Nanomaterial-based Lubricant Effect on the Vibrations of Defective Rolling Element Bearings

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***Abstract*— In a recent advancement to reduce friction and wear between rotating contact surfaces and improve machine reliability, the use of a nanomaterial based lubricant instead of the conventional mineral based-one has been promoted. Currently there is a very limited body of research on this topic due to its recent emerging. An in depth studies and research are in need to investigate the type of improvements gained by using nanomaterial additives, especially on the levels of vibrations and the changes to the diagnosis features within the vibration signal. This paper investigates the effect of the use of a nanomaterial-based lubricant on the levels of vibration from defective rolling element bearings (outer race fault). A bearing test rig with hydraulic loading has been designed to enable the collection of vibration data. A 1 mm outer race defect was seeded in a self-aligning bearing using electrical discharge machining. The level and nature of the vibration signals with 0.1%, 0.2%, 0.3% and 0.5% of copper dioxide (Cu2O) particles of two different sizes (30 nm and 70 nm) were compared. Results show that the energy level of the impact (root mean squared value) drops as a result of introducing the 30 and 70 nm particles with the highest drop reported at a concentration of 0.5% for the 70 nm. The impulsiveness of the signals (Kurtosis levels) are lower for the 70nm compared to the 30 nm and the lowest was recorded at a concentration of 0.2%. The noise associated with adding the nanomaterial is observed to increase and to affect frequency bands above 5 kHz.**

***Index Terms*— rolling element bearing; nanomaterial; defective bearing; kurtosis, root mean square**

I. Introduction

In a recent revolutionary advancement to reduce friction and wear between rotating contact surfaces and improve machine reliability, the use of a nanomaterial based lubricant has been used and promoted. A number of studies [1, 2 and 3] have emerged in an attempt to provide some understanding and insights into the tribology properties of lubricants (oil/grease) with non-material (nanoparticles) additives. The size of the nanoparticles (copper oxide, zinc oxides, etc.) quoted in these studies ranged from 5 to 100 nm and it is reported that their use provide a better carrying load capacity, a better protective film and effectively reduce wear and friction. The mechanical-tribology properties were found to be dependent on the characteristics of the nanomaterial in terms of their size, concentration and shape [1, 2]. The effect of using lubricants with different degrees of viscosity and the effect of contamination on the wear and vibration levels have been studied by s number of researchers [4-7]. The effect of the lubricant viscosity grade on the mechanical vibration of roller bearings has been discussed in ref [9]while, the influence of the lubricant film on the stiffness and damping characteristics has been discussed in [10].Oil contamination in ball bearings through vibration and wear has been addressed in [6]. A summary of the effect of different types of lubricants (including the use of Nano-material) has been recently presented in [7].

A limited number of researchers have discussed the effect of using lubricants with additives or contamination on the vibrations of rolling element bearings [8, 9, and 10]. These studies have concentrated on the amplitude of the vibration, without much in-depth discussion to the nature of the vibration generated and the effect on the diagnosis effects. In ref [8], Prakash et.al, investigated the vibration suppression characteristics of ball bearing supplied with Nano-copper oxide (CuO). Results showed a reduction of 41% in the amplitude of vibration of an outer race defective bearing when using a 0.2%, 5-8 nm CuO additive compared to base lubricant. Serrato et.al in [9] examined the effect of contaminating the oil lubricant (two types of oil used with different viscosities) with quartz particles with micro sizes (37 µm, 59 µm and 111 µm). The test was carried out for healthy bearings and included the monitoring of the vibration r root mean square value (RMS) values and observing the excited bands. In conclusion, it was reported that the presence of particles within the lubricants affects the high frequency bands of the spectrum and is a function of both the viscosity and the particle size; a phenomenon known as decantation (fluid separation). As a result of this, the particle size effect in the vibration signal did not show a clear correlation with the different test conditions. In [10] Jiao, et. al provided an interesting study into the use of synthesized alumina silica nanoparticles use as an additive to the oil lubrication of ball bearings. It was found that when optimizing the concentration to 5wt %, the diameter of the wear scar (vibration levels) and the coefficient of the friction become smaller.

This paper investigates the effect of the use of two different sizes and concentrations of a cupper-oxide nanomaterial additive on the vibrations measured from defective and healthy rolling element bearings.

Manuscript received May 9, 2018; revised September 9, 2019.

doi: 10.18178/ijmerr.8.6.935-939

II. Vibration Test Rig, Nanomaterial Additive and Data Acquisition

A test rig to collect vibration data was designed and built at Prince Mohamed University. The test rig consists of a 2-pole (3400 rpm) -2 HP motor which drives the main shaft using a V-belt-pulley system (2:1 ratio). The test bearing (self-aligning 2306 bearing) is enclosed in a steel housing and loaded using a hydraulic mechanism as shown in figure 1. The shaft is supported by two reaction bearings. The test rig was fitted with one accelerometer and a tachometer. Vibration data were collected using a sampling frequency of 60 KHz for healthy and defective outer race fault of 1mm.

Helix HX5 15W-40 was used as the oil-based lubricant. This has been chosen primarily based on viscosity recommendation for the bearing operating conditions (size, temperature, Operating speed and loads). The nanomaterial additive was selected as spherical Copper Nano-particles (Cu_2O). These small sized spherical shaped Nano-particles are ideal to the operation of rolling element as they do not scratch the surface of the bearing or cause external damages to the bearings. The copper Nano-particles are softer than mild iron, thus, the bearing will not be scratched or damaged. Two sizes of the particles were selected which are 30 nm and 70 nm and 4 different percentages were tested (0.1 %, 0.2%, 0.3% and 0.5%). In order to suspend the nanoparticles in the oil based lubricant, three ultrasonic sensors were mounted in multiple locations on the oil tank (shown in Fig.1b).

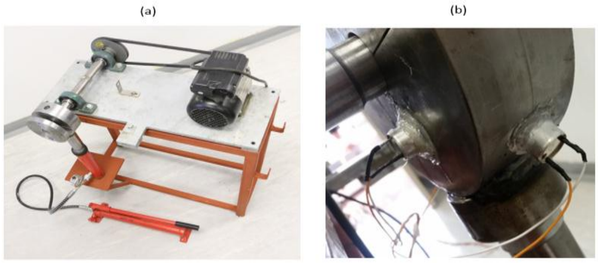


Figure 1. (a) Vibration test rig (b) Ultrasound

III. Vibration Acceleration Response (Time Domain Signals)

Fig. 2 provides plots of the acceleration time domain signals (Scaled in gs) of a 1mm outer race defective bearing at a constant 40 bars load for oil only and 0.5% additive with two particle sizes. Figure 2(a) displays the time domain signature in the case of 0% nanoparticles, where the impacts from the ball passage over the 1mm spall can be seen clearly with an amplitude of around 6 g. Figure 2(b) presents the time domain signal with 0.5% of the 30 nm nanoparticles, where a clear drop in the amplitude is observed (Almost halved). Figure 2(c) shows the response at the same 0.5% concentration, but for the 70nm nanoparticles, where further reduction in amplitude can been clearly observed. The result presented in Fig. 2 indicates that the process of adding the nanoparticles has the effect of reducing the amplitude of the impacts through an increased damping effect.

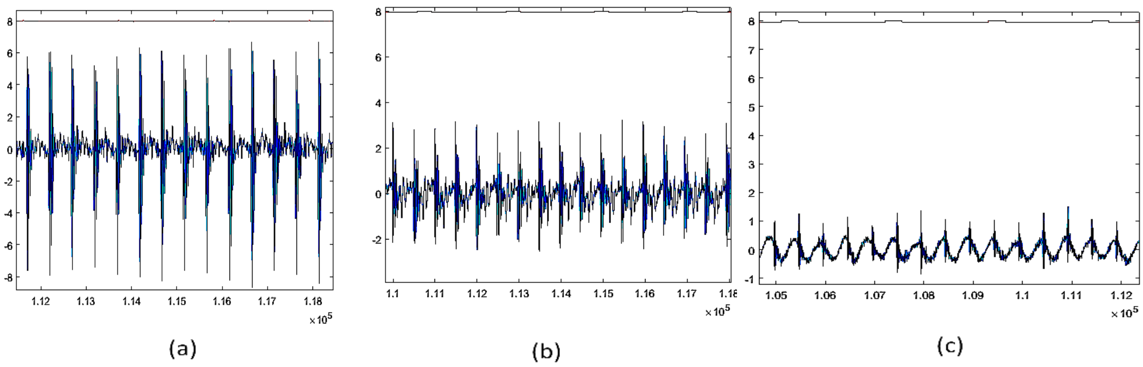


Figure 2. Time domain signal for 1mm outer race defected bearing loaded with 40 bar (a) 0% Nano (b) 0.5% 30 nm (c) 0.5% 70 nm

IV. Statistical Indicators

A comparison is held next between two statistical parameters (the root mean square value (RMS)) and the Kurtosis values) of the raw vibration signal at different levels of nanoparticle concentrations for the two sizes and for the case of no Nano additive. The RMS value is used as an indicator of how much energy is embedded in the vibration signal, while Kurtosis measures the impulsiveness of the vibration signal.

A. RMS

Figure 3 shows the effect of nanoparticles additives on the energy content of the vibration signal of healthy bearing at two loads (20 and 40 bars) with variety of nanoparticles concentrations ranging from 0% to 0.5% of 30 nm and 70 nm. A clear evidence that the RMS value drops when nanoparticles are added to the lubricant is seen. The changes between the different concentrations are not prominent. When the load is doubled, the values of the RMS are noticed to be less sensitive to the concentration levels, with less values recorded for the large size particles.

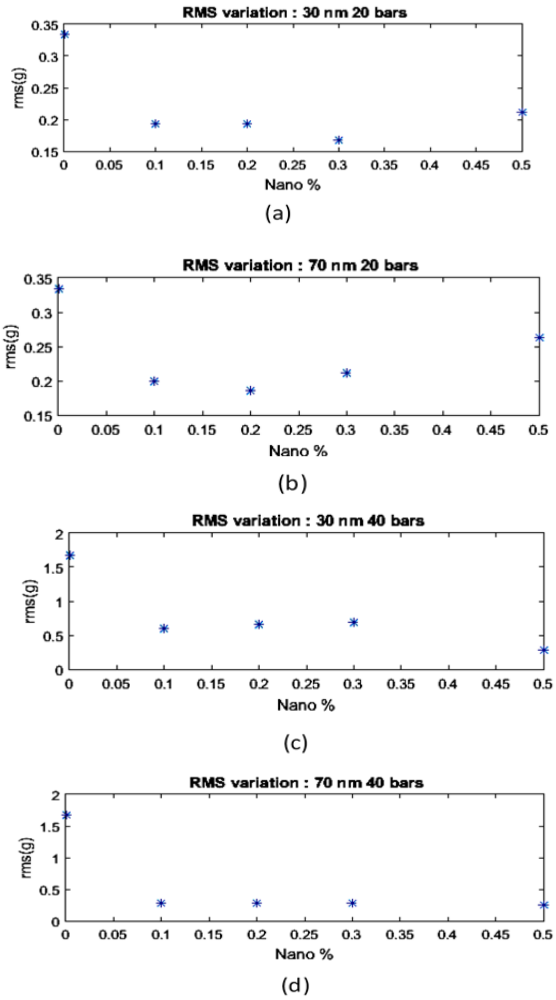


Figure 3. RMS values for a healthy bearing (a) 30 nm 20 bars (b) 70 nm 20 bars (c) 30 nm 40 bars (d) 70 nm 40 bars

A similar behavioral trend can be seen from the 1 mm outer race fault bearing (Fig. 4), where it is noticed that the value of RMS decreases once a Nano particle is presented with no much difference between the 4 different levels of concentrations and in particular when the bearing is more loaded.

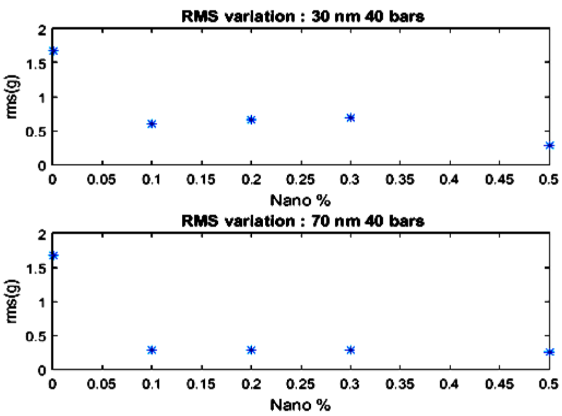


Figure 4. RMS values for 1 mm outer race defected bearing: (Top: 30 nm 40 bars) and (Bottom: 70 nm 40 bar)

B. Kurtosis and Kurtosis Excitation in different bands (Wavelet kurtogram)

The passage of rolling element over the seeded fault gives rise to a series of impulses. As a result, impulses excites structural resonances which can be detected and measured by sensors or transducers. The resulting high frequency vibrations are usually analyzed utilizing a variety of high frequency analysis indicators and techniques such as Kurtosis (statistical indicator by which the impulsive characteristic of a signal in time domain is measured), or with impulses' frequency using Envelope analysis (high frequency resonance technique) [11]. The use of wavelet *kurtogram* [12] has been proposed as a surveillance method to examine excitation in different frequency bands. Wavelet *Kurtogram* gives an indication of the bands with high impulsiveness.

Figs. 5 and 6 compare the values of kurtosis for the healthy bearing and the defective one respectively when operated with 30 nm and 70 nm Nano-additive under the load of 40 bars. It can be seen that while there is not a specific trending in the healthy bearings kurtosis values with different percentages (drops then increases for the 30 nm , while increasing and then dropping for the 70 nm), the Kurtosis values for the defective bearing shows consistency levels between the two sizes at different concentration levels.

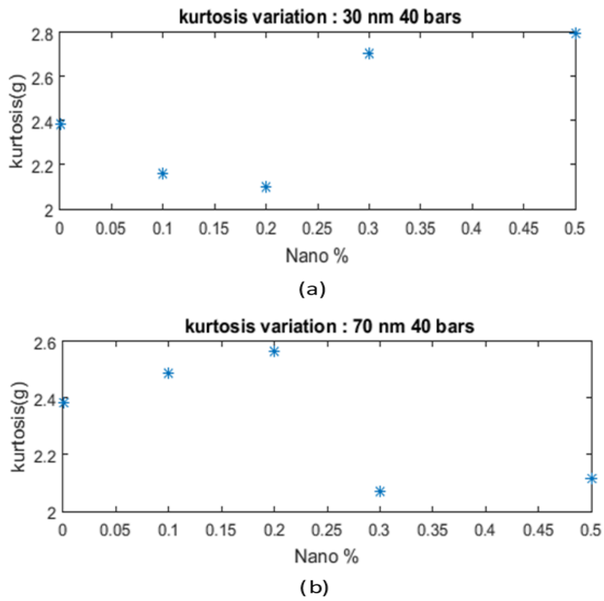
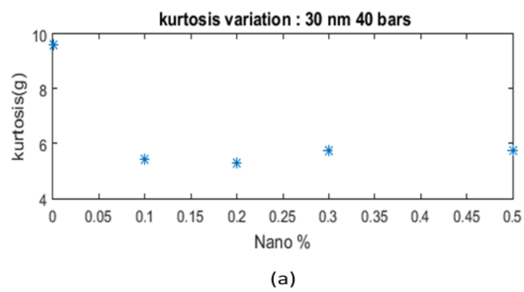
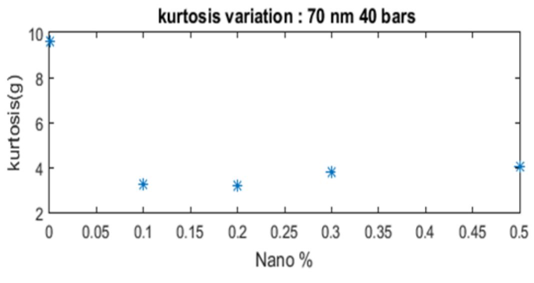


Figure 5. Kurtosis analysis for healthy bearing (a) 30 nm 40 bar (b) 70 nm 40 bar





(b)

Figure 6 Kurtosis analysis for 1 mm outer race defected bearing (a) 30 nm 40 bar (b) 70 nm 40 bar

Figs. 7, 8 and 9 show the wavelet kurtogram and the squared envelope spectra of the 1 mm outer race defective bearing with no Nano additives, 0.5% with 30 nm additive and 0.5% with 70 nm additive respectively. The Ball pass frequency of the outer race (BPFO) and its harmonics can be seen clearly in the three signals. The presence of the Nano additive has three main noticed effects. The first is the reduction of the Kurtosis values, which agrees with the observations of Fig. 6. The second effect is the spread of the excitation, where it can be seen to cover frequencies from 5 kHz to 30 kHz instead of being concentrated between 10 and 20 KHz for the case of oil lubricant alone. The third effect can be seen in the envelope signal, which shows the appearance of sidebands around the BPFO, which are clearer for the 70 nm particles and are a direct result of the interaction of the Nano particles with the Cage and rolling elements.

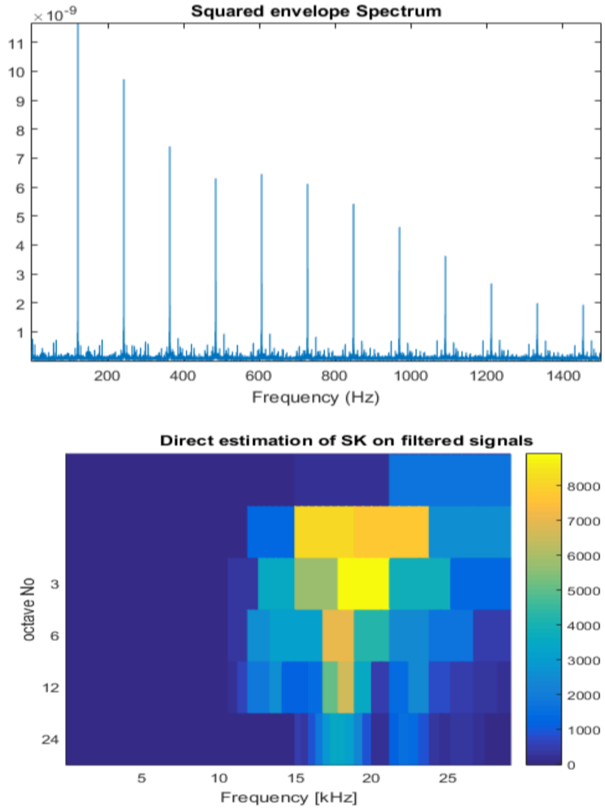


Figure 7. Squared envelope spectrum and wavelet Kurtogram of 1 mm outer race defected bearing 0% Nano

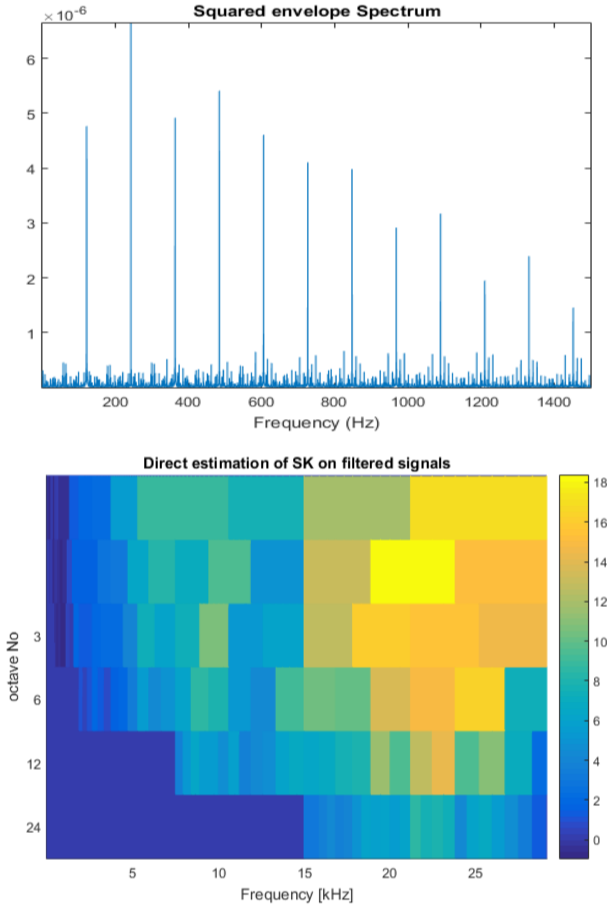


Figure 8. Squared envelope spectrum and wavelet Kurtogram of 1 mm outer race defected bearing 0.5% 30 Nano

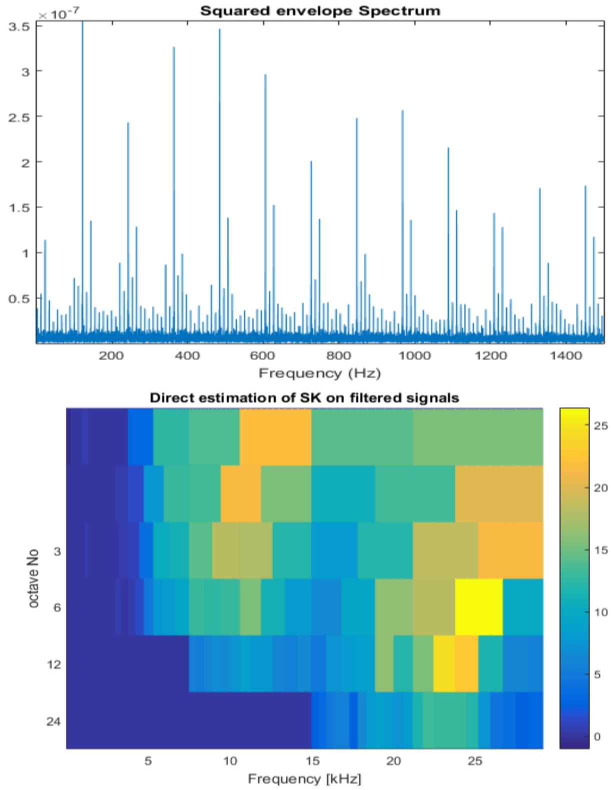


Figure 9. Squared envelope spectrum and wavelet Kurtogram of 1 mm outer race defected bearing 0.5% 70 Nano

V. SUMMARY AND CONCLUSIONS

This paper has investigated the effect of the presence of nanomaterial additives in oil lubricants on the levels of vibration of a defective rolling element bearing with an outer race fault. The amplitudes of the acceleration signals, RMS values and Kurtosis values have been observed with 0.1%, 0.2%, 0.3% and 0.5% concentrations of cupper dioxide (Cu2O) particles of two different sizes (30 nm and 70 nm) . Results have shown that RMS values drop as a result of introducing the 30 and 70 nm particles with highest drop reported at a concentration of 0.5% for the 70 nm. The impulsiveness of the signals (Kurtosis levels) have been noticed to be lower for the 70nm compared to the 30 nm and the lowest was recorded at concentration of 0.2%. The noise associated with adding the nanomaterial is observed to increase and to affect frequency bands above 5 kHz. The squared envelope spectrum has an increased activity of sidebands around the defect frequency as a result of the interactions between the Nano particles and the cage.

ACKNOWLEDGMENT

The Authors acknowledges the financial support provided by Prince Mohammad Bin Fahd University through Phase one, research grants. The design of the test rig and the collection of the data was conducted by undergraduate students as a part of their senior design project. The Authors acknowledges: Sultan Hamdi, Ahmed Aldakheel, Mohammed Alhawaj, Mohammed Alshubaily and Rami Al Gassab for their help during the course of this work.

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