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VIBRATION AND OIL ANALYSIS FOR MONITORING PROBLEMS RELATED TO WATER CONTAMINATION IN ROLLING[1]

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Abstract

Trying to reduce particle contamination in lubrication systems, industries of the whole world spend millions of dollars each year on the improvement of filtration technology. In this context, by controlling fluid cleanliness, some companies are able to reduce failures rates up to 85 percent. However, in some industries and environments, water is a contaminant more frequently encountered than solid particles, and it is often seen as the primary cause of component failure. Only one percent of water in oil is enough to reduce life expectancy of a journal bearing by 80 percent. For rolling bearing elements, the situation is worse because water destroys the oil film and, under the extreme temperatures and pressures generated in the load zone of a rolling bearing element, free and emulsified water can result in instantaneous flash-vaporization giving origin to erosive wear. This work studies the effect of water as lubricant contaminant in ball bearings, which simulates a situation that could actually occur in real systems. In a designed bench test, three basic lubricants of different viscosities were contaminated with different contents of water. The results regarding oil and vibration analysis are presented for different bearing speeds.

Key words: Vibration analyis; Oil analysis; Liquid contamination, Rolling element bearing.

MONITORAMENTO DA CONTAMINAÇÃO DE ROLAMENTOS POR ÁGUA ATRAVÉS DAS ANÁLISES DE ÓLEOS E DE VIBRAÇÕES

Resumo

Na tentativa de reduzir a contaminação em sistemas de lubrificação, as indústrias do mundo todo gastam milhões de dólares a cada ano no melhoramento da tecnologia de filtração. Neste contexto, ao controlar a limpeza do fluido, algumas companhias são capazes de reduzir as taxas de falhas em até 85 porcento. Porém, em algumas indústrias e ambientes, a água é o contaminante mais comum que as partículas sólidas e é vista como a causa primaria de falhas de componentes. Apenas um porcento de água no óleo é suficiente para reduzir a expectativa de vida de um mancal de deslizamento em 80 porcento. Para mancais de rolamentos a situação é pior ainda porque a água destrói o filme de óleo e, sob extrema temperatura e pressão gerada na zona de carga, a água livre e/ou emulsionada podem resultar em vaporização instantânea dando origem ao desgaste erosivo. Este trabalho estuda o efeito da água como contaminante do lubrificante em mancais de rolamentos que simulam uma situação que pode ocorrer em sistemas reais. Em um banco de ensaio, três lubrificantes básicos com diferentes viscosidades foram contaminados com teores diferentes de água. Os resultados das análises de vibrações e análise de óleos são apresentados para diferentes rotações dos rolamentos.

Palavras-chave: Análise de vibração; Análise de óleo; Contaminação líquida; Mancais de rolamentos.

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1 INTRODUCTION

A variety of sources can give origin to water in lubricated systems. Water can also contaminate the lubricant as a result of failure factors such as leakage in heat exchangers due to worn system elements, or else air condensed water in panels, breathers and other defective system surfaces.[1]

In a lubricant, contaminant water can appear dissolved into it, mixed to it, or else as an emulsion. The first case is characterized by individual water molecules dispersed throughout the oil. Microscopically saying, dissolved water in lubricating oil is comparable to moisture in air on a humid day since water is known to be there but, because it is dispersed molecule-by-molecule, it cannot be perceived . For this reason, oil can contain a significant concentration of dissolved water with no visible indication of its presence.[2] Moreover, depending on temperature and age, most industrial oils can present as much as 200 to 600 ppm of water (0.02 to 0.06 percent) in the dissolved state, with aged oils capable of holding three to four times more water than new ones.

On the other hand, when the amount of water exceeds the maximum level to remain dissolved, the oil gets saturated, giving origin to an emulsified mixture, where microscopic droplets appear in the oil. In lubricating oil, this emulsion is often referred to as haze, with the oil said to be cloudy or hazy.[3]

Adding more water to the emulsion will lead to the appearance of two distinct layers: one composed of free water and another of free and/or emulsified oil . For oils whose density is less than 1.0, like mineral oils and PAO synthetics, the free water layer is found at the bottom of tanks and sumps.[2]

In a lubricating system, free and emulsified water are the most harmful water contaminant conditions. For example, in rolling bearings, being water more incompressible than oil, water lubricant contamination can result in loss of the hydrodynamic oil film, which generates excessive wear.[2]

Under certain conditions, water molecules can be broken into their constituent oxygen and hydrogen atoms as a consequence of high pressures generated in the load zone of a rolling bearing element. Due to their relative small size, hydrogen ions produced by this process can be absorbed onto the surface of the bearing raceway, resulting in a phenomenon known as hydrogen embrittlement. Hydrogen embrittlement is due to changes in bearing subsurface metallurgy. These changes cause the bearing material to weaken or brittle and prone to cracking, beneath the surface of the raceway.[2] When these subsurface defects reach the surface, the result can lead to pitting and spalls.

Because the effects of free and emulsified water are more harmful than those of dissolved water, it should be ensured that moisture levels remain well below the saturation point. For most in-service oils this means 100 to 300 ppm or less, depending on the oil type and temperature. However, even at these levels, a significant amount of damage can still occur. Generally speaking, there is no such a thing as “too little water” and every reasonable effort should be made to keep water contamination as low as possible.[2-4]

Water also plays a direct role in the lubricant conditions. The presence of water may increase progress of oxidation tenfold, resulting in premature oil aging, particularly if catalytic metals, such as copper, lead and tin, are presented.

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The problems described above show how crucial it is water monitoring in lubricated dynamical systems and, in fact, several studies have been carried out concerning water monitoring in systems such as those composed by rolling bearing elements.

In this context, Saavedra[5] points out that, when a rolling bearing is inadequately lubricated, its vibration response is similar to that of a system submitted to random excitation. In the case of systems with low damping, the predominant components of such response would correspond to the natural frequencies of the rolling bearing. On the other hand, according to Berry,[6] frequency spectra of vibration signals for inadequate lubrication condition are characterized by three or four peaks in frequency bands from 900 to 1600 Hz, corresponding to natural frequency bands of the rolling bearing. In addition, he affirms that these frequency bands are also seen under adequate lubrication condition, although the vibration magnitudes are much smaller in this case.

In the same context, another study [7] concludes that vibration energy of a bearing depends on surface irregularities, external loadings, running speed and lubricant viscosity. For instance, it was observed in experimental tests that the influences of lubricant viscosity on vibration response depend on speed: for a bearing under large load and low running speeds, increase in lubricant viscosity causes reduction in vibration energy. In contrast, at high running speeds, vibration energy is high when lubricant viscosity is high.

More works on detection of localized defects in rolling bearing elements through vibration analysis can be found in the literature.[8–10]

Not only vibration is important but also oil analysis is a very useful technique for monitoring the state of a system, as it can be seeing in Gonçalves, Lago and Cunha,[11,12] Maru, Serrato and Padovese[13,14] and Maru, Castilho and Padovese.[15,16] In the four last works mentioned above, authors found out that vibration analysis, through the root mean square (rms) value, was able to show that particle size and concentration of solid contaminant affect the dynamical response of the bearing in the low frequency range.

A testing bench was built for the present study to monitor the presence of water in a rolling bearing system. In this experiment, three lubricants of different viscosities were contaminated with different contents of water. Results, obtained for different bearing speeds, were analyzed in what concerns oil and vibration signal.

2 MATERIALS AND METHODS

In the experiment, mineral oil without additive was used as lubricant. Three different viscosity grades were tested: ISO 10, ISO 32 and ISO 68. The two highest viscosity grades are recommended for bearing operation in the selected test conditions, according to manufacturer catalogues. The ISO 10 grade was included in the study to force the appearance of a critical condition of lubrication in the contact, toward boundary lubrication. Each viscosity grade was contaminated by water in the proportion of 0.1%, 0.2% and 0.3 % in volume.

The ball bearings used in tests were of type 6205, with internal diameter of 25 mm, external diameter of 52 mm and width of 15 mm. The tested bearing was vertically loaded and oil bath lubricated. Radial load was applied to the tested bearing through a

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lever and a load cell with a screw system. Figure 1 shows the rolling bearing element dimensions and the position of applied load.

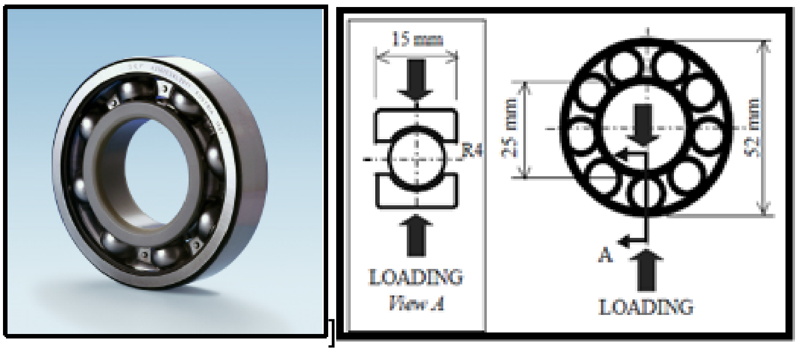

Figure 1- Rolling element bearing with dimensions and loading.

A system with pulleys transmitted power from an electric motor to the bearing shaft. Two ball bearings were used to support the shaft. A frequency inverter controlled the shaft speed.

A piezoelectric accelerometer attached to the bearing housing measured bearing radial vibration at vertical position. A PCB 353 B2 accelerometer , with 0-7 kHz useful range, sensitivity of 20 mV/g or 2.04 mV/ (m/s²) was used with an ICP sensor signal conditioner, model 480 E9.

The measured signal was amplified and filtered with a low band pass filter at a cutoff frequency of 7 kHz and then acquired through an acquisition board at sampling rate of 20 kHz. In the tests, each acquired signal was composed by 200000 data points, corresponding to acquisition time of 10 s.

The applied load was set to 800 N and the shaft speed to the interval 35 Hz - 55 Hz. Vibrations signals were acquired after stabilization of oil bath temperature. Ten signals were acquired for each lubrication condition. A sketch of the equipment is illustrated in Figure 2.

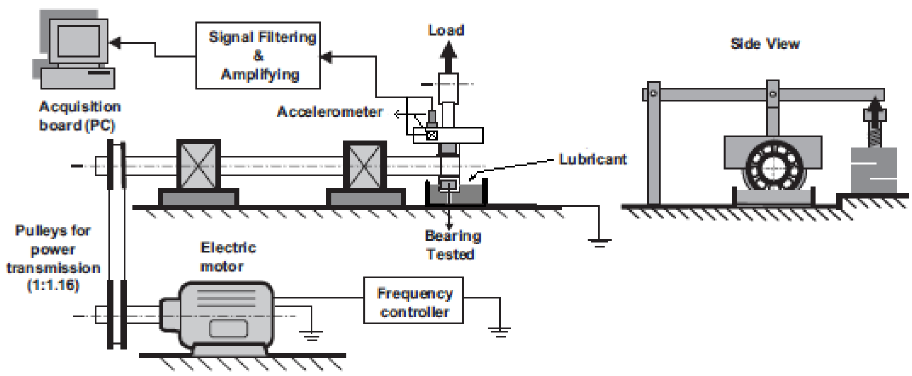

Figure 2 – Sketch of the equipment used for the test.

Experiments with every lubrication condition were repeated several times to check repeatability.

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The following oil analysis methods were used. For determination of the flash point it was used an open cup Cleveland equipment according to ASTM D92.[17]

Cannon Fenske viscometers were used for viscosity measurements according to ASTM D445.[18] Particle counting within the oils, before and after each test, was performed in an Hiac PC 4000 according to ISO 4406.[19] The PQ index, obtained from an Analex automatic particle quantifier, was used for estimating the quantity of magnetic particles inside 2 ml of tested oil.

3 RESULTS AND DISCUSSION

Table 1 presents some results of analysis of the lubricant used in the experiments.

Table 1 – Properties of the lubricant with and without water as contaminant

		Viscosity at 40^{0}C (cSt)	Flash point (^{0}C)	PQ (index)	Particle counting before test	Particle counting after test
ISO10	pure	10.0	186	14	19/16/12	19/16/12
	0.1%	10.2	190	14	19/16/12	19/16/12
	0.2%	11.0	196	14	19/16/12	19/16/12
	0.3%	11.3	199	14	19/16/12	19/16/12
ISO32	pure	33.0	230	14	19/16/12	19/16/12
	0.1%	33.4	238	14	19/16/12	19/16/12
	0.2%	33.8	241	14	19/16/12	19/16/12
	0.3%	34.1	255	14	19/16/12	19/16/12
ISO68	pure	69.0	252	14	19/16/12	19/16/12
	0.1%	69.3	258	14	19/16/12	19/16/12
	0.2%	69.9	261	14	19/16/12	19/16/12
	0.3%	70.2	267	14	19/16/12	19/16/12

As it can be seen from the Table 1, viscosity obviously increased with contaminant water content for the three kinds of lubricants. The same happened to the flash vaporization point.

Low values of PQ index mean benign wear while the constant ones point to similar severity conditions for every tested lubricant. The same can be said about particle counting since used oils presented similar values for all tested lubricants, before and after testing the rolling bearing element. Table 2 shows the meaning of the obtained 19/16/12 ISO 4406 code.

Table 2- ISO 4406 code meaning

Range number	Size of particles (µm)	Actual particle count range (per ml)
19	> 4	2,500 – 5,000
16	> 6	320 – 640
12	> 14	20 - 40

Figure 3 shows the vibration signal Power Spectral Density, PSD,[20] in frequency bands of 0 to 1 kHz and of 1 to 5 kHz, for lubricants without contaminant, and for a shaft speed of 40 Hz. These frequency bands show two kinds of spectral patterns: a

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frequency close to 0 Hz, related to shaft speed, and narrow frequencies bands close to 300Hz and 2,2 kHz, related to the system resonance .

Although some differences appear among the spectra of the three lubricants, these differences do not allow to establish correlations between these spectral partterns and the different viscosities.

In order to look for information related to water contamination, it was used a parameter named Energy of Signal (ES) defined by eq. 1.

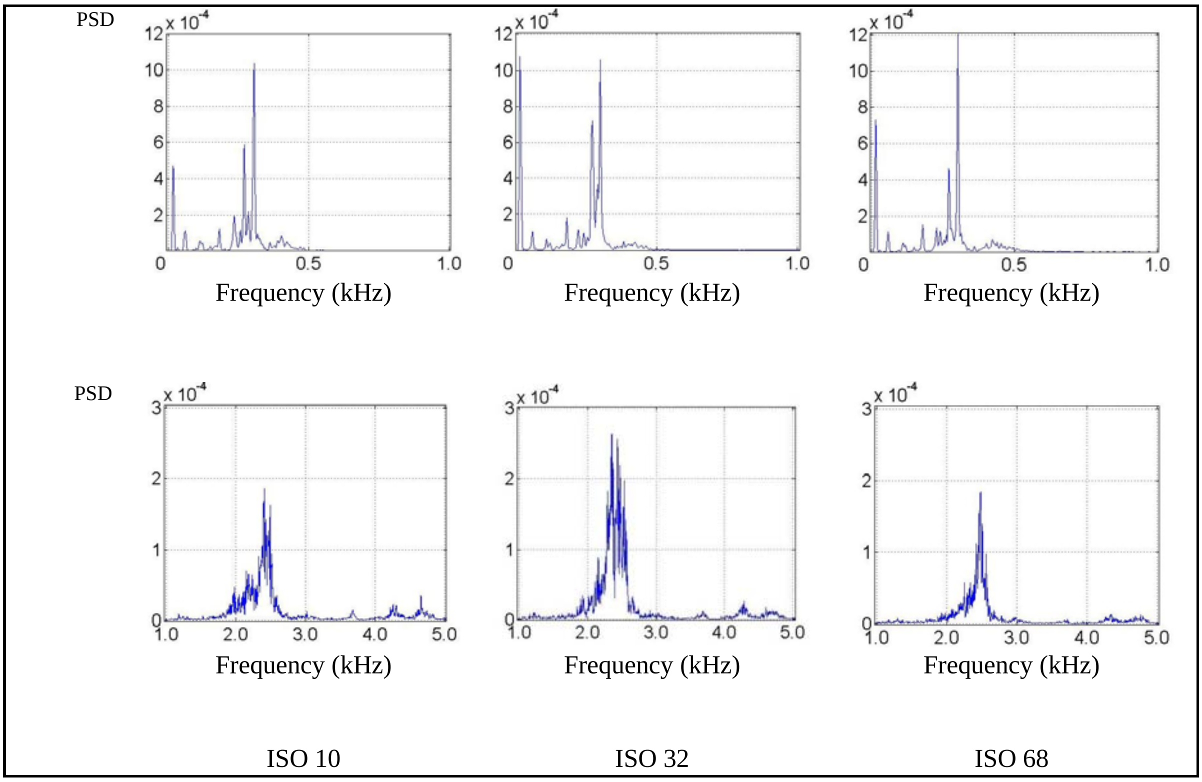

Figure 3 – Power spectral density for the three types of lubricants without contaminant from 0 to 1 kHz and from 1 to 5 kHz.

$E_s = (1/T)*\int s(t)^2\, dt$ ……………………………………………(1),

where T is a given time duration of the signal s(t).

Figure 4 and Figure 5 present results concerning the signal energy as a function of shaft rotation, for the lubricants without contaminant.

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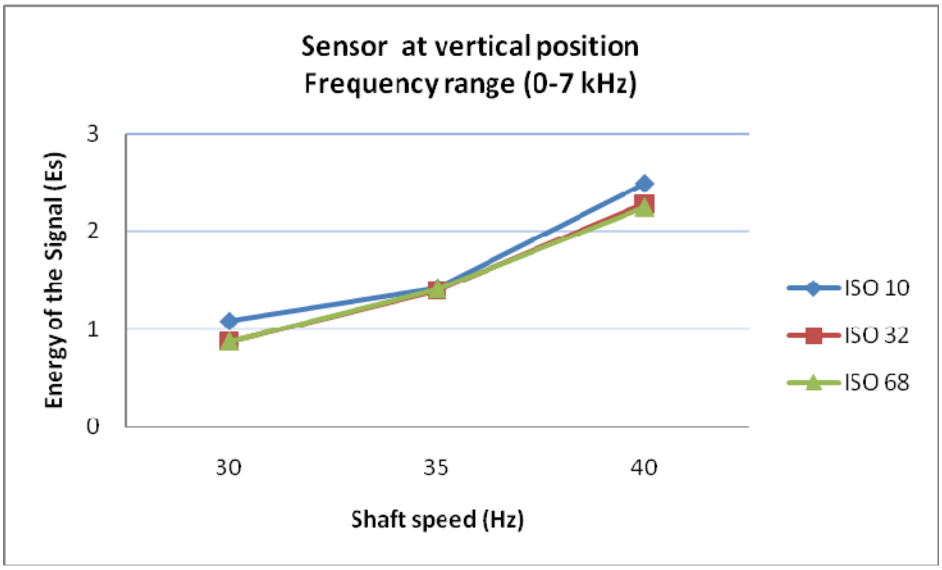

Figure 4 - Energy of the signal for "low" shaft rotation range.

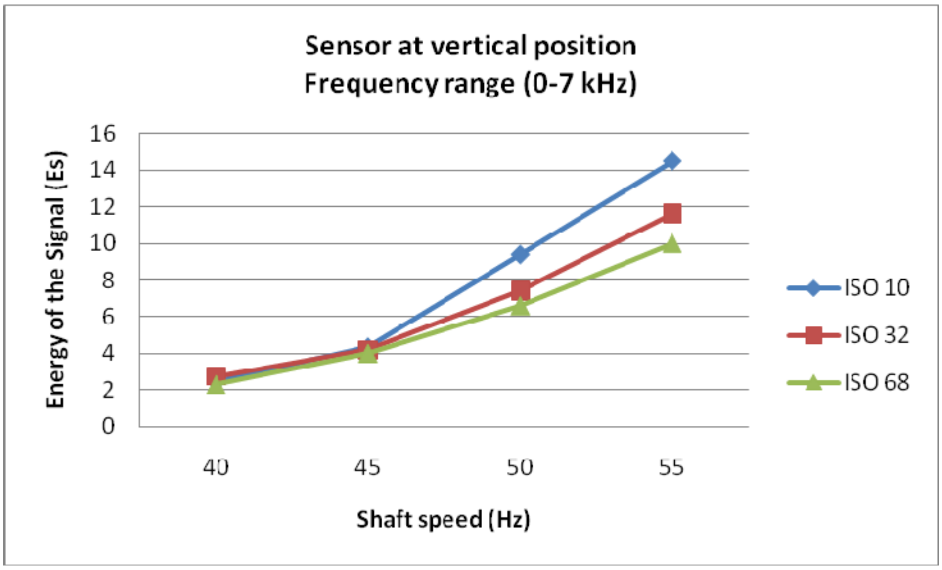

Figure 5 - Energy of the signal for "high" shaft rotation range.

From Figure 4, it can be seen that the Es parameter increases with shaft speed. This parameter does not allow, in a clearly way, to distinguish among the three types of lubricants, at least for low shaft speed. On the other hand, for high shaft speed, as can be seen in Figure 5, the difference of viscosity can be observed in the Es parameter. Additionally, one can note that the energy of the signal decreases with increasing oil viscosity grade.

Figure 6 presents results for lubricant contamination. These results cover the high shaft speed range, three lubricant types and all water contamination grades.

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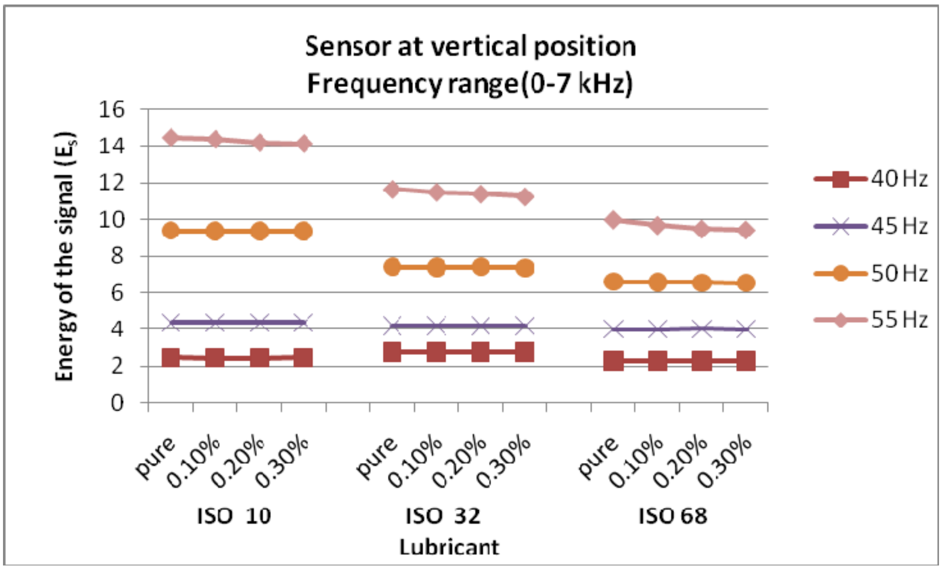
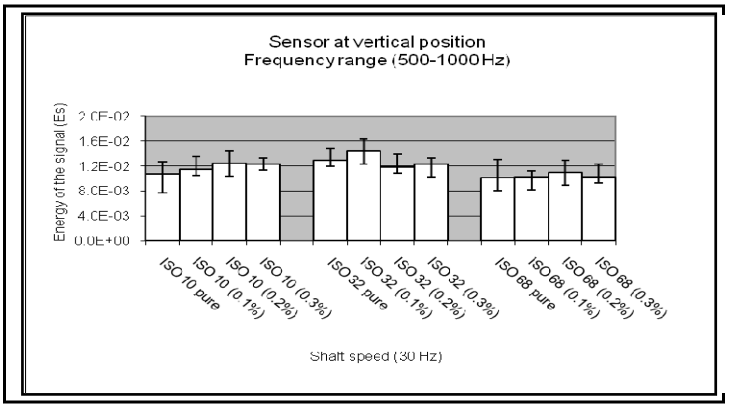


Figure 6 - Energy of the signal for lubricants with and without contamination for high shaft speed range.

From Table 1, it is clear that, as water content increases, lubricant viscosities increase either. However the change is small and difficult to be verified through the Es parameter. In Figure 6, only for 55 Hz, the energy of the signal clearly decreases with lubricant contamination, for all viscosity grades.

It is worth mentioning that several signal processing techniques were used in order to highlight contamination information in vibration signals. Only some of them are shown in this paper.

Figure 7 presents the Es parameter calculated in the 0,5 – 1 kHz interval, for the low shaft speed range. It can be seen that the influence of contamination on the vibration signal parameter are not significant. This means that viscosity variation with water content has a small impact in the vibrational behavior of the experimental bench for lower shaft speed range.



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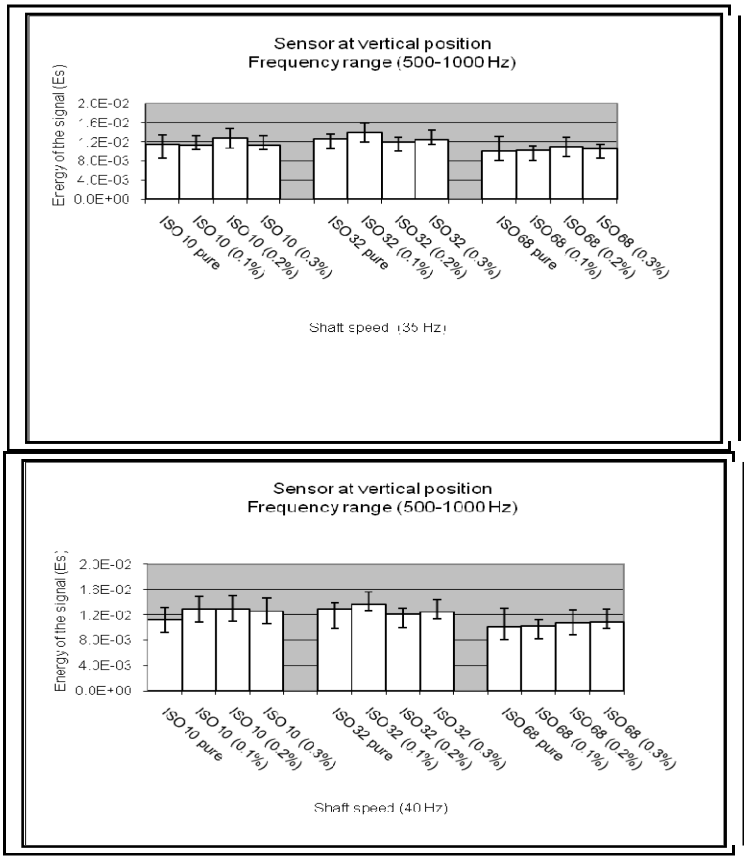

Figure 7 – Energy of the signal for three lubricant types with and without contaminant grades, from 500 – 1000 Hz, measured in vertical position at three shaft speed values.

4 CONCLUSIONS

This paper studies the influence of water lubricant contamination in the vibrational behavior of a rolling bearing, at different lubricant viscosity grades and shaft speeds.

During the experiment, rolling bearing wear was monitored but remained unmeasurable, since the particle counting and PQ index showed always normal values. This was expected, due to the short period of time of experiments. The viscosity analysis of the different contamination grades indicates an increase in viscosity as contamination grade increases.

Vibration signal was measured at the rolling bearing housing , and was analyzed by the Energy of Signal parameter, at different frequency bands. This parameter increases as shaft speed increases, but, for low shaft speed, it is not clearly possible to distinguish the different contamination grades. On the other hand, for high shaft speeds, the influence of the water contamination is clearly perceptible .

That means that the small viscosities changes, due to water contamination, are not enough to allow detection for low shaft speed.

Future studies needs to be done, by exploring others signal processing techniques in order to try increase defensibility of analysis and extend the detection capability to lower shaft speed.

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