A comparative experimental study of ultrasound technique and vibration analysis in detection of bearing defect

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Abstract

Vibration monitoring of rolling element bearings is probably the most established diagnostic technique for rotating machinery. The application of ultrasound technique for bearing diagnosis is gaining ground as a complementary diagnostic tool. In fact, many similarities exist between these two methods and their principle is to not so far. The experimental investigation reported in this paper was centered on the application of the ultrasound technique for identifying the presence and size of a defect on bearings. Also, a comparison between ultrasound technique and vibration analysis are presented to assess their effectiveness and determine their detection limits and their complementarities. The results reveal that the ultrasound technique is most effective in the early detection of bearing faults vibration monitoring.

Keywords: *Ultrasound; Vibration; Bearing defect; Condition monitoring; Defect size.*

1. Introduction

For a long time, rolling element bearings were sources of concern for mainteniciens. These highly reliable organs are often a cause of a major failure leading to discontinuation of production, even very serious operating incidents. Flaking, bearing clearance, deterioration of the outer or inner rings or the balls is often difficult to detect as mistakes in the first stage of their appearance. [1]
To prevent these failures and ensure optimum availability of bearings, there are methods such as surveillance of powerful non-destructive testing (NDT) that are part of the conditional preventive maintenance. [2] Indeed, these methods are used for the detection and diagnosis of rolling defects; and rely on the expertise using vibration, ultrasound and external bearing temperature [3].
In fact, many scientific publications have dealt with the detection and diagnosis of rolling defects. The majority of these researches focus on monitoring by conventional vibration analysis methods. As a result of its efficiency, this method is taking a very important place in the framework of the implementation of a conditional maintenance. It allows monitoring the status of the rotary machine in operation to prevent unwanted stops. [4] In this matter, it exists two vibration analysis techniques: The temporal analysis and the frequency analysis. The errors caused by the bearings induce periodic impulsive forces; it translates effectively the temporary signal by shocks in every contact of the ball with the error [5]. Several indicators were then used such as RMS, kurtosis and the crest factor and reliability has been proven in the detection of bearing defects and gear [6]. However, analysis in the frequency field has been widely used and it's proved and known as the most effective technique when it comes to diagnosing errors and monitoring their evolution over time. [7]
Certainly, the vibration analysis has been known for many years to detect the health status of an equipment, to monitor and even trace the origin of defects. However, there are other techniques such as ultrasound analysis that has gained ground as a complementary diagnostic tool. Among these two methods, the choice is difficult because each method has its preferred range of applications [8].
The objective of this study is to compare and evaluate the affectivity of controlling methods as vibration analysis and ultrasonic analysis. This will determine their detection limits and complementarities. For this, various tests are performed on tapered roller bearings with a crack.

2. Principle of control methods

For this work we used two types of NDT methods: vibration analysis and acoustic analysis. Indeed, the vibratory control is the most used and most powerful. The objective of this study is to compare the results of vibration monitoring to those obtained from ultrasound technique:

2.1 Vibration control

The vibration control is a powerful tool for diagnosis of rotating machinery failure modes: used especially to detect faults that occur in the bearings. Rolling the defects (defect cage, bead, inner race or outer race) are characterized by repetition frequencies based on known parameters [9].

2.2 Ultrasound control

Far of ultrasonic testing used in non-destructive testing to detect internal defects of materials, the ultrasound control used in preventive maintenance is to "listen" to the ultrasound emitted by the machines in operation. For that, the equipment of measure detects the ultrasonic waves of frequency above 20 kHz, and converts them into audible sounds (50 Hz to a few kHz). The audible noise then reveals the presence of problems. [10]

3. Experemental procedure

The figure 2-(A) shows the test bench used in this study. It consists of a shaft supported by two tapered roller bearings and connected to a motor with a flexible coupling. The defect (~ 11mm) was artificially induced on the outer ring as shown in the Figure 2-(B). The shaft speed is controlled by a speed variator.

Fig. 1. (A) the experimental test bench, (B) artificial defect on the outer ring

4. Analysis of results

4.1 Analysis of vibration results

4.1.1 In time domain

In this study, we focus on the study of the evolution of indicators RMS and Crest Factor in both directions (axial and radial) depending on the rotational speed.

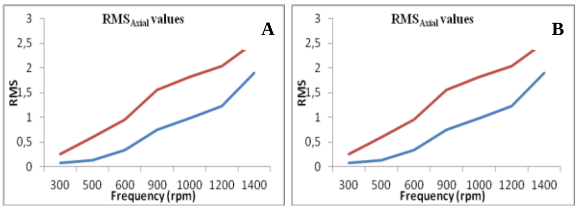

Fig. 2. RMS Values: (A) in radial direction, (B) in axial directions: defective bearing and healthy bearing.

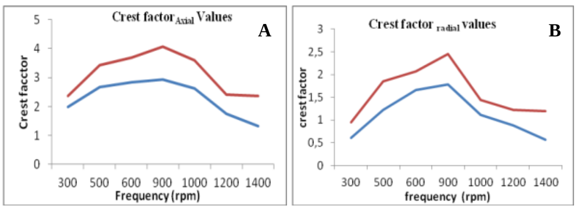

Fig. 3. Crest Factor Values: (A) in radial direction, (B) in axial directions: defective bearing and healthy bearing.

As shown in Figures 3 and 4, the RMS factor increases as a function of speed. The Crest Factor responds well in the frequency range of 500 rpm to 1200 rpm. For low and high speeds, it decreases because the signal is less pronounced and less amplified by default.

4.1.2 In frequency domain

The bearings used in this test are tapered roller bearings (TIMKEN, 6005-2Z / C3) whose frequency characteristics are listed in Table 1.

TABLE I. BEARING FREQUENCIES TIMKEN, 6005-2Z /

Rotation frequency	*FTF*	*BSF*	*BPFO*	*BPFI*
Order 1	Order 0.42	Order 5.81	Order 6.7	Order 9.3

The acceleration signals for a healthy bearing and a defective bearing, acquired at speeds of 600, 1200 and 1500 rpm, are shown in Figure 3.

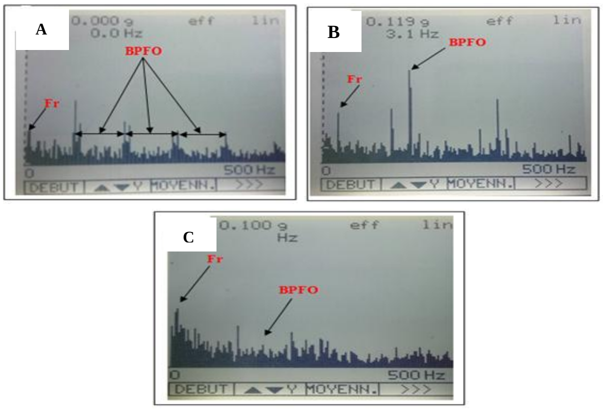

Fig. 4. vibration measurement: (A) at 600 rpm, (B) at 1200 rpm, (C) at 1500 rpm

4.2 Analysis of ultrasound results

4.2.1 In time domain

As in vibration analysis, we chose the temporal descriptors RMS and Crest factor to test their effectiveness.

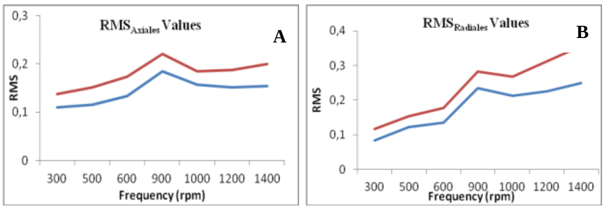

Fig. 5. RMS Values: (A) in radial direction, (B) in axial directions: defective bearing and healthy bearing.

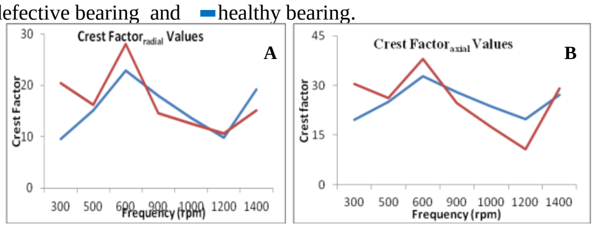

Fig. 6. Crest Factor Values: (A) in radial direction, (B) in axial directions: defective bearing and healthy bearing.

From the graphs presented in the figures 4 and 5, we notice that the RMS is gradually changed according to the rotation frequency. However, the crest factor follows a random evolution (in low frequencies, the crest factor values are very high). Consequently, the crest factor does not react appropriately according to the reconstruction of the signal.

Furthermore, we think that the RMS is more efficient to distinguish the defective bearing from the healthy one for all frequencies values.

4.2.2 In frequency domain

Now, we use the ultrasound signals to diagnosis of bearing defect for different rotation speeds. The figure 6 shows an ultrasound signal acquired at 600, 1200 and 1500 rpm.

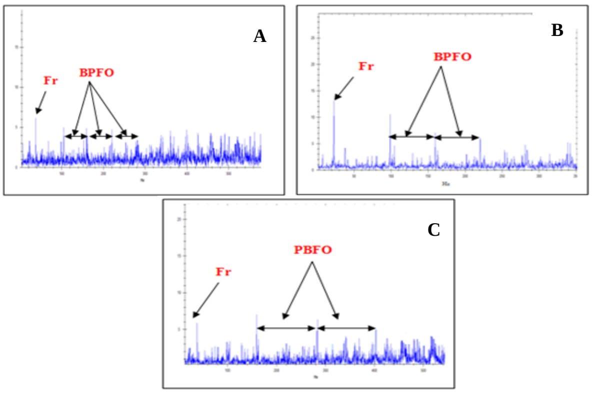

Fig. 7. Ultrasonic measurement: (A) at 600 rpm, (B) at 1200 rpm, (C) at 1500 rpm

Indeed, we note that the defective bearing shows clearly the frequency BPFO and its harmonics, what is significant of a fault on the outer race. When running at 1200 rpm and 1500 rpm respectively, the ultrasound spectra of healthy bearing and the defective one (as shown in figure 7) reveal that the ultrasound measurement was able to detect the BPFO frequency and its harmonics.

4 Discussion

The results of this article focus on a comparison between three NDT methods. The tests were made from a bearing with a crack induced artificially on the outer ring. Thus, two bearings (defective and healthy) were used. Vibration and ultrasound signals were recorded and analyzed for comparative purposes. This study was used to extract the following results:

On the one hand, the method of vibration analysis gave, generally, good results in the time and frequency domains. In the time domain, the RMS indicator was ineffective and it revealed misinterpretations because it depends on the speed. While the crest factor (which is a dimensionless indicator) reacted well on the frequency range between 500 rpm and 1200 rpm. So it is more meaningful to use the crest factor to characterize the vibration signal of a bearing. For the frequency domain, the vibration analysis is more suitable for 600 rpm and 1200rpm speed (easy visualization of the characteristic frequency of default BPFO). However, when the rotational speed increased to 1500 rpm, the frequency characteristic of the defect BPFO became hardly detectable.
On the other hand, the ultrasound method has proven effective for both temporal and frequency domains and for all frequency bands. Indeed, the RMS values and crest factor calculated from ultrasound measurements revealed unreliability of the crest factor. However, the RMS confirmed its efficiency for the characterization of an ultrasound signal. In the frequency domain, the ultrasound spectra appeared the ability of this technology to detect bearing defect in different frequency bands: clear visualization of the characteristic frequency BPFO and its harmonics at 600, 1200 and 1500 rpm.

5 Conclusion

To summarize, this study revealed that the ultrasonic technique is at least as good as the vibration measurements for the detection of bearing faults. More specifically, the ultrasound measurements are more sensitive than vibration technique to detect the defect in all frequency bands.

This work will be developed by proposing a much more sophisticated signal treatment tool for the vibration and ultrasound diagnosis of bearing defects.

References

[1] A. Djebala, *Optimisation de l'utilisation des indicateurs scalaires dans le cadre de la maintenance prédictive des paliers à roulements.* Congrès Algérien de Mécanique de Construction, Alger, 29-30 avril 2007.

[2] A. Lakehal, *Une nouvelle stratégie de diagnostic en maintenance préventive conditionnelle*, 4th International Conference on Computer Integrated Manufacturing CIP'2007; 2–5.

[3] N. Tandon N, *A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings*, Tribology International 32 (1999) 469–480.

[4] B. Raison, *Détection et localisation des défaillances sur un entrainement électrique*, thèse de doctorat, ENSIEG, 2000, pp. 25-30.

[5] C. Pachaud, *Crest factor and kurtosis contributions to identify defects inducing periodical impulsive forces*, Mechanical Systems and signal processing 11 (6), 903-916, 1997.

[6] R. Heng, *Statistical analysis of sound and vibration signals for monitoring rolling element bearing condition*, Applied Acoustics, Vol. 53, N°1-3, 211-226, 1998.

[7] M. Thomas, *Fiabilité, maintenance prédictive et vibrations de machines*.Presses de l'Université du Québec, 2011, 633 pages, D3357, ISBN 978-2-7605-3357-8.

[8] M. Zani, *Mesures mécaniques : La surveillance des machines tournantes*, Mesures 757 - septembre 2003

[9] X. Milisen, *Comparaison de différentes méthodes de détection de défauts dans les roulements*. Revue Scientifique des ISILF n°20, 2006 ; 1-15.

[10] F. Landolsi, *Cours de techniques de surveillance, Contrôle ultrasonore*, pp.73–78.