Australian Journal of Basic and Applied Sciences, 10(15) October 2016, Pages: 55-59

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Experimental study of combined gear and bearing faults by sound perception

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ARTICLE INFO

Article history:
Received 26 August 2016
Accepted 10 October 2016
Published 18 October 2016

Keywords:
vibro-acoustics sound perception
gear faults bearing faults
combined faultS

ABSTRACT

One presented in this work a vibro acoustic analysis of various signals in the case of one or several combined defects such as bearings and gears defects. The objective is to identifying each of the defects even when it combined. We begin by studying the temporal and spectral scalar indicators; a perceptive analysis of the sounds corresponding to different types of defects have been established to investigate the sensitivity of listeners to the combined defects, and the ability to distinguish between defects with different types and natures. According to the study of the vibrational indicators and of the listening test, the results are well preventative of the evolution of different defects gravity. For sound perception, the listeners could classify the sounds according to the type and the level of defects gravities.

INTRODUCTION

The gears and bearings are driveline effort and movement by physical contact between parts. This type of transmission generates vibrations and consequently emits noise. Main vibrations are produced by the input shock contacting gear teeth.

The monitoring and the diagnosis of the defects of rotating machines belong to the programs of conditional maintenance, and are 75% based on vibration analysis. Several researchers are still working on the improvement or the development of new indicators resulting from vibration and acoustic signals. In this study an acoustic approach of perception was used in order to propose an optimization of the monitoring indicators to improve the detection of defects. Indeed, subjective analyses used by maintenance technicians, based on the experience feedback, are often correlated with the worsening of the defects. The use of dissimilarity test, as acoustic perception, allowed to correlate a dimension of obtained perceptual space with Gears defects (Younes, R., *et al*., 2015; 2015).

Listening to the vibration signals of the different defects configurations, we hope to build a linear correlation between the aggravation of the defect and a combination of 2 scalar indicators used in monitoring. The advantage will be to build a defect detection model with scalar indicators, ranging from birth to the defect aggravation. To design this type of model in a new real case, should constitute a basis for signals coming from healthy and defective configurations. This approach is quite similar to a method of artificial intelligence as neural networks, but does not require any learning stage to adjust optimization settings. The originality of this article is at the level of the contribution of a subjective approach by human hearing in addition to the current physical methods.

To Cite This Article: Ramdane YOUNES, Nouredine OUELAA, Nacer HAMZAOUI, Abderrazek DJEBALA., Experimental study of combined gear and bearing faults by sound perception. ***Aust. J. Basic & Appl. Sci.,*** *10(15): 55-59, 2016*

In complement with work concerning the study of the real and simulated gears defects (Younes, R., *et al*., 2015; 2015), we presents in what follows a study of the combined defects of gears and bearings by acoustic perception; the purpose here is to extend the application of the perceptive approach presented in (Younes, R., *et al*., 2015; 2015) for the case of the defects of different nature and gravity.

2 Experimental setup:

2.1 Test rig:

One uses a device designed by the Mechanics and Structures Laboratory University of Guelma Algeria, for the realization of simulations of isolated defects on bearings and / or in gears. This experimental design is made for different speeds and different frequency bands.

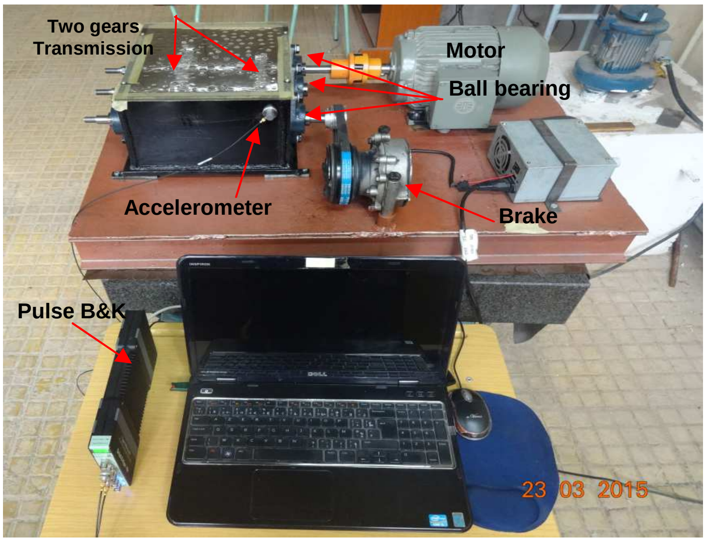

Fig. 1: Experimental Setup.

2.2 Configurations of the simulated defects:

In this experimental design, we made the acquisition of vibration signals for two rotations frequencies and two frequencies bands for different types of defects. We started by the case without defect, after that we have created three defects, small, average and great on three different bearings to ensure the possibility to combine these defects with three gears defects (small, average and great) that we created on the surface of a pinion tooth 2, see table 1.

Table 1: The values of the scalar indicators.

Sounds	corresponding defects
S1	Healthy Case HC
S2	Small Defect on Bearing2 SDB2
S3	Average Defect on Bearing2 ADB2
S4	Great Defect on Bearing2 GDB2
S5	Small Defect on PinionG2 SDG2 + Without Defect Bearing SDG2+WDB2
S6	Small Defect on PinionG2 SDG2 + Small Defect on Bearing2 PDG2+ SDB2
S7	Average Defect on PinionG2 ADG2 + Without Defect Bearing ADG2+ WDB2
S8	Average Defect on PinionG2 ADG2 + Average Defect on Bearing2 ADB2 ADG2+ ADB2
S9	Great defect on Pinion G2 GDG2+ Without Defect Bearing GDG2+ WDB2
S10	Great defect on Pinion G2 GDG2+ Great Defect on Bearing1 GDB2 GDG2+ GDB2

RESULTS AND DISCUSSION

3.1. Scalar indicators:

The evolution of scalar indicators over time can give information about the defect aggravation. One present in Table 2, the values of these indicators calculated from different time signals collected by accelerometers. The evolution of each indicator is not linear with the worsening of the combined defects; it is therefore difficult to monitor the status of defect with a single indicator.

Table 2:

		Pv	RMS	CF	K	OL	KF	SCG
Without defect	S1	15,60	3,28	4,75	4,03	2,68	51,21	351,28
Bearing defect	S2	21,60	3,47	4.83	4,80	2,84	75,04	363,88
	S3	23,30	4,04	5,77	5,22	3,30	94,03	401,96
	S4	30,80	4,01	7,67	6,02	3,28	123,65	433,38
Gear defect	S5	16,80	3,33	5,04	4,37	2,72	55,96	334,74
	S7	18,50	3,66	5,05	4,65	2,99	67,72	361,28
	S9	29,60	4,07	7,28	5,66	3,32	120,42	342,69
Combined defect	S6	18,70	3,50	6,49	6,13	2,86	65,45	359,42
	S8	19,70	3,66	5,38	4,21	2,99	72,19	339,63
	S10	19,90	3,80	5,23	4,38	3,10	75,67	361,73

The kurtosis is a sensitive indicator to signal shape and not to its energy, this is confirmed by the histogram in Figure 2, where we note the increase with the se-verity of the defect in two cases of isolated defects on bearing and gear. The combination of the two defects decreases its sensitivity and causes a decrease in its level.

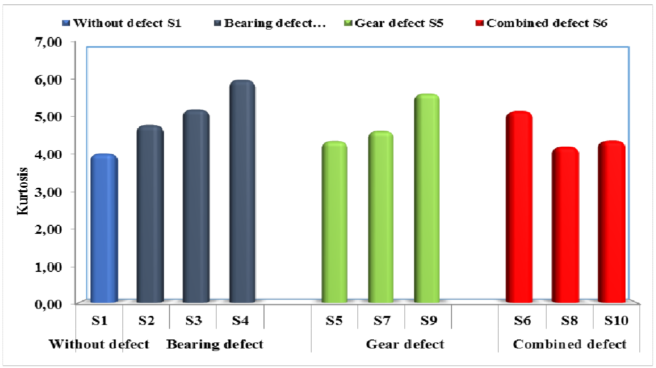

Fig. 2: Evolution of kurtosis according to the defect type.

3.2 Perceptive approach:

One chose for the treatment, only the signals measured at a speed of 15 Hz and a 12800 Hz frequency band. These are exported from Labshop Pulse soft-ware on *.wav format. We have selected 10 sounds that will be the subject of the listening test.

The listening test was conducted on the different sounds, using the paired comparison method, multidimensional analysis INDSCAL MDS was applied thereafter for the results treatment of (Younes, R., *et al*., 2015; 2015).

3.2.1 Perceptual space with two dimensions:

One present in figure 3, the perception space in 2 dimensions; we found ac-cording to DIM1, that sounds appear in the of defect degradation order from least degraded (S1) to the most degraded (S10) and this for different degradation degrees and defects types (bearing or gear).

The first group of sounds S2, S3and S4 corresponding to small, average and great bearing defect. Listeners have classified them just after the S1 sound (healthy case).

The second group of sounds (S5, S7 and S9) corresponding to the small, medium and large gear defect. Referring to the analysis of DIM1, listeners have classified the gear defects as being more degraded defects (important) that bearing defects, including the great defect S9, which has been classified with the defect S10 which is the combination of two great defects on the bearing and the gear.

The third group of combined defects sounds S6, S8 and S10 corresponding to the small-small, average-average and great- great defects of bearing and gear. The S6 can be grouped with S5 and S7 of the gear sounds, view to the little influence of bearing defect over the gear defect. While the S8 and S10 sounds were perceived by listeners as the more degraded defect that small and average gear defect. The S8 and S9 and S10 sounds can be grouped together as defects with great severity.

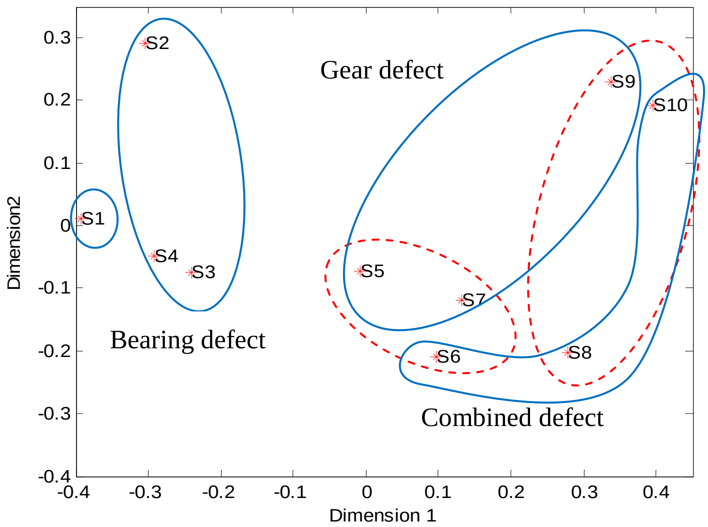

Fig. 3: Perceptual space.

One presents by histogram of the figure 4 coordinates sounds of DIM1 of the 10 sounds. The results of this figure, confirm the analysis which we presented in (Younes, R., *et al* 2015), where we found that the passage of DIM1 values from negative to the posi-tive means that that we have achieved a stage of deterioration that requires stopping the machine.

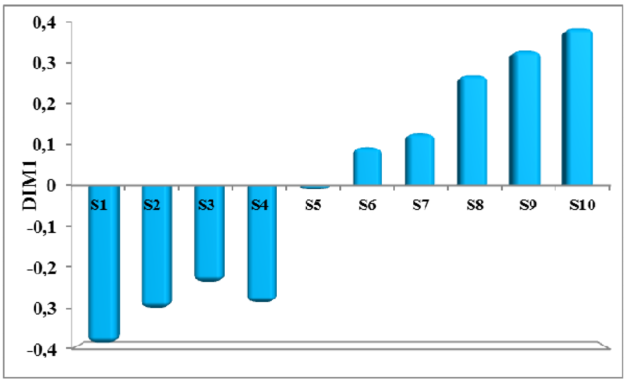

Fig. 4: DIM1 values of the 10 sounds.

3.2.2 Correlations between scalar indicators and dimensions:

The correlation of scalar indicators in Table 2 with the results of sound perception, does not give a good result except for the DIM2 with two indicators: the kurtosis and crest factor. We get a mathematical model (1) with a correlation coefficient R2 = 0.72.

$$DIM2=-0.462*Kurtosis+0.287*\text{ Crest factor}+0.598 \quad (1)$$

The dimension DIM1 that is physically correlated with the degradation state (bearing and / or gear) can be modelled via a linear combination of indicators in Table 1; it will therefore analyse other indicators.

Conclusion:

The objective of this work is to extend the application of perceptual approach to the study of single and combined defects of different nature (gear and bearing). The aim is to propose mathematical models to DIM1and DIM2 allowing the correlation of some indicators with sound perception.

For sound perception, listeners were able to classify the sounds according to the type and the level of defects severity. While the correlation between scalar indicators and sound perception, does not give a good result except for the second dimension with two indicators: the kurtosis and crest factor.

The application of perceptive approach has proven effective in cases investigated in Younes(2015a,b), real and simulated gear defects, but its application in the case of several defects with different type and nature can be still useful extending it to other indicators.

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