ANALYSIS AND PREDICTION OF VIBRATIONS OF BALL BEARINGS CONTAMINATED BY OPEN PIT COAL MINE DEBRIS PARTICLES

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Preliminary communication

Analysis of the relevant literature has shown that only few researches are dealing with the bearings dynamic behaviour in real environmental conditions - where high concentration of solid contaminant particles is evident. There is still no established mathematical correlation between bearings vibration characteristics, working time and concentration level of contaminant particles in their grease. Solving this problem was the main goal of research described in this paper. First step was thorough analysis of the chemical composition and structure of contamination particles directly causing the sample bearings failure on open pit coal mines. After that, specific experimental methodology was developed and implemented. Finally, by processing of the experimental results, new mathematical correlation between listed bearings characteristics was determined.

Keywords: bearings; conveyor idlers; coal mines; contamination; particles; vibrations

Analiza i predviđanje vibracija kotrljajnih kugličnih ležaja kontaminiranih nečistoćama s površinskih kopova uglja

Prethodno priopćenje

Analiza relevantne literature pokazuje da se vrlo mali broj istraživača bavi problematikom dinamičkog ponašanja kotrljajnih ležaja u realnim eksploatacijskim uvjetima – gdje je evidentno prisustvo visoke koncentracije čvrstih čestica nečistoća. Još uvek nisu ustanovljene matematičke korelacije između vibracijskih karakteristika kotrljajnih ležaja, vremena koje su proveli u eksploatacijskim uvjetima i razine koncentracije čestica nečistoća u njihovom mazivu. Upravo je rješavanje ovog problema glavni cilj opisanog istraživanja. Prvi je korak u njegovoj realizaciji bila detaljna analiza kemijskog sastava i strukture čestica nečistoća koje direktno uzrokuju otkaze kotrljajnih ležaja sa površinskih kopova uglja. Nakon toga, razvijena je i implementirana specifična eksperimentalna metodologija za ispitivanje vibracijskih karakteristika odabranih uzoraka kotrljajnih ležaja. Konačno, statističkom obradom dobivenih eksperimentalnih rezultata, utvrđena je nova matematička korelacija između navedenih karakteristika kotrljajnih ležaja.

Ključne riječi: čestice; kontaminacija; kotrljajni ležaji; rudnici uglja; transportni valjci; vibracije

1 Introduction

Nowadays power industry worldwide is mainly based on fossil fuel processing and exploitation. However, lack of energy resources in nearby future is inevitable and that is why improvement of overall reliability and efficiency of power production systems is one of the main tasks of 21st century science. It is determined by numerous researchers that very high percentage of energy losses in thermal power plants is caused by their transportation systems, especially by belt conveyors and their key elements – conveyor idlers [1-3].
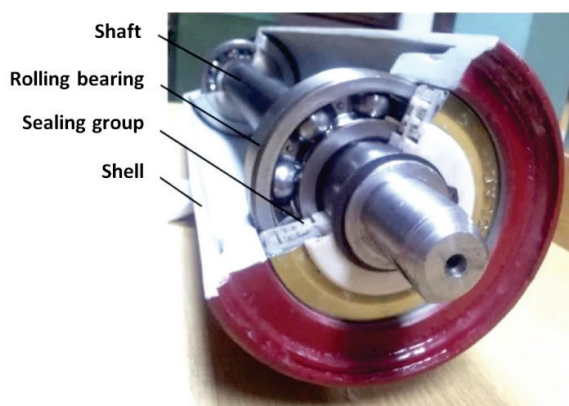

Figure 1 Component parts of typical conveyor idler assembly

Conveyor idlers (Fig. 1) are assemblies commonly consisting of shaft, shell, pair of sealing groups and pair of rolling bearings, with main purpose to provide support for conveyor belt and transported material. Taking into account that there are over 80000 conveyor idlers per standard open pit coal mine, it is clear that any improvement of its reliability leads to the significant improvement of power production systems overall performances.

Rolling bearings (usually ball bearings) are critical components of conveyor idlers. They are the most common reason for conveyor idlers failures on open pit coal mines [4-6]. If bearings are correctly installed and properly maintained, the time of their failure can be accurately predicted using modified equation of their basic life [7]:

$$L_n = \left(\frac{Q_c}{Q}\right)^p , \tag{1}$$

Where: L_n – Basic rating life (n - probability); Q_c – Basic dynamic load; Q – Actual load; p – Constant.

Constant p is a function of the three constants regarding maximum shear stress exponents, Weibull slope and bearing type. Different correlations of these constants were determined [8] but no matter the approach, constant p has been approximated to the values 3 (ball bearings) and 10/3 (roller bearings).

The basic rating life $L10$ is commonly used, calculating the expected service life which 90 % of bearings of the same type will reach before failure. Also, the basic dynamic radial C_r and axial C_a load are used in conjunction with the dynamic equivalent radial P_r or axial P_a load [9].

Rating life $L10$ is relevant for ideal working conditions, so it has to be improved by correction factors in order to predict bearings service life in working conditions. Those factors are described in detail in standard ISO 281:2007 which takes into account rolling

bearing lubricating conditions, lubricant contamination level, operating temperature and fitting stresses:

$$L_{nm} = a_1 \times a_{ISO} \times L_{10},\qquad(2)$$

where: L_{nm} – Modified rating life; a_1 – Life modification factor for reliability; a_{ISO} – Life modification factor.

The life modification factor a_{ISO} is calculated as:

$$a_{ISO} = f\left(\frac{e_c, C_u}{P}, \kappa\right),\qquad(3)$$

where: e_c – Contamination factor; C_u – Fatigue load limit; P – Dynamic equivalent load; κ – Viscosity ratio of the lubricant.

According to the previous equations, it is clear that contamination can significantly affect rolling bearings service life, especially in case of conveyor idlers rolling bearings [4-6], because of very high concentration of solid contaminant particles in their working environment. The study of conveyor systems has shown that no matter how efficient the conveyor idlers sealing devices are, the environment conditions could be so varied and hostile that their bearings eventually become seriously damaged – due to contamination by debris particles which have entered the bearings inner space [5].

Nowadays, in order to prevent premature bearing failure, there are several monitoring techniques in use such as oil analysis, wear debris analysis, vibration analysis and acoustic emission analysis [10, 11]. However, the vibration and the acoustic emission analysis are most frequently used because they provide complex information about the state of rolling bearings component parts [12, 13]. According to Tomovic et al. the cause for vibration inducement in rolling bearings can be classified into four groups [14]:
1. Specific construction and operating profile of the rolling element bearing (primary bearing induced vibration - structural vibrations);
2. Bearing elements micro and macro geometry errors (vibrations of technological origin);
3. Bearing elements damage (vibrations due to damage of bearing elements);
4. Negative environmental impact (vibration due to the environmental effects).

When minor damages (due to fatigue, denting, scuffing, scoring, wear etc.) are present on rolling bearings contact surfaces, vibrations are increased as the motion of the rolling elements is more disturbed. The vibration signal can be then processed in time and frequency domain with statistical and arithmetical methods. However, data recorded in time domain could later be represented in the frequency domain by the use of a Fourier transformation (usually Discrete Time Fourier Transform (DTFT) by Fast Fourier Transform (FFT) algorithm). Also, vibration acceleration (usually expressed as the RMS value) is the most logical choice for consideration because it is most dominant vibration characteristic on high frequency ranges typical for rolling element bearings.

Despite numerous performed experiments and analysis there are still no mathematical models for contaminated bearings vibrations prediction. Solving this problem is the main goal of research presented in this paper: to establish a correlation between bearings vibrations characteristics change in time and concentration level of contamination particles in the grease of the bearings.

It is important to mention that in this particular research, working conditions for conveyor idler bearings from open pit coal mines were simulated but basic principles and presumptions are universal so they can be conditionally applied on any kind of rotating machinery. In addition to that, thorough analysis of real open coal mine debris particles was performed in order to find out the structure and origin of contaminant particles which cause the failure of rolling bearings in above mentioned working environment.

2   Theoretical and experimental background

According to the relevant literature, there are several possible mechanisms of rolling bearings wear due to contamination [15, 16]. When hard particles go into the interference, surface damage by mechanisms such as denting is inevitable [17, 18]. Dents essentially represent stress concentration sites, which increase the possibilities for the occurrence of spalling, accelerating the failure process [19]. In terms of contaminant particle sizes, Maru et al. [20] and Nikas et al. [21] state that the critical size of the contaminant particles is in the order of the lubrication film thickness. However, other authors claim that when particles larger than the oil film thickness enter the contact zone, they cause stress peaks and permanent indentations in the raceway as they are over rolled. These stress peaks lead to a reduced life of the rolling bearing due to fatigue [9].

Relation between grease contamination level and bearing vibrations is rather complex. The contact surface damage caused by contamination particles induces the bearings radial clearance change, significantly reducing its service life and increasing the overall vibrations level [22]. Also, load distribution between balls and rings of the rolling bearing is disturbed, which also affects the bearings vibrations level [23]. That is why selection of correct preload and number of bearing balls is very important as claimed by Tomovic [24] and Mitrovic [25]. Contact surface damage level also depends on the hardness of the ductile contamination particles and the strength of the brittle contamination particles, because they deform or fracture when they enter the zone between balls and rings of the contaminated bearing [26].

There are many experimental researches performed in order to determine precise relations between bearing contamination level and its vibrations. Maru et al. [20, 27-29] presented works with a goal to study how contamination in the lubricant can affect vibrations, taking into account the effect of the contaminant particle size and its concentration level in the lubricant. In their experiments the oil of 6205 ball bearings (bore diameter: 25 mm) was contaminated by standard quartz particles, with the average sizes of 37 µm, 59 µm and 111 µm. Also, three oil contamination levels were used, with

nominal concentrations from 0,04 g/l up to 0,7 g/l. The results have shown that it is possible to identify the presence of contamination from some specific frequency bands of the bearing vibration signal. Retesting of the rolling bearings with clean oil also revealed that some frequency bands are excited due to wear in the contacting elements.

Koulocheris et al. [9] performed experiments with three types of ball bearings (1207, 2207 and YSA – bore diameter: 35 mm) whose grease was contaminated by hard corundum particles (alumina, Al2O3, hardness 2000HV) with sizes of 62-73 μm and 105-177 μm, where a quantity of 0,75 cm^3 of particles were premixed with 50 g of clean SKF LGMT3 grease. Their goal was to find a pattern in the relationship between contamination particle sizes and wear progress, using vibrations analysis tools. The results have shown that wear is progressing faster when smaller particles are used. Similar experiment was performed by Lazovic et al. [17, 18] with standardized diamond dust as contamination material. Gained results were very similar and the influence of contamination on ball bearings internal radial clearance was also determined.

Mahajan and Utpat [30] investigate the trends in the amounts of vibration affected by contamination in the bearing grease and by the bearing wear itself. Experimental tests were performed on 6206-2RS deep-groove ball bearings (bore diameter: 30 mm) and the Dolomite powder in three concentration levels (5 %, 15 % and 25 % of contaminant in 5 g of grease) and three different particle sizes (53 μm, 75 μm and 106 μm).

The method of vibration analysis was effective in trends characterization in vibration due to solid contaminant in lubrication. The results have shown that, as the contaminant is added in the lubrication, there is a considerable increase in the vibration signatures of ball bearings. As the parameters like speed and load are varied, the acceleration values also vary, and as the particle size is increased the corresponding acceleration values are also increasing up to a certain limit, then they start to decrease.

It is clear from described experimental researches that particles used for artificial contamination were different depending on specific research approach and goal so they cannot accurately represent the contamination particles from exploitational working conditions of open pit coal mines conveyor idlers bearings. Also, rolling bearings used in conveyor idlers are much larger in size than those tested in described experiments. However, general conclusion could be made – there is a significant relation between rolling bearings vibrations and contamination, which leaves the space for further researches in this field, including mathematical models development of appropriate correlations.

3   Starting assumptions

Taking into account that per 1 m of open pit mine conveyor there are usually three linked idlers carrying the conveyor belt with transported material ('garland', Fig. 2), only the conditions of the middle one are simulated and aggravated by increased radial load and rotational speed – axial loads acting on the side conveyor idlers are fully neglected and it is presumed that middle idler takes

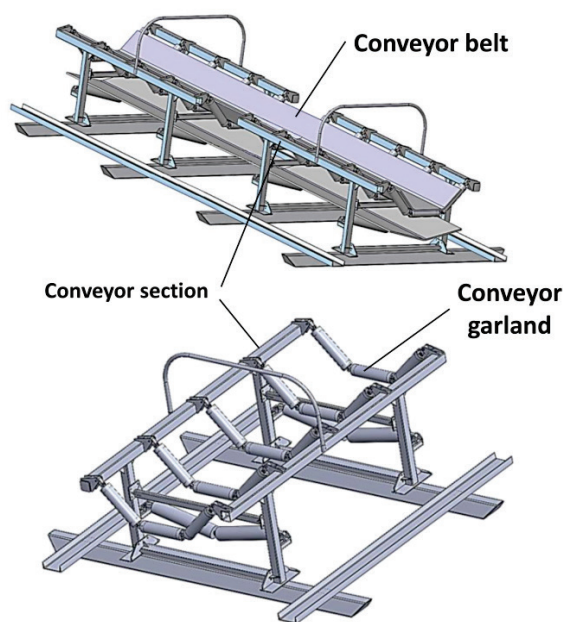70 % of total load due to weight of belt and transported material [31, 32].

Figure 2 3D Model of typical open pit coal mine belt conveyor

In case of coal transportation, where transported material is lignite (density: 1,3 t/m^3) and weight of 1 m of rubber belt is approximately 33 kg, radial load acting on the middle conveyor idler equals 3,875 kN. If radial load due to conveyor idlers rotational parts mass is added (0,165 kN, obtained by standard 3D modelling software), it is calculated that exploitational radial load acting on each of the two conveyor idlers bearings in described conditions equals ~2,0 kN. However, during the experimental research in this paper, experimental load applied on tested rolling bearings was ~4,6 kN in order to accelerate the bearings contact surface damage (it is important to mention that under this load bearing rings permitted angular deflection was not exceeded) .
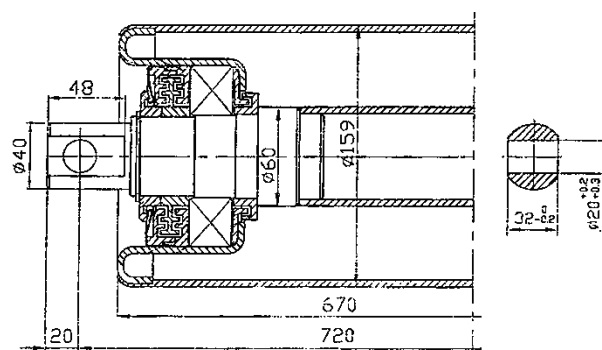

Figure 3 Technical drawing of conveyor idler assembly commonly used in the Republic of Serbia and Western Balkan region

The most common conveyor idlers used on open pit coal mines of the Republic of Serbia and Western Balkan region are those with outer diameters of 159 mm (Fig. 3) so their rolling bearings (usually, 6310-2Z/C3) are chosen to be experimentally tested. When the conveyor belt speed is 5 m/s, those idlers rotational speed equals approximately 600 RPM. Similar to the experimental radial load, in order to accelerate the damage of the tested conveyor idler bearings, applied experimental rotational

speed (~1140 RPM) was roughly two times larger than exploitational, which leads to the conclusion that acceleration of the performed experiments was ~22,7x. This means that 1 hr. of bearings work in experimental conditions corresponds to 22,7 hrs. of their work in exploitation – without contamination particles present [33].

Regarding the grease of the tested rolling bearings – it is considered that mass of grease in the rolling bearing does not decrease during the exploitation and that contamination particles coming from the environment to the internal area of the bearing are evenly distributed in its grease.

The average amount of grease per 6310-2Z/C3 bearing (9,3 g) is experimentally determined by weight measuring and averaging of the results from 70 tested samples and this value is used as the basis for further experiments. Also, as the standardised grease for pre-contamination, the SKF LGWA 2 grease was chosen because it is the commonly used grease for high loads and extreme pressures like those in conveyor idler bearings.

Despite the fact that chemical structure and origin of the contamination particles causing the failure of the rolling bearings from conveyor idlers on open pit coal mines were experimentally determined (as it will be described in one of the following chapters) they have to be normalised to be used as an artificial contaminant regarding their size so it is adopted that their size could not be larger than 120 μm (similar to the other author's experiments described in Chapter 2) which is achieved by sieving with appropriate mechanical screens.

3.1 Test samples

The 6310-2Z/C3 rolling bearings were selected for testing because they are commonly used in conveyor idlers with outer diameters of 159 mm. Basic characteristics of those bearings are presented in Tab. 1 and Fig. 4 [34] and all samples (70 in total) were measured, cleaned and measured again in order to determine the average weight of grease inside them.

Table 1 Main characteristics of 6310-2Z/C3 bearings

| Principal dimensions			Basic load rating		Speed ratings	
			Dynamic	Static	Reference speed	Limiting speed
d	D	B	C	C_o		
mm	mm	mm	kN	kN	r/min	r/min
50	110	27	62,4	38	15000	7800
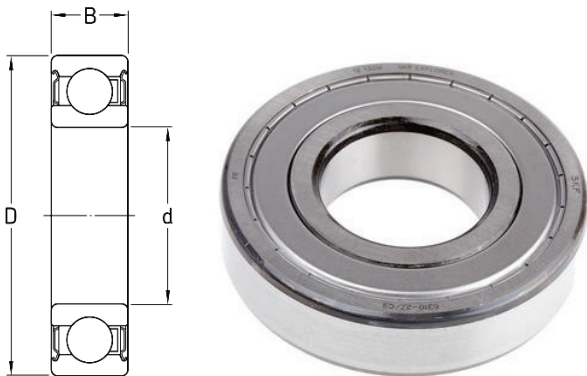
Figure 4 Designation and overall look of 6310-2Z/C3 rolling bearings

Among those samples, 6 were chosen for further testing because their internal radial clearance was the same – 30 μm (measured by accredited Laboratory for Machinery Elements and Systems Testing at the Faculty of Mechanical Engineering – University of Belgrade). That was important because, as described in Chapter 2, after a while the contamination increases the bearings internal radial clearance, thus affecting the overall level of bearings vibrations.

Selected bearings were then regreased with pre-contaminated SKF LGWA 2 grease and exposed to the previously determined experimental radial load and rotational speed (Chapter 3).

3.2 Experimental contamination particles

First step taken in order to gain contamination particles relevant for planned experiment was to take samples from open pit coal mine – it was concluded that there are three types of particles present: surface dust, excavation dirt and coal dust (Fig. 5-7).
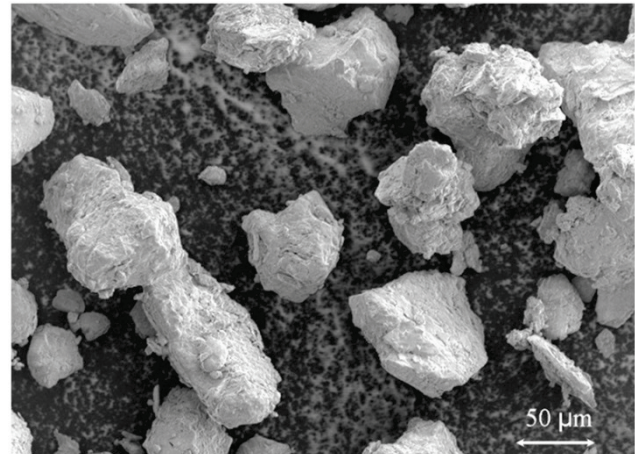
Figure 5 SEM image of the particles from open pit coal mine – surface dust
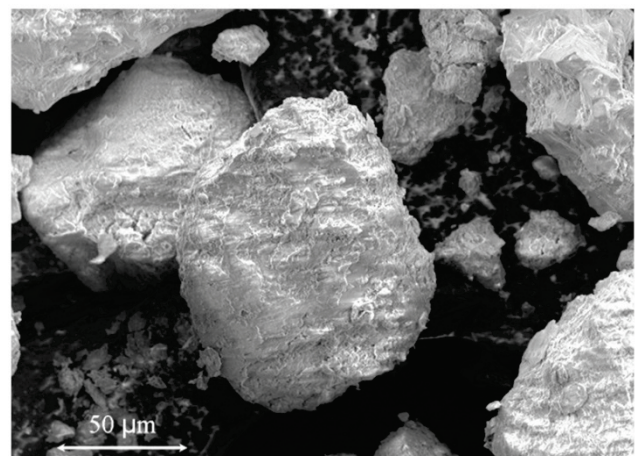
Figure 6 SEM image of the particles from open pit coal mine - excavation dirt

Samples from all three listed types of particles were taken and analysed regarding the size distribution and chemical composition. After that, fifteen failed conveyor idlers were taken from the open pit coal mine and disassembled. Contamination particles from their bearings were extracted, analysed and compared with the previous

results, pointing out that typical cause of conveyor idler bearings failure was the excavation dirt (not the surface dust, as expected), mostly consisting of different kinds of quartz and fematite and magnetite (Fig. 8).
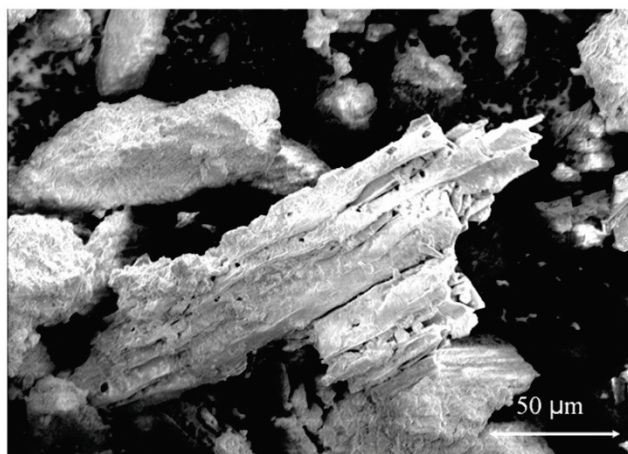

Figure 7 SEM image of the particles from open pit coal mine - coal dust
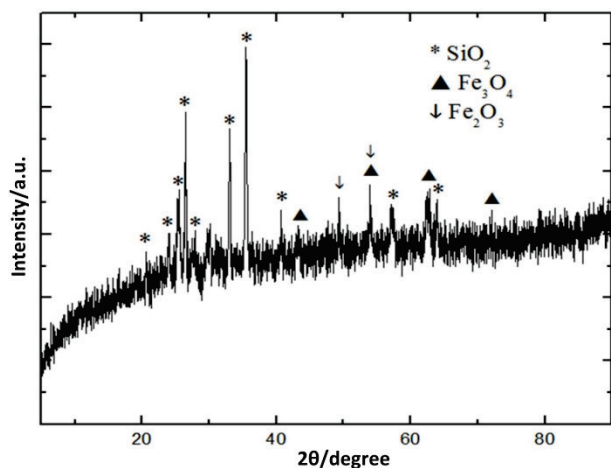

Figure 8 XRD analysis of contaminant particles - cause of conveyor idler's bearings failure on open pit coal mines
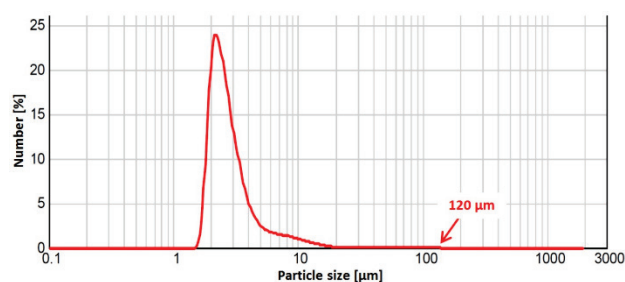

Figure 9 Experimental contamination particles size distribution

When the origin of conveyor idlers contamination particles was successfully determined, a sample for artificial bearing contamination was prepared by sieving excavation dirt with appropriate mechanical screen (mesh size less than 120 μm) – gained particle size distribution is shown in Fig. 9 (Horizontal axis – Particle size in μm, Vertical axis – % of particles of certain size).

3.3 Precontaminated grease characteristics

Because of its high endurance and temperature resistance, as well as widespread usage, the SKF LGWA

2 grease was chosen for pre–contamination. Basic characteristics of mentioned grease are presented in Tab. 2 [35].

Table 2 Basic characteristics of SKF LGWA 2 grease

DESIGNATION	SKF LGWA 2
DIN 51825 code	KP2N-30
NLGI consistency class	2
Soap type	Lithium complex
Base oil type	Mineral
Operating temperature range	−30 to +140 °C (−20 to +285 °F)
Dropping point DIN ISO 2176	
Base oil viscosity	
40 °C, mm²/s	185
100 °C, mmVs	15

In total, three samples of pre–contaminated grease were prepared:
1. Clean grease (in packages of 9,3 g);
2. Grease with 10,75 % of contaminant particles (in packages of 9,3 g of clean grease + 1 g of contaminant particles);
3. Grease with 21,5% of contaminant particles (in packages of 9,3 g of clean grease + 2 g of contaminant particles).

During the sample preparation, METRON (Germany) scales with precision of 0,001 g were used. However, estimated uncertainty of measurement was much higher – approximately 0,1 g. The primary cause of this uncertainty was the fact that grease gets stacked on the walls of containing vessels during the measuring and manipulation.

3.4 Testing equipment

For applying of the predetermined bearings radial load and rotational speed the custom made test frame, developed at the University of Belgrade – Faculty of Mechanical Engineering, was used (Fig. 10). Its working principle is shown in Fig. 11.
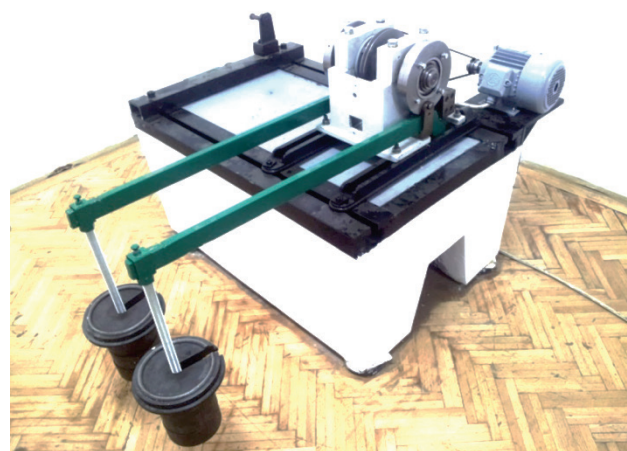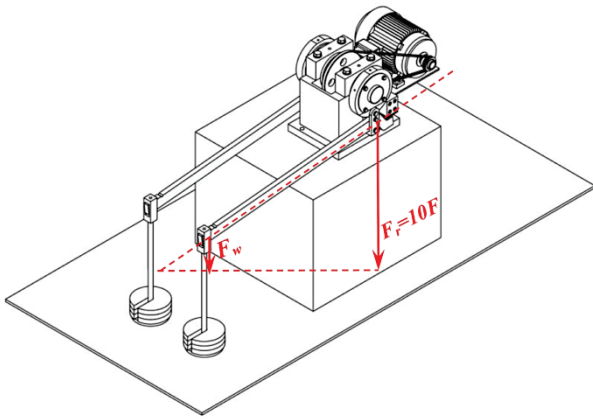

Figure 10 Rolling bearings test frame developed at the University of Belgrade - Faculty of Mechanical Engineering

Different radial loads were generated by levers with appropriate weights and different bearing rotational speeds by belt pulleys change.
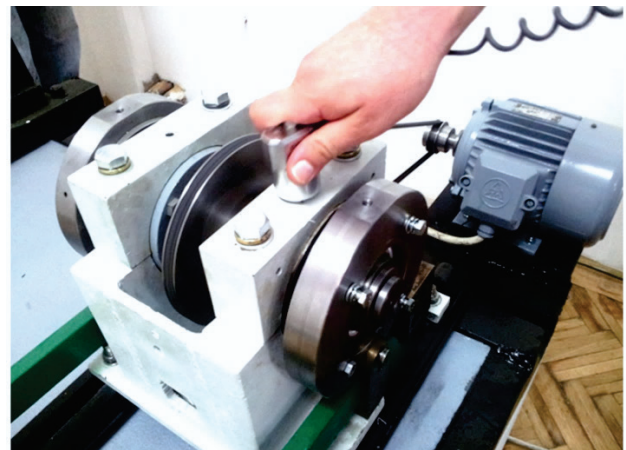
Figure 11 Working principle of rolling bearings test frame developed at the University of Belgrade - Faculty of Mechanical Engineering

Figure 12 Vibration measurement instrument
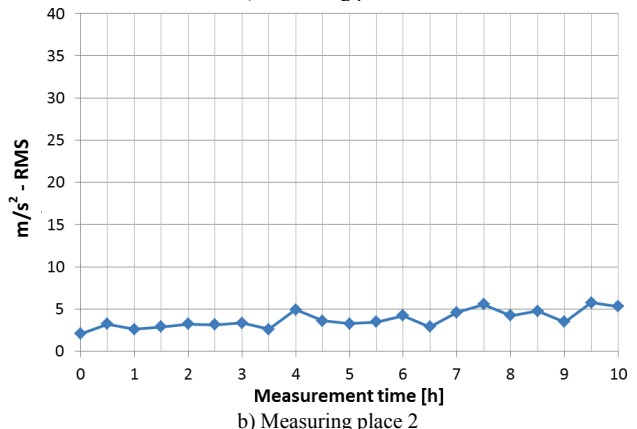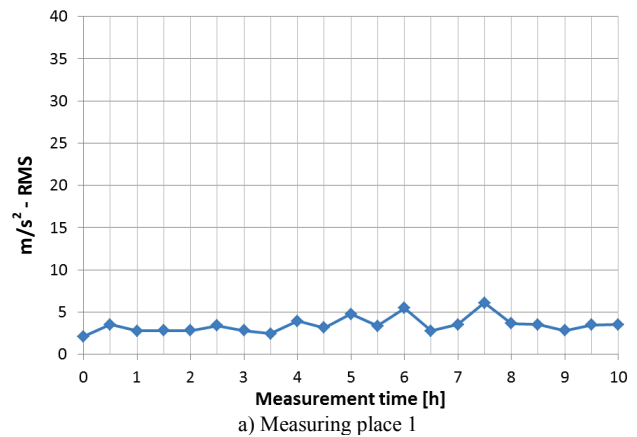SKF Microlog Analyzer GX

Bearings vibrations level measurements were performed by standard vibration measuring instrument – SKF Microlog Analyzer GX with appropriate accelerometers (vibration sensors) – Fig 12.

During the testing, vibration sensors were placed to measure bearings acceleration in vertical radial direction and fixed by adequate threads (Fig. 13).

3.5 Testing procedure

All six selected samples (6310-2Z/C3 ball bearings with internal radial clearance of 30 μm) were tested in pairs on two test frames measuring places, according to the following procedure:

1. First pair of samples was greased by 9,3 g of clean grease per sample;
2. Second pair of samples was greased by 9,3 g of grease contaminated by 1 g of prepared particles per sample;
3. Third pair of samples was greased by 9,3 g of grease contaminated by 2 g of prepared particles per sample;
4. First pair of samples was mounted on the test frame and exposed to radial load of 4,6 kN and rotational speed of 1140 RPM;
5. Every half hour samples radial vibrations acceleration expressed as the RMS value was recorded (Fig. 7);
6. After 10 hrs. of testing experiment was finished and sample bearings were dismounted from the test frame;

7. Second pair of samples was mounted on the test frame and exposed to radial load of 4,6 kN and rotational speed of 1140 RPM;
8. Every half hour samples radial vibrations acceleration expressed as the RMS value was recorded;
9. After 10 hrs. of testing the experiment was finished and sample bearings were dismounted from the test frame;
10. Third pair of samples was mounted on the test frame and exposed to radial load of 4,6 kN and rotational speed of 1140 RPM;
11. Every half hour samples radial vibrations acceleration expressed as the RMS value was recorded;
12. After 10 hrs. of testing experiment was finished and sample bearings were dismounted from the test frame.

Figure 13 Fixation of the accelerometers during testing

a) Measuring place 1

b) Measuring place 2
Figure 14 Bearings radial vibrations expressed as the RMS value of samples greased by SKF LGWA 2 clean grease

4 Results

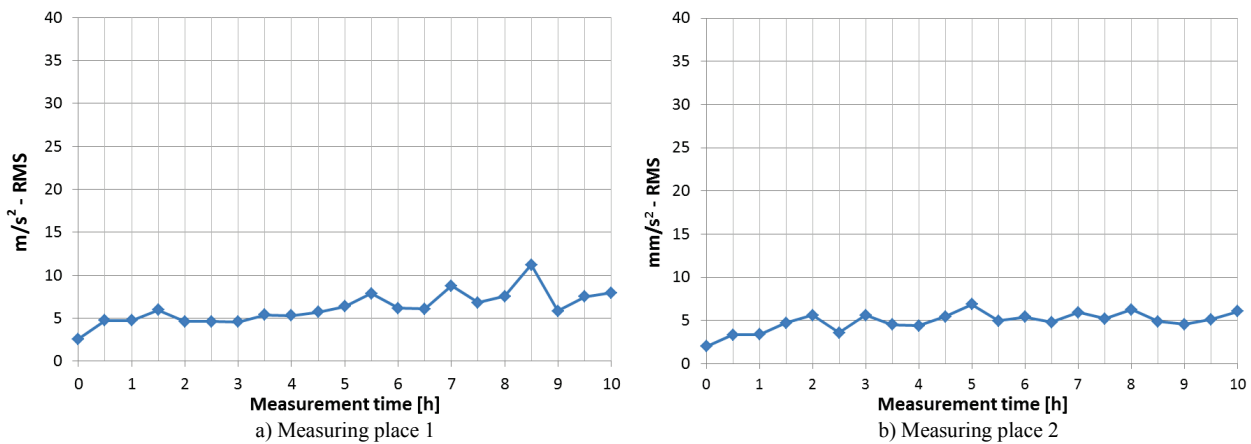In Figs. 14-16, the diagrams with recorded bearings radial vibrations (expressed as the RMS value) are presented.

a) Measuring place 1   b) Measuring place 2
Figure 15 Bearings radial vibrations expressed as the RMS value of samples greased by SKF LGWA 2 grease with 10,75 % of contamination particles

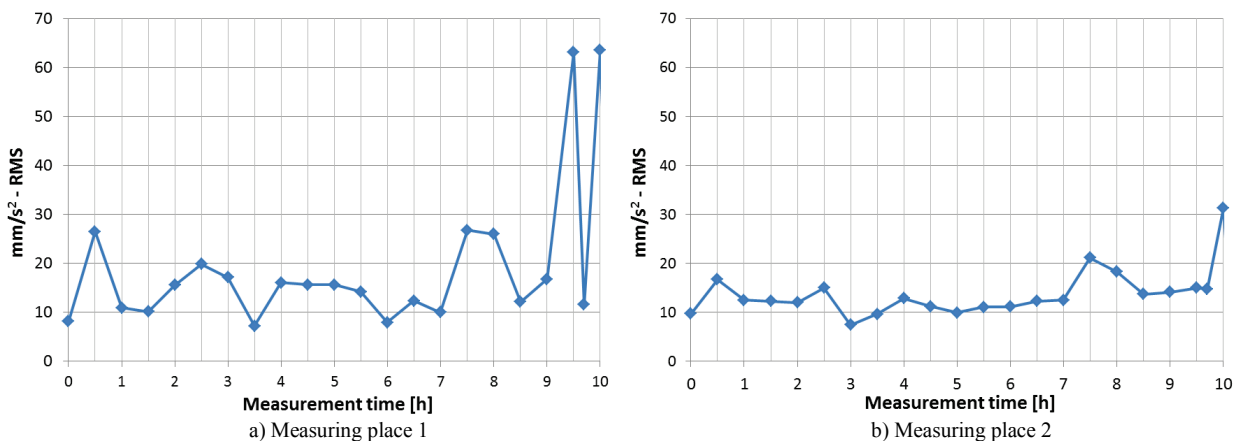a) Measuring place 1   b) Measuring place 2
Figure 16 Bearings radial vibrations expressed as the RMS value of samples greased by SKF LGWA 2 grease with 21,5 % of contamination particles

5 Generated mathematical model

Using software for statistical analysis and data interpolation, over 200 different interpolation models were implemented on measured experimental values, and the most relevant regarding its statistical significance was:

$$y = a + b \times x_1 + c \times x_2 + d \times x_1^2 + e \times x_2^2 + f \times x_1 \times x_2 \quad (4)$$

Where: y – bearings radial vibrations intensity expressed as the RMS value (mm/s²); x_1 – time (s); x_2 – mass of added particles per 9,3 g of clean grease; a, b, c, d, e, f – coefficients depending on experimental conditions.

Graphical presentation of generated correlation for experimental conditions described in Chapter 5 is shown in Fig. 17.

Residual plot (errors) of all measured vibrations intensities, expressed as RMS values, is graphically presented in Fig. 18.

It is important to mention that coefficient of multiple determination (R^2) for correlation presented in Fig. 17 equals 0,531 and its adjusted coefficient of multiple determination (Ra^2) is 0,512 – which are the highest gained values for all implemented interpolation models.

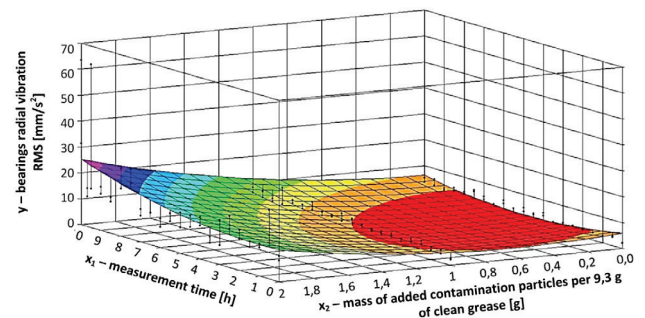

Figure 17 Graphical presentation of interpolated measured bearings radial vibrations expressed as the RMS
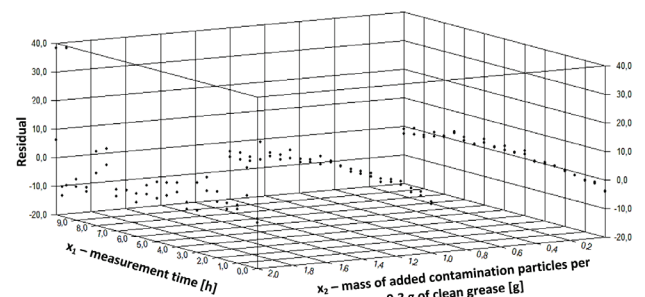

Figure 18 Graphical presentation of interpolated measured bearings radial vibrations expressed as the RMS

Coefficients a, b, c, d, e and f (from the equation No. 4) depend on demanded confidence intervals and their values for described specific experimental conditions are shown in Tab. 3.

Table 3 Values of coefficients a, b, c, d, e and f for different confidence intervals

Variable	Value	(+/−)	Lower Limit	Upper Limit
90 % Confidence Interval				
a	5,996126	3,373442	2,622683	9,369568
b	−1,558572	1,207329	−2,765901	−0,351243
c	−5,606899	4,452887	−10,059786	−1,154011
d	0,158217	0,11121	0,047007	0,269427
e	4,380776	1,954214	2,426562	6,334989
f	0,633565	0,36473	0,268835	0,998295
95 % Confidence Interval				
a	5,996126	4,029242	1,966883	10,025368
b	−1,558572	1,442035	−3,000607	−0,116537
c	−5,606899	5,318533	−10,925432	−0,288366
d	0,158217	0,132829	0,025388	0,291046
e	4,380776	2,334114	2,046661	6,714890
f	0,633565	0,435633	0,197932	1,069199

6 Results discussion

Analysis of the results presented in Figs. 14-18, have shown that there is a peak of bearings vibration at the beginning of their work, which is in accordance with the theory that contamination particles larger than the bearings grease film thickness are at first mechanically crushed, directly inducing initial vibration level increment. Later, when contamination particles are smaller in size, bearings radial vibrations levels slowly grow until they reach the certain value when their intensity rapidly rises in time. That moment could be conditionally taken as the beginning of failure.

It is also interesting to notice that bearings vibrations levels and their measured maximal values are very consistent – bearings tested in the same experimental conditions have shown almost identical dynamic behaviour.

Regarding the generated interpolation equation of the experimentally measured values, it could be considered that gained R^2 and Ra^2 are relatively high (>0,5), which leads to the conclusion that it represents measured values with rather reasonable accuracy. If the gained R^2 and Ra^2 values were too low that could be a sign that interpolation model was not statistically good (not necessary, according to some authors [36]). Additionally, residual probability of determined correlation does not oscillate around a straight line, which could be also interpreted as a sign that regression model is well chosen.

7 Conclusion

In this paper the correlation between bearings vibration characteristics, their working time and concentration level of exploitational contamination particles in their grease for specific working conditions of open pit coal mine conveyor idlers was presented.

Developed mathematical model was generated by accurate software for statistical analysis and data interpolation with rather high gained values of coefficient of multiple determination and adjusted coefficient of multiple determination – which confirmed the validity of developed equation. At the moment the presented correlation model is unique, regardless of the total number of tested bearing samples (among 70 tested bearings only 6 happened to have equal internal radial clearances) – so it could be successfully used as a basis for further researches.

For example, contamination factor e_c (from standard ISO 281:2007 and equation for life modification factor a_{ISO}) could be additionally improved, especially regarding the way it is adopted nowadays – still by descriptive contamination grades presented in Tab. 4 [37], despite the fact that quantitative means are far more accurate.

Table 4 Contamination factor e_c (standard ISO 281:2007)

Grade of Contaminations	Lubricant Contamination Factor e_c	
	DPW < 100	DPW ≥ 100
Extreme Cleanliness	1	1
High Cleanliness	0,8 to 0,6	0,9 to 0,8
Standard Cleanliness	0,6 to 0,5	0,8 to 0,6
Slight Contaminations	0,5 to 0,3	0,6 to 0,4
Typical Contaminations	0,3 to 0,1	0,4 to 0,2
Strong Contaminations	0,1 to 0,0	0,1 to 0
Very Strong	0	0

Additionally, the developed testing methodology could be used for qualitative assessment of rolling bearings produced by different manufacturers, new and repaired rolling bearings, rolling bearings of different types etc. indirectly increasing the overall quality of matching conveyor idlers and other rotating machines. Precisely determined bearing service life can provide the most effective preventive maintenance of conveyor idlers according to the JIT principle ('Just in Time'), avoiding losses due to unplanned standstills and emergency maintenance.

Importance of developed methodology also lies in the fact that it could be potentially used for improvement of existing bearings state monitoring techniques – by setting the new reference bearings vibrations values, appropriate for comparison with the vibrations measured in real working conditions.

Bearing in mind previous observations, future experimental researches are already planned. Within them, the following variables will be varied:
1. Quantity of the bearings' grease;
2. Types of tested bearings;
3. Mass and size of added contamination particles;
4. Applied radial loads and rotational speeds.

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