The Influence of the Lubrication on the Vibroacoustic Signal Generated by Rolling Bearings

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Abstract

Long-life and failure-free operation of rolling bearings depends on the proper lubrication. Additionally lubrication reduces vibration and noise generated by the operating bearing. However, from the point of view of the post-production diagnostics, lubrication can lead to undesirable masking of damage and manufacturing defects. This article presents the comparison of parameters of vibroacoustic signals generated by tapered roller bearings under different lubrication conditions. The influence of the lubricant on the form of vibroacoustic signals in both amplitude and frequency terms was determined. The premises on the choice of the lubricant for the post-production diagnostics of rolling bearings have also been specified.

Keywords: tapered roller bearings, lubrication, post-production diagnostics

1. Introduction

The purpose of the rolling bearings' lubrication is to separate the metal rolling elements and the races by a thin lubricant layer. This provides among others the reduction of friction in the rolling bearing, as well as an improvement of tribological properties and increase of operational reliability [1, 2]. Moreover, proper lubrication of rolling bearings provides: protection against corrosion and contamination, better heat dissipation, as well as noise reduction. The choise of the lubricant depends on: the type of rolling bearing, the material of the cage (metal or plastic) and operating parameters such as: nominal operating temperature, rotation speed range, load and environmental conditions [3-5].

The fulfilment of all mentioned earlier purposes of the lubrication is expected from the point of view of the operation [6]. On the other hand, the presence of a lubricant can significantly influence the form of vibroacoustic (VA) signals generated by the rolling bearing, both in qualitative and quantitative terms. Most of the diagnostic methods are based on measurements and analyses of vibrations and noise [7, 8]. Hence the type of the used lubricant is relevant. This influence should be taken into consideration during the post-production diagnostics of the rolling bearings. The ISO standard 15242 *Rolling bearings – Measuring methods for vibration* orders to:

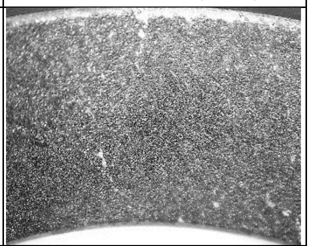
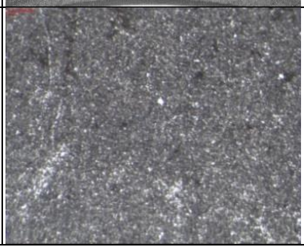
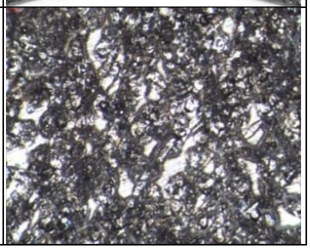
- test pre-lubricated bearings in the so-called delivery condition
- lubricate unlubricated bearings before testing with oil of viscosity from 10 mm^2/s to 100 mm^2/s (adequate for the type and the size of a bearing).

It is noted that some of anti-corrosive materials meeting lubrication criteria can also be used while measurements [9].

2. Experiment setup

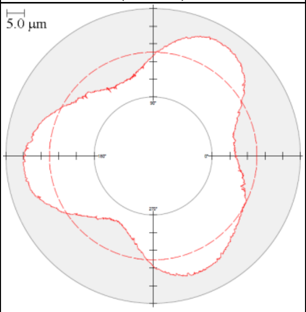
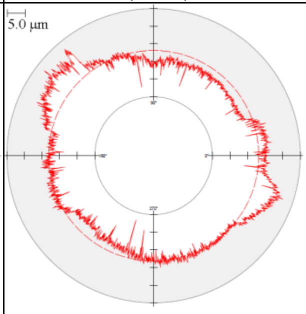
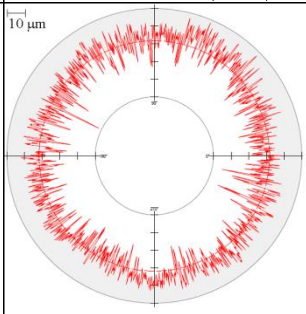
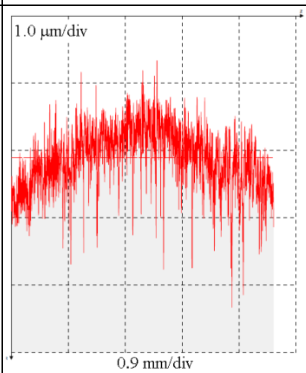
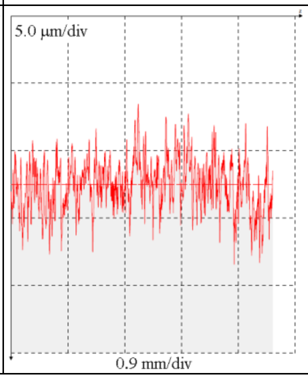
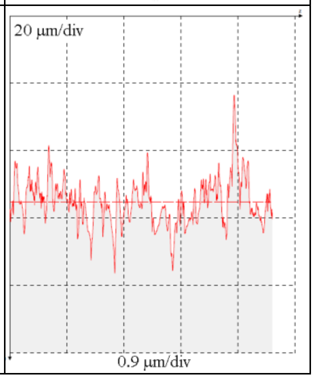
The aim of the research was to compare quantitative (measures) and qualitative (characteristics) changes in the vibration signals generated by rolling bearings as a result application of various lubricants. The tests were carried out using three CBK 171 tapered roller bearings with varying damage intensity. Among them there were one undamaged bearing (UDB), one sandblasted bearing (SBB) and one bearing damaged by electoerosion (EEB). Imperfections was introduced on the entire surface of the outer races. It should be noted that the remaining bearing parts (rollers, inner races) were free from defects and damage. Pictures of outer races of testing bearings (views and magnifications) are presented in Table 1.

Table 1. Outer races of the set of testing bearings

	undamaged bearing (UDB)	sandblasted bearing (SBB)	bearing damaged by electoerosion (EEB)
view			
magnification			

Before testing, the outer races (UDB, SSB, EEB) were parameterized on a coordinate measuring machine. The roundness and the roughness deviations (Table 2) were measured with specialized instrument Hommel-Etamic roundscan 535. The machine was equipped with Turbo Form software for the analysis of shape errors by the contact method. In this case, the measurements of the roundness deviation were carried out by a non-floating method.

Table 2. The results of geometric measurements of outer races of testing bearings (pay attention for different scales)

	undamaged bearing (UDB)	sandblasted bearing (SBB)	bearing damaged by electro-erosion (EEB)
roundness profile			
roughness profile			

The acquisition of the vibroacoustic signals was carried out on a test stand (sampling frequency was equal to 96 kHz). Experiments have been performed with specified operating parameters such as: radial load equal to 15 N, axial load equal to 55 N and rotation speed of inner ring equal to 1450 rpm. The measurements of rotation speed and analysis of vibrations and noise generated by the bearings were repeated for different types of lubricants. Table 3 contains the description of the used lubricants.

The vibration accelerations and the noise were linearly recorded (up to 50 kHz). Signal sequences (180-second long) have been acquired. The ICP ® M352A60 (PCB) accelerometer was used for vibrations measurements. The noise measurements were made by the polarized free-field microphone G.R.A.S. 40BF compatible with the low noise preamplifier Brüel & Kjaer NEXUS type 2691. The acquisition module VibDAQ 4+ was used for the analogue-digital conversion of VA and tachometer signals. Data acquisition ran synchronously on 4 channels. Digital signal processing was performed using a dedicated software elaborated in DASYLab® Data Acquisition System Laboratory.

The bearings were carefully prepared before testing. They were cleaned (duration 3 min) in an ultrasonic cleaner filled with kerosene and then rinsed in petroleum ether. Before each test the cleaning procedure was repeated twice. Oils (1/8 ml volume) were dosed precisely with a syringe to the bearing previously mounted on the stand whereas greases (approx. 1/3 g) were applied before mounting the bearing on the stand.

Table 3. Types and codes of the tested lubricants

Lubricant	Code
silicon oil	A
hydraulic oil	B
gear oil	C
universal grease, class NLGI: 2	D
long-lasting grease, class NLGI: 2, KP2 K-30	E
high pressure grease with MoS_2, class NLGI: 2, KP2 K-30	F
copper mounting paste	G

3. Results

The influence of the lubricant on the change of the VA signals was considered both in quantitative and qualitative terms.

The quantitative analysis was performed basing on the observation of instantaneous peak values of vibration acceleration a_{peak} determined from 84 ms long signal sequences. This measure, for sampling frequency f_s = 96 kHz, allows the observation of instantaneous changes in the VA signal (with minimal duration approx. 10 μs). It is worth mentioning that the RMS value of the signal, which is widely used in technical diagnostics, as an integration operator (it has averaging properties) is much less suitable to detection of the instantaneous changes of the VA signals. The vibrations were measured on the bearing housing in the radial direction.

The qualitative analysis (time-frequency analysis) was performed basing on both for the bearing housing vibrations and noise generated by operating bearing. The noise has been recorded at a distance of 100 mm from the bearing (along axis of rotation).

The research in quantitative term was conducted using three previously described testing bearings (UDB, SSB, EEB). Figure 1 shows the changes in the instantaneous a_{peak} values resulting from the use of different lubricants. The graphs illustrate changes that occurred in the first 180 seconds after the beginning of the test.

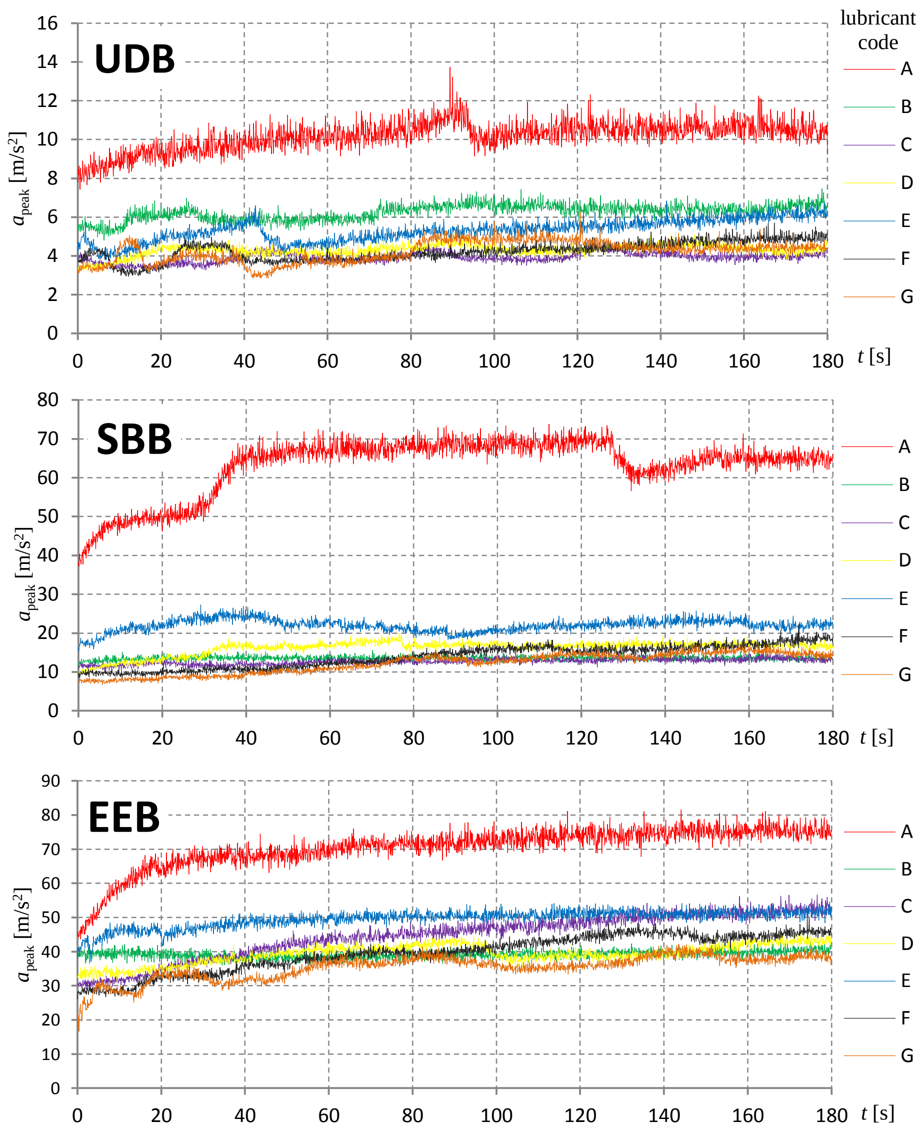


Figure 1. Instantaneous peak values of vibration acceleration (the value axis has been auto-scaled in order to better visualize the changes of a_{peak})

For all bearings, the highest instantaneous a_{peak} values through all the testing time (180 s) have been observed while silicone oil (A) was used. This means that lubricants with low viscosity slightly mask the appearance of defects and damage of bearings in the vibration signal.

Instantaneous a_{peak} values were noticeably lower in the case of the other lubricants. Therefore the masking of defects and race damage took place. Among the other lubricants the lowest instantaneous a_{peak} values were noted while grease (G) was used regardless of the intensity of the race damage. It is worth mentioning that when the intensity of defects and damage is small similar masking occurs while lubricating with oil (C).

There were 4 levels of defect masking introduced: low, moderate, significant and superior. They allow for an approximate classification of lubricants. A categorisation of the tested lubricants in terms of the masking levels is provided in Table 4.

Table 4. The level of masking of defects and damage in vibration signal of rolling bearings for tested lubricant.

level of defect masking	undamaged bearing (UDB)	sandblasted bearing (SBB)	bearing damaged by electro-erosion (EEB)
low	A	A	A
moderate	B	E	E
significant	D, E, F	B, D, F	B, C, D, F
superior	C,G	C,G	G

Table 5 shows the expanded parameterization of instantaneous a_{peak} values in the first 180 s from the beginning of the test. The highest peak value ($\hat{a}_{\text{peak}}$), the lowest peak value ($\check{a}_{\text{peak}}$) and the mean peak value ($\bar{a}_{\text{peak}}$) were determined for the considered period of time. In addition, the standard deviation (σ) and standard deviation normalized to mean peak value ($\sigma/\bar{a}_{\text{peak}}$) were determined.

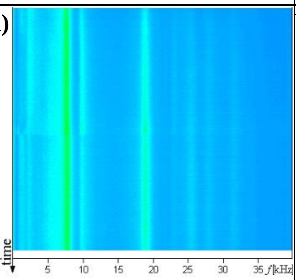
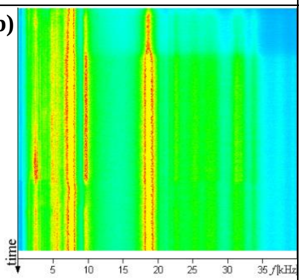
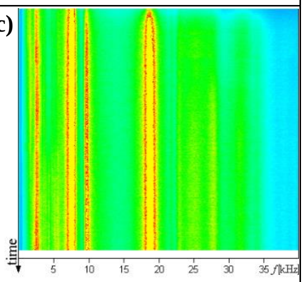
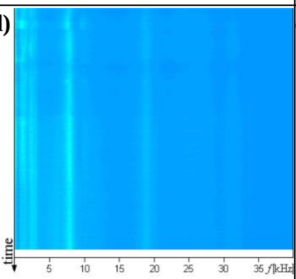
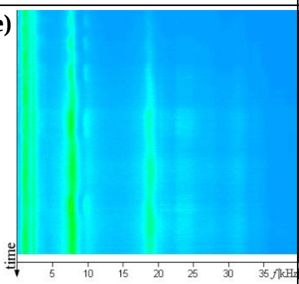
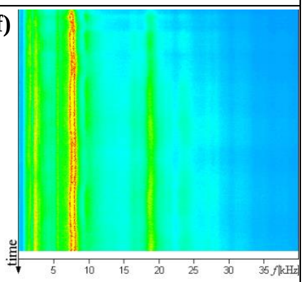
Table 5. The expanded parametrization of the instantaneous a_{peak} values of vibration accelerations in the first 180 s from the beginning of the test

lubricant type	undamaged bearing (UDB)					sandblasted bearing (SBB)					bearing damaged by electoerosion (EEB)				
	$\check{a}_{\text{peak}}$	$\hat{a}_{\text{peak}}$	$\bar{a}_{\text{peak}}$	σ	$\frac{\sigma}{\bar{a}_{\text{peak}}}$	$\check{a}_{\text{peak}}$	$\hat{a}_{\text{peak}}$	$\bar{a}_{\text{peak}}$	σ	$\frac{\sigma}{\bar{a}_{\text{peak}}}$	$\check{a}_{\text{peak}}$	$\hat{a}_{\text{peak}}$	$\bar{a}_{\text{peak}}$	σ	$\frac{\sigma}{\bar{a}_{\text{peak}}}$
A	7.43	13.74	10.18	0.75	0.07	37.21	73.75	63.09	7.44	0.12	43.60	81.55	70.46	6.08	0.09
B	4.81	7.47	6.25	0.41	0.07	11.30	15.60	13.52	0.56	0.04	35.82	42.99	39.18	1.15	0.03
C	3.22	4.69	3.91	0.27	0.07	10.07	15.20	12.69	0.79	0.06	28.55	56.69	44.64	6.47	0.14
E	3.18	5.33	4.30	0.30	0.07	9.52	20.02	16.17	1.86	0.11	30.65	45.77	39.36	2.83	0.07
F	3.68	6.84	5.31	0.57	0.11	15.34	27.25	21.95	1.63	0.07	37.07	54.59	49.55	2.53	0.05
G	2.95	5.70	4.24	0.49	0.12	8.51	22.33	13.90	2.89	0.21	26.08	50.15	39.63	5.40	0.14
H	2.85	6.29	4.23	0.55	0.13	6.74	16.96	12.19	2.62	0.21	16.66	42.22	35.34	3.62	0.10

The mean peak value $\bar{a}_{\text{peak}}$ (averaged in 180 s) was proposed to the assessment of the level of defect masking in the VA signal. The higher the value of this parameter, the less the defect is masked. Therefore, for the purpose of post-production diagnostics of the rolling bearings, it is justified to use lubricants for which $\bar{a}_{\text{peak}}$ reaches the highest values (the lowest level of defect masking). Among the considered lubricants this criterion is best met by oil (A) regardless of the intensity of the race damage.

On the other hand, basing on the standard deviation normalized to the mean peak value ($\sigma/\bar{a}_{\text{peak}}$), the amplitude stationarity of the whole 180-second testing process can be determined. In order to obtain low measurement uncertainty, the lowest possible value of this parameter is desired. From this point of view, the oil (B) best meets this criterion, while oil (A) does the same only for undamaged bearing (UDB).

Table 6. Spectrograms of vibration accelerations of the bearing housing for lubricants: silicon oil (A) and copper mounting paste (G)

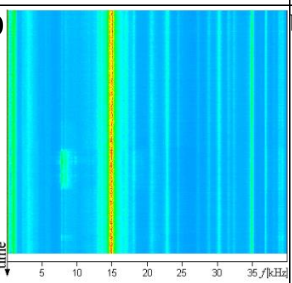
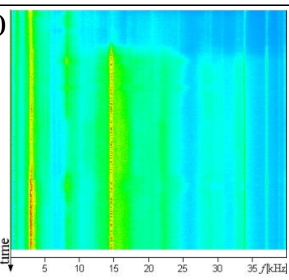
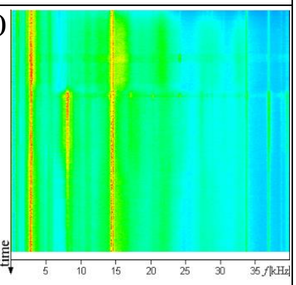
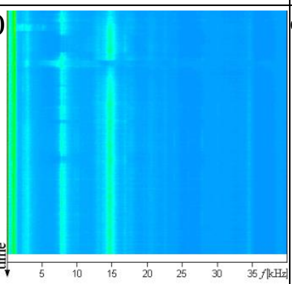
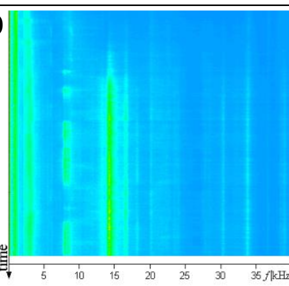
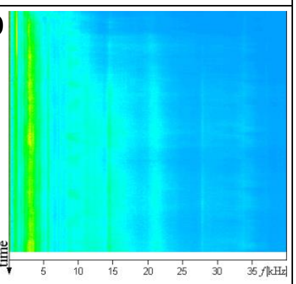
	undamaged bearing (UDB)	sandblasted bearing (SBB)	bearing damaged by electro-erosion (EEB)
silicon oil	a) 	b) 	c) 
copper mounting paste	d) 	e) 	f) 

The spectrograms of vibration accelerations of the bearing housing (Table 6) and of acoustic pressure (Table 7) allow us to compare the influence of the used lubricants on the VA signal in the quality term. The comparison concerns the use of oil (A) (the least masking) and grease (G) (the most masking). The figures in Table 6 and Table 7 (short-time spectra) illustrate changes occurring through all the testing time (180 s).

The signal components associated with the eigenfrequencies of the bearing-housing system (about 7.5 kHz and about 19 kHz) are clearly visible on all the vibration spectrograms (Table 6). According to ISO 15242, it is recommended to measure vibration velocity in the frequency band from 50 Hz to 10 kHz [9]. Spectrogram analysis demonstrates that in case of the used test stand it is possible and justified to perform measurements and analyses of vibration accelerations in the extended frequency band up to 50 kHz. The spectrum above 10 kHz apart from resonance vibration of the stand contain components related to defects and damage of the bearing. Therefore limiting the measurement bandwidth in accordance with ISO 15242 only to 10 kHz may deprive us of essential diagnostic information. It can be observed that some of the high frequency components of the signal appear with a delay to the beginning of the test. This is clearly visible for damaged bearings (see Table 7, Figures b, c, e and f). It mainly relates to the distribution of the lubricant in the bearing. In practical approach, the use of the band-stop filtering in resonance bands should yet be considered.

The vibration and noise spectrograms are similar in quality term. Theoretically the acoustic signal compared to the vibration accelerations is more sensitive to the environment noise. However the tests carried out prove that it is worth taking into account the results of measurements and analysis of noise in the post-production diagnostics of rolling bearings.

Table 7. Spectrograms of acoustic pressure measured in the distance of 100 mm from the bearing for lubricants: silicon oil (A) and copper mounting paste (G)

	undamaged bearing (UDB)	sandblasted bearing (SBB)	bearing damaged by electro-erosion (EEB)
silicon oil	a) 	b) 	c) 
copper mounting paste	d) 	e) 	f) 

4. Summary

The carried out tests allowed the formulation of the following conclusions. In order to obtain reliable results it is necessary to properly prepare the bearings to the tests (especially cleaning them).

The $\bar{a}_{\text{peak}}$ parameter can be used to assess the level of defect masking in the VA signal by the used lubricant. The $\sigma/\bar{a}_{\text{peak}}$ parameter can be used to determine the stationarity of the testing process.

Among the tested lubricants, low viscosity oil (A) had the best features for post-production bearing testing. Due to the significant level of defect masking greases should not be used for post-production diagnostic purposes (compare table 6 pictures a and e). This confirms the recommendations of ISO 15242.

The noise and vibration spectrograms clearly show signal changes in quality term. They also allow the specification of the time from the beginning of the test, in which VA signals can be treated as quasi-stationary.

Spectrograms have shown the purposefulness of taking into account components in the higher frequency band (over 10 kHz). Extraction of resonance components should be considered.

The results of the carried out tests have shown that the improper type of lubricant used for post-production diagnostics can lead to the masking of manufacturing defects. As a consequence, this may reduce the reliability and the accuracy of the classification in categories of good / bad and significantly reduce the possibility of defect detection.

Acknowledgment

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