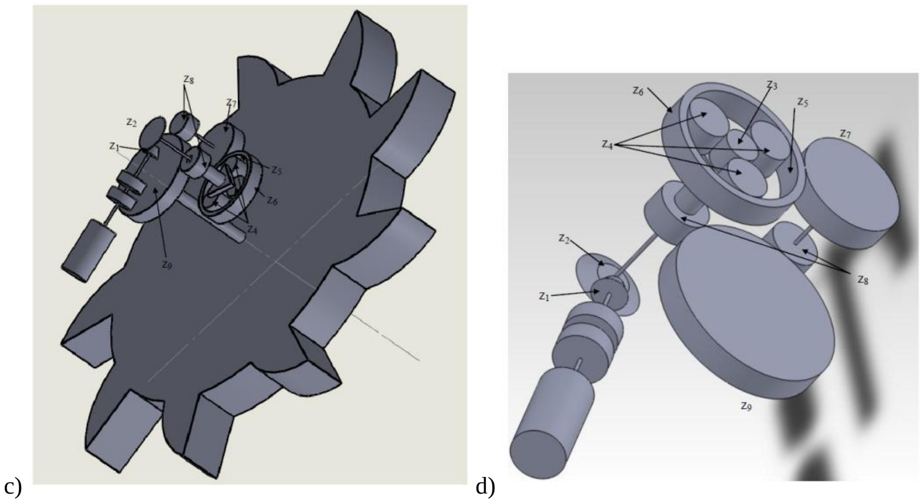


Fig. 8. Two schemes a) and b) of different designs of driving systems,
c) and d) more details for driving system b)

but their design factors are quite different, which is given by planetary gearbox ratios u_p and many other differences presented in (Bartelmus, Zimroz, 2011) and (Bartelmus, 2011). Interpretation on relation between vibration and gearbox condition is developed from several characteristic frequencies, which are embedded in vibration signals. These frequencies are named shaft frequencies, meshing frequencies, hunting frequencies, ghost frequencies. In condition monitoring one can also, when identifying some gear faults, call some frequencies as connected with distributed faults and local faults. To identify these frequencies one ought to refer to (Bartelmus, Zimroz, 2011) and (Bartelmus, 2011).

Following the quotation (2) from (Mining Magazine, 2011) “We get lot information from on-board systems to help improve maintenance, but sometimes there is so much data we don’t know what to do with it.” Fig. 9 left shows hundreds of measurements, which have been taken from two gearboxes. The gearbox drive bucked wheels in excavators. Each point on the Fig. 9 left presents one measurement, which is based on frequency analysis of vibration signal. The measurements shows that must be the deference in conditions of two gearboxes but the problem is how precisely show the condition difference between two planetary gearbox systems given in Fig. 8b. Most of vibration diagnostic systems use frequency analysis for gearbox condition assessment. If the system suggests some vibration limit let say acceleration 20 m/s^2 and a diagnostician is given confusing results of measurements once the system is in good condition once the same system is in bad condition. To improve the situation first step is to present the data in the probability distribution functions and assess a mean value and a standard deviation. It is also a good suggestion to reject the data, which are measured when the system is no loaded and next assess a mean value and standard deviation. It is first suggestion that the data are load dependant. The new set of the data is presented in Fig. 9b. But the data are still overlapping each other. It may be taken in advance that the system which data are represented by circles is in good condition and the system which is represented by stars is in bad condition. Making assessment on the mean value when the data overlap each other is not good, is risky. To solve the problem the design factors of the system ought to be taken. The gearbox system is driving by a asynchronous electric motor and the motor is connected to a gearbox by fluid coupling, so the system is susceptible to the varying load. Also mechanical part of the system is susceptible to the varying load. The varying load is caused by the machine operation condition.

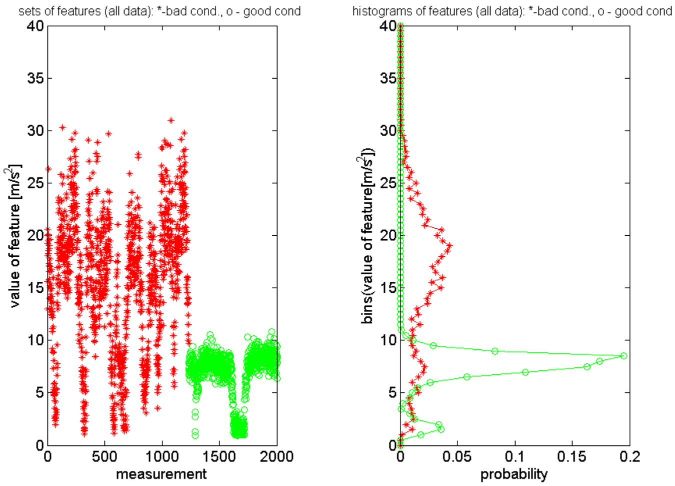
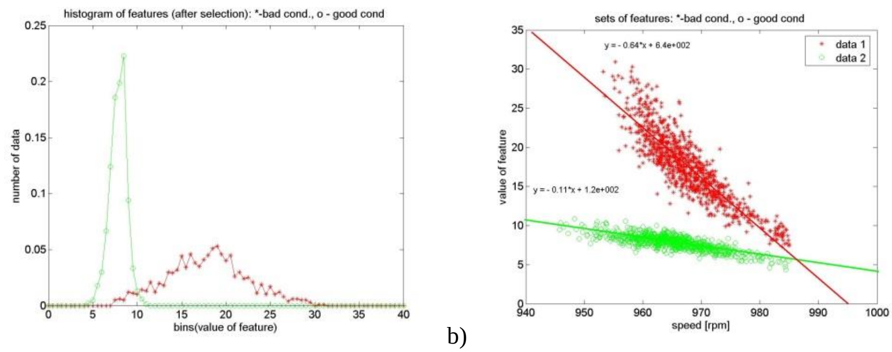


Fig. 9. Probability of feature distributions for two diagnosed objects: circle marked distribution for object in good condition and star marked distribution for object in bad condition

In (Bartelmus, 1992) and (Bartelmus, Zimroz, 2009b) has been pointed that the during the gearbox operation the mine environment is the cause of rolling element bearings frictional wear, which is caused by fine particles getting into gearbox oil. It is mainly caused by fine hard quartz particles. The frictional wear cause the inner gearbox shafts and gears misalignment (IGSGM) (Bartelmus, 2012).



a) b)

Fig. 10. a) Data distribution of measured diagnostic parameters b) Load susceptibility characteristics as diagnostic features for planetary gearbox as a function of rotation speed RPM; for a gearbox in good ("o" dots) and bad condition ("x" dots)

To present IGSGM here has been described the case of planetary gearbox condition evaluation where has been demonstrated that the frictional wear of bearings causes IGSGM. The IGSGM is evaluated on the base of susceptibility characteristic (SC) and bearing frictional wear has been measured after the planetary gearbox dismantling and tooth gearing faults as surface micro cracking has been noticed. In the paper (Bartelmus, Zimroz, 2009b) the term load susceptibility (LS) or S.C. is introduced.

The load susceptibility characteristics are expressed by linear equation

$$y = ax + b \tag{1}$$

where: y – the value of the signal feature, x – the operating conditions (instantaneous speed in this case) indicator, a, b – the parameters to be determined.

The load susceptibility is presented by the regression characteristics in Fig. 10b) as diagnostic features for planetary gearbox as a function of rotation speed RPM; for a gearbox in good ("o" dots) and bad condition ("x" dots). In this case, presentation of susceptibility characteristics is based on a linear relationship between the transmitted moment and rotation speed, the case when a gearbox is driven by a synchronic electric motor. It means that one may use the load susceptibility characteristics as the function of a load or function of a rotation speed RPM as has been given in Fig. 10b). In the presented cases of the load susceptibilities the characteristics are interpreted as follows: the case for a good condition of a gearbox shows that the planetary gearbox system behaves as a linear system under increasing load, that means with increasing load the system deflection increases. In the case of bad condition, as results from frictional wear of bearings, the gear mesh, under the condition of an IGSGM gives a linear increase of the gear cooperation error and linear increase of inter teeth force, which causes linear increase of a vibration acceleration signal as has been presented by linear regression line in Fig. 10b, the case of the bad gear condition. Fig. 10b) also shows very good separation of data for the good and bad condition, much better than is given in Fig. 10a) when the data distribution functions overlap each other. The consideration on IGSGM gives the clues on possible maintenance improvement that means the base for bearings replacement to avoid degradation of the gears details are given in (Bartelmus, 2014)

Referring to (1) “We receive a lot of information on on-board systems, in order to help to improve maintenance, but sometimes there are so many data that we don’t know how to deal with it” one can reduce the data by presenting them in the suitable forms of susceptibility characteristics of the object in respectively for good condition

$$y = -0.12x + 120$$

and bad condition

$$y = -0.52x + 550.$$

The presented result in Fig. 10b shows the condition of two gearbox system one is good condition after operation approximately 10000 h and second is in bad condition after operation about 20000 h. In condition monitoring to show change of condition monitoring there is a need to present several load susceptibility characteristics during operation time of a gearbox as it is presented in paper (Zimroz and others, 2014a) for a wind turbine bearing.

After dismantling of the gearbox which operation is 20000 h the gearbox condition directions for repair are as follow:

- All rolling elements bearings have over limit radial backlash so have to be replaced by new ones
- Almost all gears should be improved by grinding because scuffing on the teeth and micro cracks have been sported.
- Some conclusions arrive from the above consideration. The harsh environment at which the gearbox operates is thought as an operation factor, which has influence to change of the gearbox condition. The condition change is caused by frictional wear of components and especially rolling elements bearings.
- The operation time of 20000 h was too long because scuffing on the teeth and micro cracks have been sported.

- It is difficult to say that improvement by grinding would be successful for another 20000 h of gearbox reliable operation.
- To avoid such dilemma the operation time should be shorten and the bearings in the gearbox replaced to obtain suitable prevention from the teeth and micro cracks.

CONCLUSIONS

The paper gives the supporting ways for improving mining equipment maintenance. It shows how to fulfill the expectations expressed in discussion given in Mining Magazine September 2011 and also shows that these can not be fulfill by directions presented in Mining Magazine July/August 2013. The expectations can be fulfill if one is conscious that the mining equipment works under varying operation condition and this condition needs the new ways of vibration signal analysis. It needs a new way of vibration data presentation and storing. The discussion presented in Mining Magazine September 2011 leads to the diagnostician demand like understanding the measured data. The paper shows that it can be fulfilled by object and operation support maintenance, by proper data analysis taking into consideration design, production technology, operation and change of condition factors.

The new way of data processing leads to presentation of data in the form of load susceptibility characteristics. The linear system shows its linearity properties that with increase in the load the mean value of generated vibration given by acceleration signals increases linearly. It is given in Fig10.b) Load susceptibility characteristics as diagnostic features for planetary gearbox as a function of rotation speed RPM; for a gearbox in good ("o" dots) and bad condition ("x" dots). As it is given in Fig. 10b, using the load susceptibility characteristic gives better separation in comparing with presenting them in terms of data distributions Fig.10a. The use of susceptibility characteristics and its interpretation comes from the results of a study on influence: design, production technology, operation and change of condition factors. Further examples of using the susceptibility characteristics are given in the cited papers.

LITERATURE

ALBAN L.E., 1985, *Systematic analysis of gear failures*, ASM, ISBN 0-87170-200-2. American Society for Metals.

BARTELMUS W., XVI 2011, *Fundamentals for condition monitoring and diagnostics for driving bucket wheel system with overload mechanism of bucket wheel excavator* Scientific Papers of the Institute of Mining of the Wroclaw University of Technology, Mining and. and geolog,y Wroclaw, pp. 5–16.

BARTELMUS, W. CHAARI F. ZIMROZ, R. HADDAR M., 2010 *Modelling of gearbox dynamics under time varying non-stationary operation for distributed fault detection and diagnosis* European Journal of Mechanics – A/Solids 29, 637–646.

BARTELMUS, W. ZIMROZ, R., 2009a, *Vibration condition monitoring of planetary gearbox under varying external load*. Mechanical Systems and Signal Processing 23, 246–257.

BARTELMUS, W. ZIMROZ, R., 2009b *A new feature for monitoring the condition of gearboxes in non-stationary operation conditions*. Mechanical Systems and Signal Processing 23 (2009), 1528–1534.

BARTELMUS, W. ZIMROZ, R., 2009c *Gearbox condition degradation models*. Proceedings of Conference on Condition Monitoring and Machine Failure Prevention Technology. Dublin, Ireland, 22–25 June 2009.

BARTELMUS, W., 1992, *Vibration condition monitoring of gearboxes*. Machine Vibration nr 1, pp. 178–189.

BARTELMUS, W., 2006, *Condition monitoring of open cast mining machinery*. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.

BARTELMUS, W., 2009, *Influence of design, production technology, operation and change of condition factors on gearbox vibration diagnostic signals.* Proceedings, Resent Developments in Acoustic, Noise and Vibration. The Sixteenth International Congress on Sound and Vibration, Kraków, Poland, 5–9 July.

BARTELMUS, W., 2012, *Secondary misalignment as the main cause of gearbox failure International* Conference on Condition Monitoring, 12–14 June, London, United Kingdom.

BARTELMUS, W., 2013, *Editorial statement*, Mechanical Systems and Signal Processing, 38, pp. 1–4.

BARTELMUS, W., 2014, *New focus on gearbox condition monitoring for failure prevention technology*, Key Engineering Materials, Vol. 588, pp. 184–191.

BARTELMUS, W., April 2008, *Root cause and vibration signal analysis for gearbox condition monitoring*, Insight Vol. 50, No 4.

BARTELMUS, W., ZIMROZ, R., XVI 2011, *Vibration spectra characteristics frequencies for condition monitoring of mine machinery compound and complex gearboxes*. Scientific Papers of the Institute of Mining of the Wroclaw University of Technology Wroclaw, pp. 17–34.

BARTELMUS, W.: 2011b *Gearbox damage process*. Journal of Physics. Conference Series. [electronic document] , Vol. 305, nr 1, 9p. 9th International Conference on Damage Assessment of Structures, DAMAS 2011, Oxford, UK, 11–13, July.

GOODBODY, A., 2013, *Smooth Operations* Mining Magazine July/August, pp. 44–55.

GRIDKHOR P., SCHEFFER C., 2004, *Practical machinery vibration analysis and predictive maintenance*. Elsevier.

HATANGADI A. A., 2005, *Plant and machinery failure prevention* McGraw-Hill.

KEITH MOBLEY, 2002, *An introduction to predictive maintenance*, Buttterworth-Heimann.

MORALES-ESPEJEL G.E., 2012 *Understanding and preventing surface distress*. Gear Solutions, July 29 – 38 pp.

NEVILLE W. SACHS, P.E., 2007, *Practical plant failure analysis*. Taylor & Francis.

SAWICKI M., P. STEFANIAK, R. KRÓL, R. ZIMROZ, M. HARDYGÓRA, 2012, The integration of thermography data and Diag Manager system for diagnostic management of technological system, , International Journal of Transport & Logistics (Belgrade), vol. 10, pp. 263–267.

STADLER K., STUBENRAUCH A., *Premature bearing failures in industrial gearboxes*. Lagerfrühausfälle in Industriegetrieben.. SKF GmbH.

STEFANIAK P., R.ZIMROZ, R. KRÓL, J. GÓRNIAK-ZIMROZ, W. BARTELMUS, M. HARDYGÓRA, 2012: *Some remarks on using condition monitoring for spatially distributed mechanical system belt conveyor network in underground mine - a case study*, P., Springer, Berlin, str. 497–507, ISBN978-3-642-28767-1.

STEFANIAK P., WYLOMANSKA A., OBUCHOWSKI J., ZIMROZ, R., 2014, *Procedures for decision thresholds finding in maintenance management of belt conveyor system – statistical modelling of diagnostic data*, 12th International Symposium Continuous Surface Mining, Aachen.

WAYNE CHMIEL, 2011, *Integrated, predictive maintenance strategies: what can we expect of the future*? *'Load & Haul Round Table Discussion*, Mining Magazine September, pp. 92–94.

WOWK V., 2000, *Machine Vibration; Alignment* McGraw-Hill.

ZIMROZ, R., BARTELMUS, W., BARSZCZ T., URBANEK, 2014a, *Diagnostics of bearings in presence of strong operating conditions non-stationarity- A procedures of load-dependent features processing with application to wind turbine bearings*, Mechanical Systems and Signal Processing, vol. 46, Issue 1, 3, pp. 16–27.

ZIMROZ, R., STEFANIAK P., BARTELMUS, W., HARDYGORA M., 2014b, *Novel techniques of diagnostic data processing for belt conveyor maintenance*, 12th International Symposium Continuous Surface Mining, Aachen.

Condition Monitoring of Machinery in Non-Stationary Operations. Springer 2012.

Advances in Condition Monitoring of Machinery in Non-Stationary Operations. Springer 2013.

An Introduction to Modern Vehicle Design - page 503 - Google Books result.

books.google.pl/books?isbn=0750650443 – Julian Happian-Smith – 2001 – Design.

*Failure preventio*n – *The role of endurance and durability*. *studies in the design and manufacture of reliable vehicles*. F.L. Jones, BSc, PhD, MIM, CEng, **.**

OBIEKTOWO I EKSPLOATACYJNIE WSPOMAGANE UTRZYMANIE GÓRNICZEGO WYPOSAŻENIA

Artykuł powstał w odpowiedzi na dyskusję w Mining Magazine (MM) wrzesień 2011 i lipiec/sierpień 2013. Artykuł pokazuje, że dyskusja przedstawiona w MM 2013 nie spełnia oczekiwań wyrażonych w MM wydanie 2011. Przedstawiana praca jest przeglądem na temat obsługi maszyn, która bazuje na monitorowaniu jako narzędzie dla detekcji uszkodzeń i ich zapobieganiu. Uszkodzenia są uważane jako nieuchronne w eksploatacji jako proces zużycia i degradacji. Istnieje pytanie czy można wpłynąć na proces zużycia i degradacji wykorzystując monitorowanie stanu. Artykuł przedstawił technologię (w odniesieniu do cytowanych prac), które pokazują, że wykorzystując monitorowanie i znając scenariusze zużycia i proces degradacji można racjonalizować eksploatację. Przedstawiony artykuł pokazuje możliwe ulepszenia, które są potrzebne, aby spełnić oczekiwania wyrażone w MM wrzesień 2011, a które nie są brane pod uwagę w MM 2013. Te ulepszenia mogą być spełnione na podstawie wspomagania wnioskowania wynikającego z znajomości cech obiektu i warunków eksploatacji.