NOISE CHARACTERISTICS OF BALL BEARING LUBRICATED WITH ENGINE OIL ENHANCED WITH HEXAGONAL BORON NITRIDE PARTICLE ADDITIVE

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ABSTRACT: The use of rolling element bearings is significant in most mechanical applications. Thus, the reliability and efficiency of the mechanical machines depend critically on the health of the rolling bearings. Vibration and noise generated by bearings are one of the big concerns in the industry since it limits the performance of the machines. The aim of this paper is to determine the noise characteristics for ball bearings lubricated with hexagonal Boron Nitride (hBN) nanoparticles additives in engine oil with different volume concentrations of hBN namely 0.1%, 0.2%, 0.3%, 0.4%, 0.5%. A test rig consisted of a motor that drives the system, coupling, rotor to support the imposed loads and a ball bearing in which its performance to be validated. Samples of hBN nano-lubricant with different % volume of hBN concentrations were prepared using the ultrasonic homogenizing technique. Three conditions of ball bearing investigated which were healthy bearing, inner defected bearing and outer defected bearing. Sound Level Meter was used to record the noise level for 10 minutes for each concentration and load condition and the average of the equivalent sound level for that period was calculated. The measurement of noise level has shown that the imposed load and concentration of hBN nanoparticles in the lubricant have a significant contribution to the noise level of the bearing. The noise level increased slightly with the increase of unbalance imposed load while the noise level decreased with the addition of the 0.2% volume concentration of hBN nanoparticles. The overall performance has shown a reduction in noise level.

KEYWORDS: *Noise Characteristic; Ball Bearing; hBN Nanoparticles*

1.0 INTRODUCTION

Bearing is a part of machine components that is designed to reduce the friction between the moving parts or to support moving loads. There are thousands of sizes, shapes and kinds of rolling bearings such as ball bearings, roller bearings, needle bearings and tapered roller bearings which are the major kinds. A source of noise in bearings is mainly due to the structural vibration and sound. There are several types of noise in bearings such as race noise, click noise, squeal noise, cage noise and rolling passage vibration [1]. More studies and researches are being carried out in order to improve the bearing performance and reduce the noise and vibrations that it produces. The addition of nanoparticles to lubricants was reported by Pisal and Chavan [2] as an effective factor to reduce noise, friction and wear. Past researchers have used nanoparticles like zirconia/silica (ZrO3/SiO2) composite, copper oxide (CuO), titanium oxide (TiO2), nano-diamond as well as hexagonal boron nitride (hBN) [2-4]. These nanoparticles have been proven to be efficient in improving the tribological properties whereas it also can reduce the coefficient of friction and wear rate when dispersed into diesel engine oil [5].

Boron nitride exists in various forms, one of them is the hexagonal form that has the same structure as the graphite which is the most stable and soft and the most widely used. Its thermal and chemical stability properties make it useful at elevated temperature equipment [6]. The advantages of using hBN are it has low thermal conductivity, low cost and environmentally friendly. Past researchers have proven in the tribological field that hBN has the low coefficient of friction which makes it a good lubricant additive [7-8]. Reduction in friction and rate of wear depends on nanoparticle characteristics such as concentration, shape and size which mostly range from 2 to 120 nm [9-10]. In the vibration monitoring condition, the hBN performance was investigated in reducing the vibration on new and defected bearing which it is successfully determined that 0.2 vol% of hBN nanoparticles mixed lubricant is the optimum volume of concentration in reducing vibration amplitude [11]. The vibration level is smaller as the oil viscosity degree becomes higher, in contrast to the effect of temperature on oil viscosity [12]. However, there is a little finding of the performance of hBN mixed lubricant in reducing the noise level of the new and defected bearings. Thus, the aim of this paper is to determine the noise characteristics for ball bearings when lubricated with hexagonal Boron Nitride (hBN) nanoparticles additives in engine oil for different concentrations of hBN namely 0.1%, 0.2%, 0.3%, 0.4%, 0.5%.

2.0 METHODOLOGY

2.1 Nano-Oil Preparation

Nano-oil samples were prepared by dispersing hBN nanoparticle powder in conventional diesel engine oil (SAE 15W40). After the addition of hBN powder to the base oil, the ultrasonic probe homogenizer was used for 15 minutes to ensure that hBN nanoparticles are completely dispersed in the lubricant base oil. In this study, five concentrations of hBN nanoparticles additives were used which were 0.1 vol%, 0.2 vol%, 0.3 vol %, 0.4 vol% and 0.5 vol%. Figure 1 shows the ultrasonic homogenizer used for the nano-oil samples preparation.

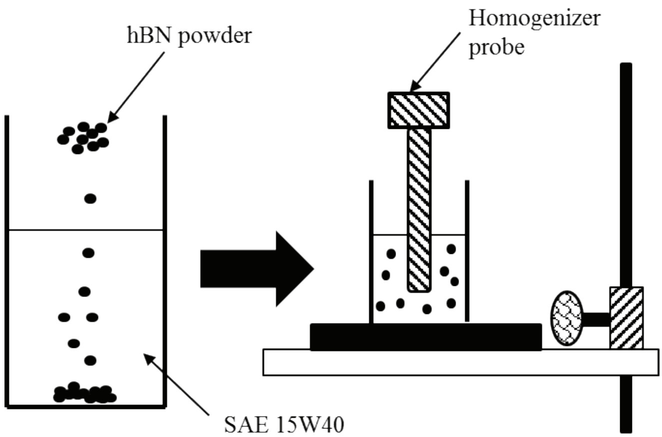


Figure 1: Ultrasonic homogenizer

2.2 Experimental Procedures

The test rig was setup as illustrated in Figure 2. Three conditions of ball bearing were investigated which were healthy bearing, inner defected bearing and outer defected bearing. First, the ball bearing is lubricated with the nano-lubricant. Next, the Sound Level Meter was fitted inside the insulating box hole with a 100 mm distance from the ball bearing. The measurements for each volume concentration were carried out under four load conditions. First, the shaft rotates without the addition of unbalance load (load 0), one unbalance load (load 1), (load 2) and (load 3). Sound Level Meter was calibrated to measure the noise level of A, weighting sound level and F, frequency weighting and time for 10 minutes. The data were imported from the Sound Level Meter and analyzed using MATLAB and Excel software to calculate the mean sound level and sketch the graphs.

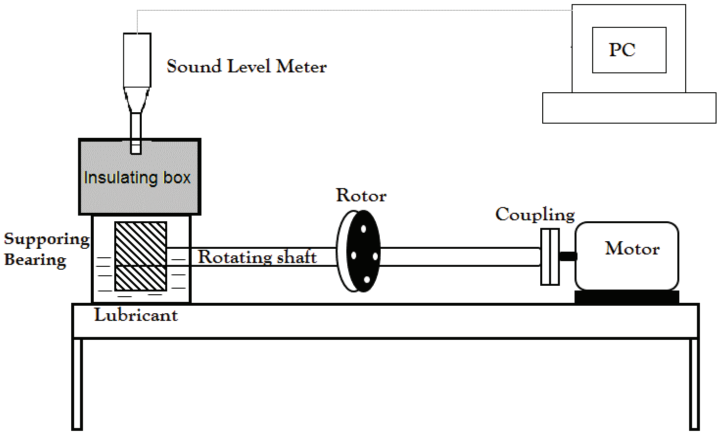


Figure 2: Schematic diagram for the experimental apparatus setup

3.0 RESULTS AND DISCUSSION

3.1 Noise Behavior in A Healthy Ball Bearing

Figure 3 shows the behavior of the noise of a ball bearing in a healthy condition without any defects. The noise level varies from 89 dB to almost 94 dB depending on the loading and the hBN nanoparticles concentration on the lubricant. It is apparent that the addition of hBN nanoparticles to the lubricant reduced the noise level at small rates. The different concentrations of the hBN nanoparticles vary in the amount of reduction in the noise level and reach a maximum for 0.2% for load 0. The graph shows that the highest level of noise is for the 0.0 % concentration which is for the conventional oil without any addition of hBN nanoparticles. Similar behavior can be observed for the other loading conditions.

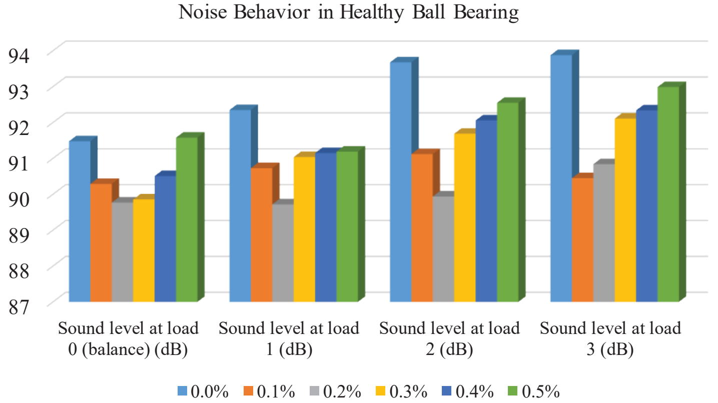


Figure 3: The noise behavior in a healthy ball bearing

The equivalent sound level in dB (A) at different loads and concentrations for healthy bearing are tabulated in Table 1. From Table 1, it shows that the noise level increase with the addition of an unbalanced load applied on the rotor and the noise level for conventional oil has decreased from 91.48 dB to 90.29 dB for 0.1 % concentration at balanced load. The reduction increased for 0.2 % concentration of hBN nanoparticles to 89.77 dB at the same loading but then decreased gradually with the increase of volume concentration from 0.3 % - 0.5% concentration up to 91.58 dB.

Table 1: The equivalent sound level in dB (A) at different loads and concentrations for healthy bearing

Volume of concentration (%)	Sound level at load 0 (balance) (dB)	Sound level at load 1 (dB)	Sound level at load 2 (dB)	Sound level at load 3 (dB)
0.0	91.48	92.35	93.68	93.88
0.1	90.29	90.73	91.12	90.45
0.2	89.77	89.72	89.94	90.84
0.3	89.86	91.04	91.69	92.11
0.4	90.51	91.15	92.06	92.34
0.5	91.58	91.19	92.55	92.99

3.2 Noise Behavior in an Inner Defected Ball Bearing

Figure 4 shows the effect of the addition of hBN nanoparticles additives to the lubricant on the noise characteristics comparing to the conventional oil in ball bearing with minor inner defects. The chart reveals a rise in the noise level with the addition of unbalance loads. As shown in Figure 4, there is a slight reduction in the noise level as with the addition of hBN nanoparticles for 0.1% and 0.2 % as compared to 0.0% volume concentration which is the conventional oil without addition of hBN nanoparticles. However, the reduction is less significant as compared to the hBN concentration more than 0.2 % and then the noise level rises as the concentration increased. Based on the chart, we can conclude that the optimum concentration for the inner defected bearing is 0.2% of hBN which matches with the results obtained for the healthy bearing.

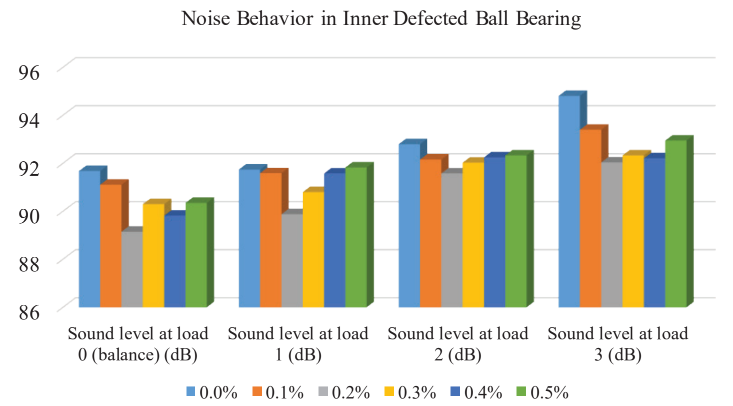


Figure 4: The noise behavior in inner defected ball bearing

Table 2 tabulates the noise level measured in inner defected bearing with different concentrations and loads. From Table 2, it shows that 0.2 vol% have the lowest noise level at different loads compared to the other volume of concentrations of hBN.

Table 2: The equivalent sound level in dB (A) at different loads and concentrations for inner defected bearing

Volume of concentration (%)	Sound level at load 0 (balance) (dB)	Sound level at load 1 (dB)	Sound level at load 2 (dB)	Sound level at load 3 (dB)
0.0	91.68	91.74	92.8	94.81
0.1	91.11	91.59	92.16	93.4
0.2	89.15	89.88	91.58	92.04
0.3	90.3	90.8	92.03	92.33
0.4	89.82	91.58	92.25	92.21
0.5	90.35	91.83	92.33	92.95

3.3 Noise Behavior in an Outer Defected Ball Bearing

Figure 5 shows the noise characteristics for the outer defected ball bearing lubricated with hBN nanoparticles for six hBN volume concentrations and four load conditions. The bar chart shows clearly that the noise level increase with the addition of unbalance loads. Based on Figure 5, the highest level of noise reached is for the concentration of 0.0% which is for the conventional oil without any addition of hBN nanoparticles and it is considered as the baseline to be compared with the noise level after the addition of hBN nanoparticles. The bar chart shows a slight reduction in noise level with the addition of hBN nanoparticles. Similarly, 0.2% volume concentration produces the least noise level at all loads.

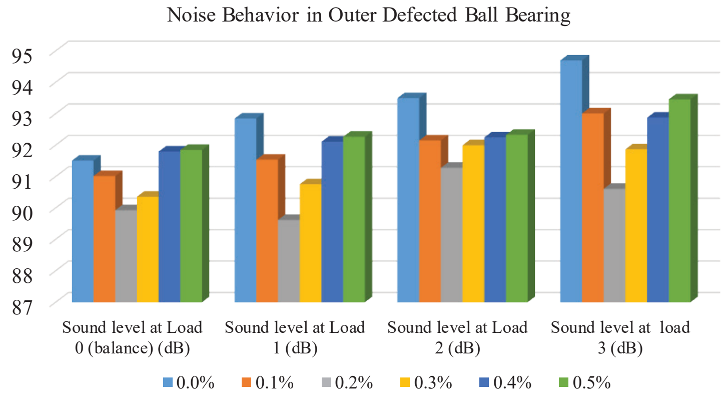


Figure 5: The noise behavior in outer defected ball bearing

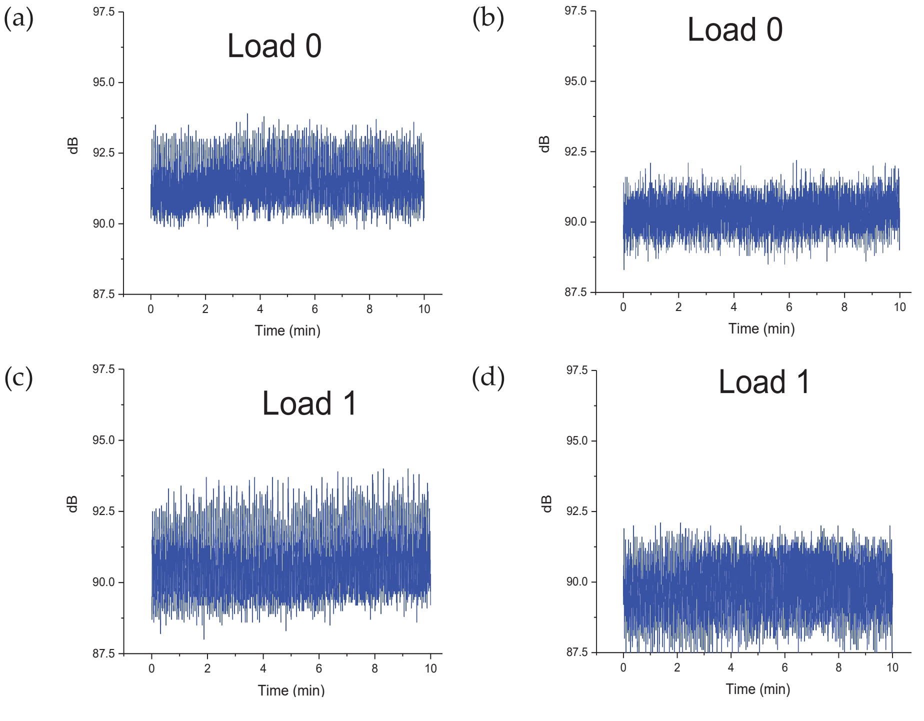
Table 3: The equivalent sound level in dB (A) at different loads and concentrations for outer defected bearing

Volume of concentration (%)	Sound level at load 0 (balance) (dB)	Sound level at load 1 (dB)	Sound level at load 2 (dB)	Sound level at load 3 (dB)
0.0	91.51	92.85	93.5	94.7
0.1	91.02	91.54	92.15	93.01
0.2	89.93	89.62	91.28	90.61
0.3	90.36	90.76	92	91.87
0.4	91.8	92.11	92.25	92.88
0.5	91.85	92.27	92.33	93.46

3.4 Noise Behavior in Time Domain

MATLAB software was used to sketch the graphs that show examples of the behavior of noise for every load at 0.0 % concentration of hBN nanoparticles (base oil) and oil mixed with 0.2% volume concentration of hBN nanoparticles. SLM was set to record the sound level every 100 ms which means about 6000 values for sound level were recorded during the 10 minutes for each load and concentration in dB (A). Figure 6 shows a comparison between 0.0% and 0.2% concentrations of hBN nanoparticles for sound level in dB using A filter against time for the four loading conditions. The graphs show that the range of noise is much wider and scattered in the conventional oil without the addition of hBN nanoparticles as compared with the graphs obtained for the lubricant mixed with 0.2% volume concentration of hBN nanoparticles. Based on Figure 6, it can be inferred that the noise level measured in dB increases with the addition of unbalance loads. It is also apparent that with the addition of 0.2% hBn nanoparticles, the noise level drops for each load. Table 4 shows the rate of noise reduction between 0.0% and 0.2% volume concentrations.

An equivalent sound level of ball bearing for the base was obtained by subtracting the constant sound level of the room which is approximately at 45 dB as the sound level meter shown before the test rig was operated from the measured data when the test rig was being operated. Then, the reduction rate was calculated for change in the sound level for base oil and 0.2% of hBN volume concentration. The reduction in noise for 0.2% in comparison with 0.0% conventional oil was 4.30% for healthy new ball bearing, 5.7 % for inner defected bearing and 5.8% for outer defected ball bearing, respectively.



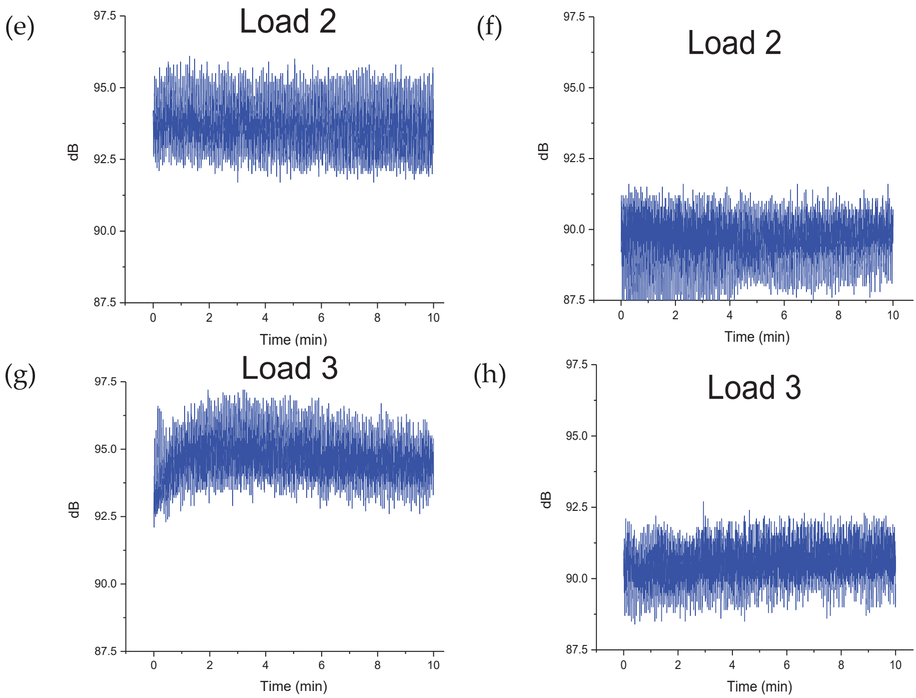


Figure 6: Comparison for sound level in dB (A) against time: (a), (c), (e) and (g) without hBN and (b), (d), (f) and (h) with 0.2% volume concentration of hBN

Table 4: The reduction in equivalent sound level between 0.0% and 0.2% of hBN nanoparticles volume concentration

Item	Average sound level of ball bearing for base oil in dB (A)	The average reduction in noise for 0.2% of hBN in dB (A)	Average rate of reduction in noise level
Healthy new bearing	47.75	2.09	4.30%
Inner defected bearing	47.77	2.78	5.70%
Outer defected bearing	48.14	2.80	5.80%

According to the results obtained using the Sound Level Meter for filter A, it can be seen that the noise reduction was highest at 0.2% concentration at least for the experimental work conditions. Therefore, it can be concluded that 0.2% is the optimum volume concentration that can improve the tribological characteristics which in return reflects in the enhancement of reduction in vibration and noise. The results achieved by this study are supported by previous studies that have reached similar conclusions such as Abdullah et al. [7] who stated that hBN nanoparticles additive presence in the diesel engine oil lowered the friction coefficient which suggests that hBN nanoparticles affected ball bearing. The nanoparticles presence changed the sliding friction to rolling friction between the frictional pairs, which reduce the contact area. Another property for the hBN nanoparticles that was realized is providing a good anti-wear effect a reduction in the material's wear rate by 58%, which is considered as a good quantitative agreement with the coefficient of friction [2].

Furthermore, a smoother worn surface was obtained with hBN nanoparticles additive. The particle size and shape have effects on the tribological performance where smaller particles in nanometer-size are more spherical which allow the particles to coalesce more easily in the asperity valleys, creating a smoother transfer layer that is less abrasive, where the particles align themselves parallel to the relative motion and slide over one another with relative ease providing lubrication and effectively reducing friction. This demonstrates the effects of particle size and shape on the tribological performance where smaller more spherical particles have a greater affinity for minimizing wear. Particles with size larger than Nano still lower wear when compared to a lubricant mixture with no particle additives, but not to the same degree as smaller particles because the larger particle size and plate-shaped geometry tends to behave detrimentally by acting as a third-body abrasive particle that can damage the softer disk surface by plastic deformation [13].

The friction low coefficient can be attributed to the viscosity effect at low temperature and the rolling effect at high temperature. The sphere-like nanoparticles may result in a rolling effect between the rubbing surfaces, and the situation of friction is changed from sliding to rolling. Therefore, the friction coefficient can be reduced. For the anti-wear test, when CuO was added to the SF oil and the Base oil, the worn scar depths were decreased by 16.7 and 78.8%, respectively, as compared to the oils without nanoparticles. The anti-wear mechanism is attributed to the deposition of CuO nanoparticles on the worn surface, which may decrease the shearing stress, thus improving the tribological properties [14].

4.0 CONCLUSION

The results showed a reduction in the noise level of the ball bearings lubricated with mixture of hBN nanoparticles and base oil compared with the noise level of the same ball bearings lubricated with the conventional oil. Based on the data obtained, it is apparent that the noise level increases with the addition of unbalance loads. The experimental measurements revealed that 0.2% volume concentration of hBN nanoparticles is the optimum concentration among the other five concentrations with a 5.8% reduction in noise for healthy new ball bearing, 5.7 % for inner defected bearing and 4.3% for outer defected ball bearing. This effect could be due to the rolling of the sphere-like nanoparticles between the rubbing surfaces, thus reducing friction which in return reduces the noise produced by the ball bearing. With an increasing concentration of nanoparticles, the level of noise increased but not more than the noise level of oil without hBN nanoparticles, this effect can be justified due to the agglomeration of hBN nanoparticles. we can conclude that the noise characteristics of hBN nanoparticles agree very well with vibration characteristics in which it showed that 0.2 % volume of concentration functions effectively as an additive.

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