Study of the short term effect of Fe_3O_4 particles in rolling element bearings

Observation of vibration, friction and change of surface topography of contaminated angular contact ball bearings

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1. Introduction

The mining industry has to increase the productivity in order to satisfy the increasing demand of steel and iron. The harsh environment is considered as one of the biggest challenges to manage an increased productivity.
Rolling element bearings situated in the production lines of mining industries are mainly affected by the contamination of iron ore particles. This contamination leads to a shortening of the bearing life and decrease thereby the productivity. Even the use of advanced sealing and lubrication systems can not prevent the significant decrease of the life of rolling bearings working in the mining environment.
Most of the investigations regarding particle contaminated rolling bearing are carried out based on quartz contamination [1,2]. However the understanding of interaction between rolling element bearings, lubricant and iron based contaminants is poor. In many bearing applications in iron mining industry the main contamination is not quartz, but iron oxides. Most investigations like M.M. Maru *et.al.* [2] focus on the relation between vibration and particle size, rather than the relation between vibration and lubricant type.
From discussions with representatives from the mining industry is shown that the concentration of contamination particles in previous investigations is often much lower than the situation in the mining industry. Studies with contaminated rolling element bearing are often done with concentrations as low as 0,01 %, like the study of T.Akagaki *et.al.* [3]. But the harsh environment in mining industry would correspond more likely to a concentration of several percent.
In this work rolling bearings were tested with a degree of contamination close to the ones in mining industry. The short term effect of this contamination on raceways and vibration signals were studied and the influence of the lubricant was investigated.

2. Experimental setup

2.1. *Rolling bearing test rig*

The investigation was carried out in a in-house rolling bearing test rig (Figure 1 and Figure 2). The principle of the rig is based on a free moving bearing carrier (pos. 4 in Figure 1) to be able to measure the sum of the friction torque from both test bearings (pos. 2 in Figure 1). The tested bearings are loaded with an axial load by a spring shown in Figure 2-a.

1: support bearing
2: test bearing
3: rack
4: free moving bearing carrier

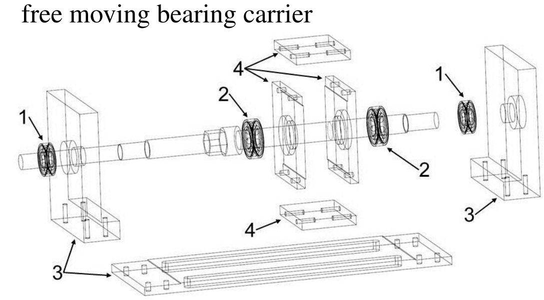


Figure 1: Schematics of the Rolling bearing test rig used for the investigation.

The measured variables are friction torque and vibrations of the test bearings. Friction torque is measured by a force sensor connected to a lever (Figure 2-b). A commercial SKF-vibration system called WindCon is used to investigate vibrations from the tested bearings. The accelerometer (SKF-607M69) was placed in the center of the test bearing carrier in order to measure vibrations from both test bearings (Figure 2).
During this investigation mainly the trend analysis function of the vibration system was used. The trend value (1) in this case is the quadratic mean value across the frequency interval for one measured sample.

$$\mathrm{Trendvalue} = \sqrt{\frac{1}{\mathrm{f_E}}\sum_{\mathrm{i=0}}^{\mathrm{f_E}} \mathrm{a_i^2}} \quad (1)$$

The trend values during a period of one minute are compared with each other and the highest value is stored. These stored values within the test duration represent the trend of vibration level.

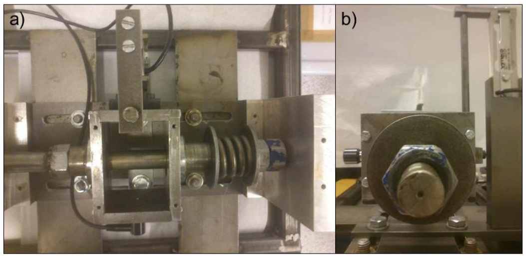


Figure 2: Image of the free moving bearing carrier. a) top view, b) side view.

2.2. *Test setup*

Four different test setups were used in the investigation, see table 1. Two of them (test 1 and 2) were used as reference without contamination.

Table 1: Test setup

test-number	lubricant	contami-nation (wt)	number of samples
1	SL12-602	0%	2
2	SL12-603	0%	2
3	SL12-602	10%	4
4	SL12-603	10%	4

Standard angular contact ball bearings (SKF 7204BEP) were used in all tests and for each sample one pair of bearings was tested. Before the test the bearings were cleaned by an ultrasonic cleaning in heptane as a solvent and then lubricated with 3 g of grease. The reference samples were lubricated with uncontaminated grease and the samples of test 3 and 4 were lubricated with a mixture of 3 g grease and 0,3 g magnetite particles (Fe_3O_4). The size distribution of the contaminant is shown in Figure 3. The contaminated grease was blended in a beaker before it was applied to the bearings.

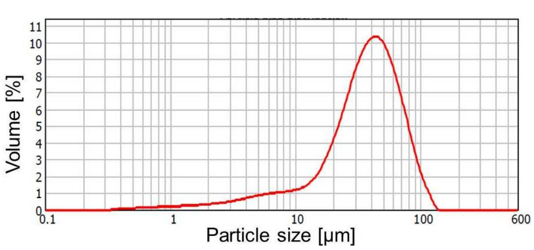


Figure 3: Size distribution of the magnetite particles used as contamination.

As lubricants the greases SL12-602 and SL12-603 were used. SL12-602 (non-EP grease) is a grease with a lithium thickener and a mineral base oil. Antioxidants are the only additives in the grease. SL12-603 (EP grease) is based on the grease SL12-602, but also a sulfur based Extreme pressure additive is used in the oil.

The prepared bearing samples were tested during 24 hours at a rotational speed of 180rpm and by applying a axial load of 2 kN. During the test the friction torque was measured in order to calculate the coefficient of friction. Additionally the vibration trend was monitored. After the test duration of 24 h the tested bearings were disassembled and cleaned by ultrasonic cleaning in a solvent (heptane) and the surface topography of the raceways was measured. For this measurements a 3D optical interferometry spectroscope called WYKO NT1100 was used.

3. Results

The measurements of the surface topography are shown in Figure 5. The image marked with a) is a new bearing, while the images b) and c) show tested bearing raceways of non-EP grease and EP grease without contamination. In all these samples the grinding grooves of the manufacturing process are still visible.

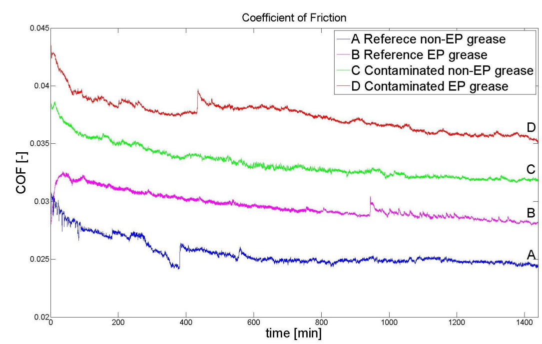


Figure 4: Average coefficient of friction over time for the used test setups.

The grinding grooves still remain in the sample with EP grease and a 10% particle contamination (Figure 5-e). However the grinding grooves are not visible for the contaminated sample without EP-additives, as shown in Figure 5-d. Figure 4 shows the coefficient of friction over the test duration of 24 hours. Both addition of contamination and EP-additives show an increase of coefficient of friction in comparison to the reference sample.

The vibration signals shown in Figure 6 are the trend (1) of envelope signals with different frequency ranges. Beside test setup 3 (non-EP grease with contamination) all tests show a constant vibration trend signal. The vibration trends of the tests with non-EP grease and contamination are increasing during the 24 hours of testing. The end value increases to as much as three times the initial value.

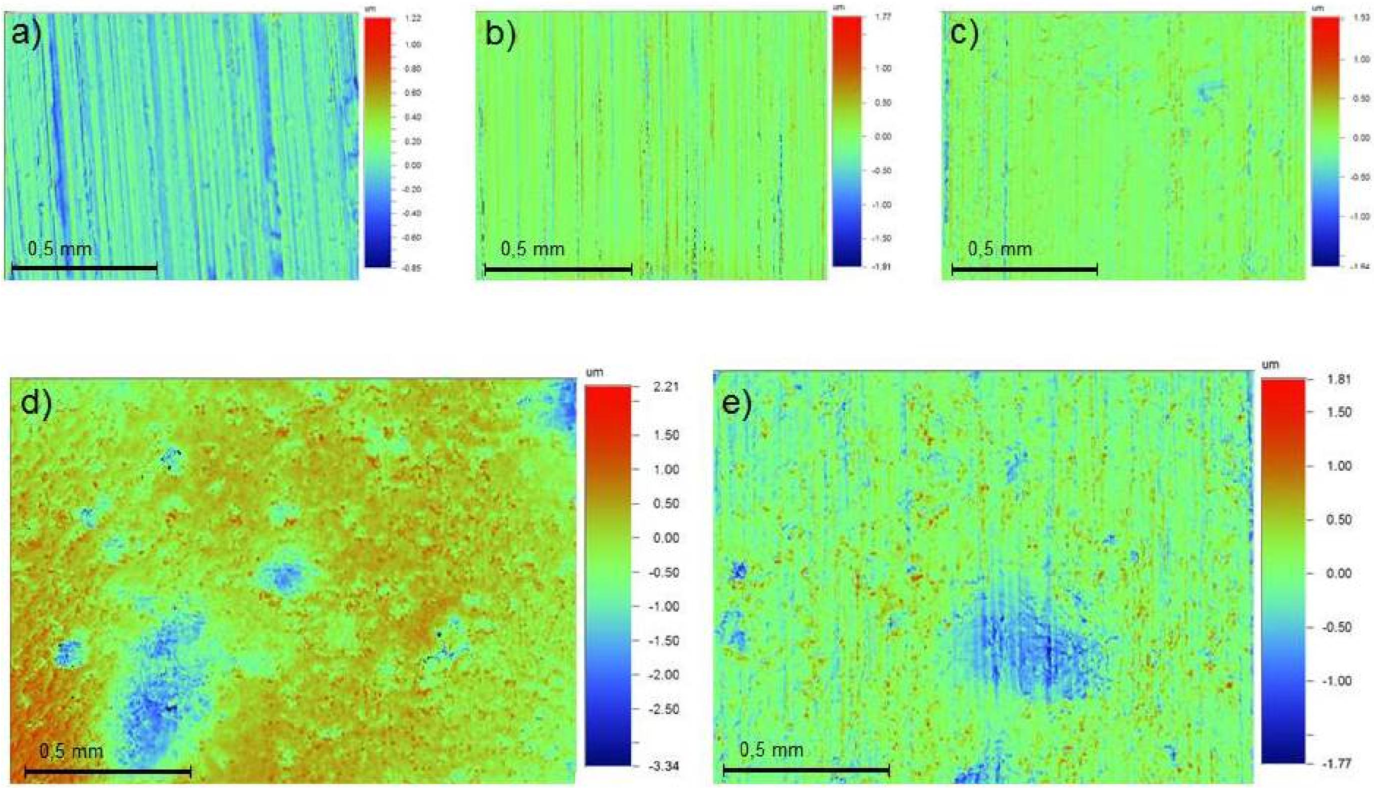
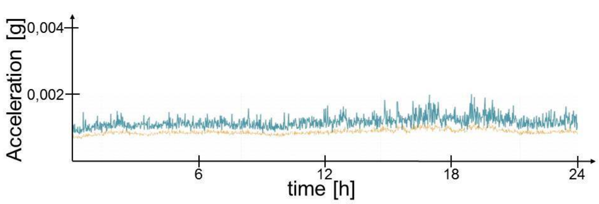
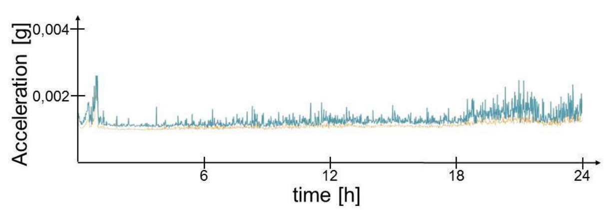


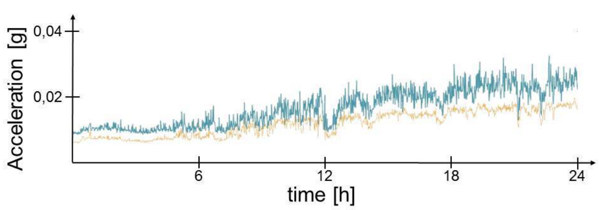
Figure 5: Images of the surface measurements with interferometric spectroscopy. a) unused bearing, b) bearing with non-EP grease, c) bearing with EP grease, d) contaminated bearing with non-EP grease, e) contaminated bearing with EP grease



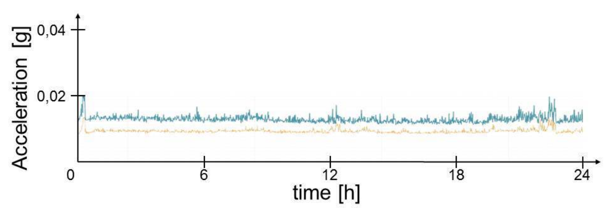
(a) Non-EP grease



(b) EP grease



(c) Non-EP grease with particle contamination



(d) EP grease with particle contamination

Figure 6: Observation of vibration signal for the different test setups. Yellow: trend of an envelope signal with a range of 10 Hz-1 kHz. Blue: trend of an envelope signal with a range of 10 Hz-100 Hz.

4. Discussions

Both the contaminated test setups simulate the harsh environment in the iron mining industry and show a difference in vibration trend and surface topography already after the relatively short test duration of 24 hours. The missing grinding grooves of samples with non-EP grease and contaminations compared to the other test samples could be a indication of higher wear rate. This difference in wear rate between test setup 3 and 4 could be a result of a possible chemical reaction (2) of the sulfur based EP-additive with the contaminants.

$$\begin{aligned} 2\ \mathrm{Fe_3O_4} + 4\ \mathrm{S{=}R} + \mathrm{O_2} \rightarrow \\ \rightarrow 2\ \mathrm{FeSO_4} + 2\ \mathrm{FeS} + 2\ \mathrm{FeO} + 4\ \mathrm{R} \end{aligned} \tag{2}$$

J.M.Martin *et.al.* [4] have shown that abrasive wear of iron oxide particles can be reduced by a chemical reaction with additives. In case of J.M.Martin *et.al.* [4] the reaction between hematite (Fe_2O_3) and ZDDP was investigated. Another study was carried out by L.Yuan-Dong *et.al.* [5]. In this study they showed the favorable effect of FeS and $FeSO_4$ particles on the wear behavior of grease lubricated steel on steel interfaces. Both studies support the theory of a reduced wear rate due to a chemical reaction of parts of the contaminants with the EP-additives. Another indicator for a reduced wear in combination with EP-additives are the vibration measurements, which are consistent with the surface topography measurements. Whereas the measurement of the friction coefficient do not indicate a difference in wear rate. At least not within the short test duration of 24 hours. An expansion of the test duration could provide information about the progress of wear and its effect on the vibration trend.

5. Acknowledgments

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6. References

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