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Perceptive analysis of bearing defects (Contribution to vibration monitoring)

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ABSTRACT

The objective of this article is to improve bearing monitoring via vibration indicators, by developing combinations of indicators, which is more effective than using isolated classical indicators. We use a new perceptive approach to seek correlations between vibration analysis and the perception of noise generated by the defects of rotating machines. Therefore, an experimental bench was developed to simulate machine defects (bearings, alignments and gears) and to perform vibration and acoustic measurements. This study was split into three stages: the first was to process the signals of simulated defects using different vibration analysis techniques (scalar indicators and spectral analysis). The second phase was devoted to a perception test of the noises generated by the simulated defects; this test was carried out on different auditors. The results obtained from the perception test were then processed using multidimensional analysis (MDS), to calculate the dimensions of the sound perception space. The final stage of this study consisted in searching the dimensions correctly representing the deterioration of the simulated defects, and in correlating these subjective dimensions with objective classical indicators (RMS, Kurtosis, Crest factor, CGS, etc.), to define more sensitive indicators calculated from combinations of classical vibration indicators.

1. Introduction

The evolution of production resources with the introduction of increasingly complex machines has led to a new perception of the challenges linked to the maintenance function, which has changed significantly. These developments emphasize the crucial importance of maintenance and more particularly of conditional maintenance in industry.

Among the tools of conditional maintenance, vibration analysis is currently undergoing radical change due to the development of computer technology and signal processing techniques. Vibration monitoring ensures the safety of the installation by avoiding significant degradation through the use of specific scalar indicators such as kurtosis, RMS, the crest factor, etc., and it allows monitoring the state of health of the equipment and tracking all the precursors of defects.

Very often, these indicators are not sensitive to vibration change [1], especially in the case of nascent and aggravated defects. In this work, a perceptive study is proposed to improve bearing monitoring through the correction and optimization of classical vibration indicators.

The sound perception method developed by E. Parizet [2] in view to improving acoustic quality represents the match between what the object sound evokes and the image that the designers want to give it. We cite the study used by E. Parizet [3] in the automobile field that analyzed the noise caused by closing a car door. In the field of machine monitoring, N. Hamzaoui and M. Kanzari [4] carried out a perceptive study to develop a vibration indicator for gear monitoring; this indicator was defined as a function of the spectral center of gravity (SCG). Similarly, R. Younes [5] defined a combination of indicators for gear monitoring, by combining two vibratory indicators: overall level (OL) and kurtosis. In this article, the author worked on gear defects occurring in a 2-stage transmission system. Several defects were combined between two gears and ranged from a very small defect to a critical case. The indicator formulated was validated for other gear defects on the same test bench. In Ref. [6], the authors worked on real gear defects on the same test bench as in Ref. [5], loading the gears and rotating them for several days. The particularity of the sound samples tested is that they equalized them at 89.6 db.

The present work focuses on bearing defects from their onset to their aggravation. These bearing defect signals were submerged by gear defect signals for the first test bench and an imbalance defect for the second test bench used to evaluate the proposed detection model

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Fig. 1. Test bench.

without modifying the original sound level. The most important contributions of articles [5,6] stem from the validation test applied to defects from another completely different test bench, and the combination of defects of different natures

Most physical studies use a scalar indicator to monitor the state of degradation of a machine element. The global level (RMS) is one of the indicators most commonly used for different types of defects and it often provides information on the existence of a problem that must be identified using the diagnostic procedure with tools capable of identifying the type of spectrum, envelope, etc. This indicator is also quite sensitive to different types of defects such as poor lubrication, loosening, resonance problems, etc. The kurtosis and crest factor not related to the signal energy increase with the occurrence of the defect and diminish when it worsens. Therefore, the objective of our work is to define combinations of indicators for bearing monitoring. We searched for a method with a design of experiments to correlate a combination of indicators as a function of the evolution of defect severity, but were unable to find one.

The approach proposed in this article is based on a subjective and perceptive analysis, inspired by the feedback and expertise of maintenance technicians who often use their senses (listening, smell, sight and touch) to analyze the severity of a defect. It appeared very interesting to apply a sound perception approach based on similarity and preference test results to this area. This approach consists in searching a correlation between vibration analysis and the perception of noise emitted by rotating components, i.e. bearings, to develop combinations of vibration indicators capable of tracking bearing degradation of any level, even in the presence of other defects such as gear defects.

The principle of this study is to perform vibration and acoustic measurements using simulated defects on a test bench built by us, and ask different auditors to listen to and evaluate the dissimilarity between these signals. We used multidimensional MDS analysis to model the dissimilarity obtained in subjective sound dimensions. After finding the dimensions that correctly represent the evolution of the degradation of simulated defects, we apply linear regression to correlate these dimensions with objective vibration indicators.

2. Theoretical formalism

The perceptual study proposed in this article is based on seeking a correlation between the vibration analysis and sound perception. In the following, we present the classical vibration indicators to be correlated and the mathematical tools necessary for calculating the sound dimensions from the results of the dissimilarities found in the perception test, by implementing multidimensional analysis MDS and the formula of the Bravais-Pearson correlation coefficient.

2.1. Vibration indicators

Three classical vibration indicators [7] were chosen to perform the perceptive study proposed; the RMS in acceleration and the two shock indicators; kurtosis and the crest factor (CF), which are usually used for bearing monitoring.

$$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(x(n))^2} \tag{1}$$

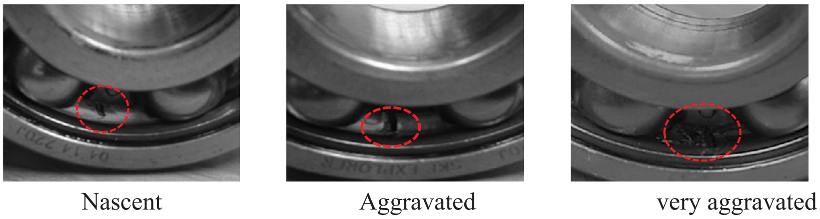
$x(n)$ is the measured time signal, N represents the number of samples.

$$CF = \frac{V_{\text{Crest}}}{RMS} \tag{2}$$

V_{Crest} is the maximum value of $|x(n)|$.

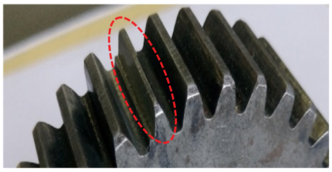
$$Kurtosis = \frac{\frac{1}{N}\sum_{n=1}^{N}(x(n)-\bar{x})^4}{\left[\frac{1}{N}\sum_{n=1}^{N}(x(n)-\bar{x})^2\right]^2} \tag{3}$$

$\bar{x}$ is the average value of the amplitudes.



Nascent Aggravated very aggravated

(a) Bearing defects



Module= 2
Number of teeth = 35
Width = 20 mm
Material : 35CD4
Pitch diameter = 70 mm

(b) Gear defect

Fig. 2. Simulated defects.