CONTRIBUTION TO THE EVALUATION OF SOUND QUALITY OF ELECTRIC MOTORS

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ABSTRACT

Currently, the market requirements force the industry to establish quality control processes that ensure the viability and conditions of their products. This kind of controls has been widely used in engine and machinery analysis through techniques such as spectral analysis of vibration. However, under certain circumstances, the application of traditional methods proves to be highly complex and therefore, the use of alternative techniques is necessary in order to provide an objective diagnosis. This study examines the feasibility of using psychoacoustic sound quality parameters in vibration measurements and their correlation with auditory perception for small electric motors.

RESUMEN

Actualmente, las exigencias del mercado obligan a la industria a establecer controles de calidad capaces de garantizar la viabilidad y el buen estado de sus productos. Este tipo de controles han sido ampliamente utilizados en el análisis de máquinas y motores a través de técnicas como el análisis espectral de vibraciones. Sin embargo, en determinadas circunstancias, la aplicación de métodos tradicionales presenta una gran complejidad y, por tanto, es necesaria la utilización de técnicas alternativas capaces de proporcionar un diagnóstico objetivo. Este estudio analiza la viabilidad del uso de parámetros psicoacústicos de calidad sonora en medidas de vibración y su correlación con la percepción auditiva para motores eléctricos de pequeño tamaño.

INTRODUCTION

The current market demands require the implementation of new tools able to carry out the quality product evaluation from an objective point of view, rejecting those unfit for marketing.

The vibration analysis has been widely used in the detection of mechanical faults, forming a valuable tool for predictive maintenance in engines and machinery. Frequently, this kind of analysis is based on the establishment of historical measures whose drifting is indicative of malfunction. However, this methodology can be hardly applied to newly manufactured products whose behaviour is unknown in advance. It is therefore necessary to reimagine the measurement process and develop alternative techniques in order to achieve the desired objective.

Currently, there are multiple methods capable of performing the machinery evaluation from their vibrations. Thus, techniques such as spectral analysis or order analysis can help to understand the origin of the fault or defect. Nevertheless, there are certain situations where such techniques may not be completely useful. The analysis of elements with a reduced size, low rotation speed, or a considerable stack between its components make the results fluctuate significantly, complicating the diagnostic. Similarly, techniques like order analysis require the use of an additional tachometer signal to know how the engine rotation is. This kind of signals cannot be extracted from all of market machines, so in most cases it is impossible to obtain satisfactory results.

In certain machines the existence of a fault can be properly detected by means of the sound pressure level generated and their perception as a subjective evaluation. At present, there are numerous psychoacoustic parameters able to offer an objective view of the perception of the human ear to sound stimulus. However, because of the hardness of the industrial environment, the acquisition of acoustic signals may become a truly daunting task.

The aim of this work consists of studying the vibration produced by the joint motor-gearhead, evaluating the correlation between the subjective perception of the noise generated and the use of classical psychoacoustic parameters with vibration signals. This work is part of a collaborative project between the University of Alicante and Compañía Levantina de Reductores for the development of a quality control tool.

MATERIALS AND METHODS

Experimental Measurements

The measures have been performed on a total of 96 correct items and 96 defective, according to the following scheme:

- Samples classification. Subjective test.
- Creation of a defects catalogue.
- Vibration measurement for right samples.
- Results processing. Validity ranges determination.
- Vibration measurement for defective samples.
- Results processing and comparison with right items.

Acquisition System

The acquisition and signal processing have been carried out by the NI USB-6351 platform and the development tool Labview. Three different types of transducer have been used: 4519 Brüel & Kjær miniature accelerometer, Keyence LK-G5000 Laser vibrometer and Bruel & Kjær type 4188-A-021 microphone.

Figure 1. Transducers.

The use of microphones and laser heads allows for measurements without contact between transducer and the tested item, which shows a clear advantage compared to the accelerometers. However, these types of transducers have high noise sensitivity, being inadvisable in an industrial environment.

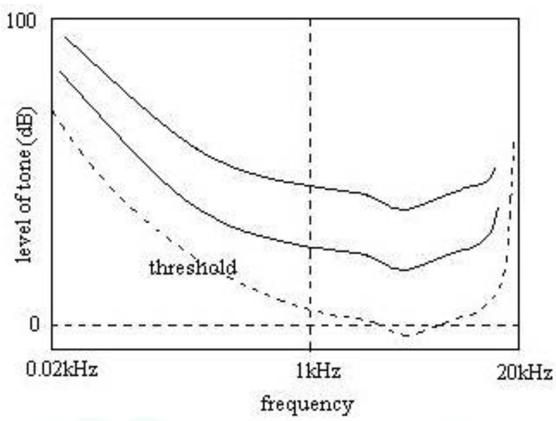
Optimum Measurement Point

For a proper detection of defects it is essential to establish the most appropriated point to perform the measurements. Therefore, from the defects catalogue produced, the appearance of the signals associated with each of the fails is verified in different parts of the sample. The finally selected point is directly related to the rotation axes of the different components of the sample.

Measurement Parameters

The psychoacoustic parameters used in this study are inspired by those with the same name used in sound pressure measures [3], being in this case applied to the signal coming from vibration transducers. According to the signal associated to each defect the following parameters have been selected:

- *Vibration Level:* determine the acceleration level of the surface studied.
- *Crest Factor:* ratio between the maximum and rms level of a signal. It will indicate the existence of impulsive noise in the analysed signal.
- *Loudness:* provides a subjective perception measure of the level of a signal.



$$N = (10^{\frac{L_N - 40}{10}})^{0.30103} \approx 2^{\frac{L_N - 40}{10}}$$

Figure 2. Basic shape of equal loudness [3].

- *Sharpness:* measurement of high frequency content which has a signal. This parameter is directly related to the Loudness and will be given by the following expression:

$$S = c\frac{\int_0^{24\,Bark} N' g'(z) \cdot z \cdot dz}{\int_0^{24\,Bark} N' dz}$$

where g'(z) corresponds to a weighting function given by the following figure:

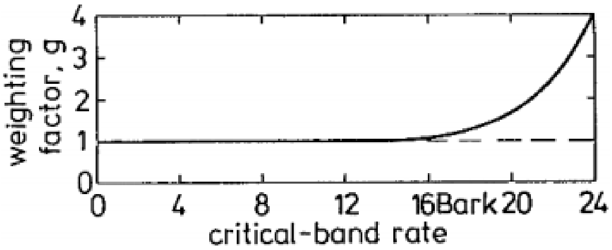
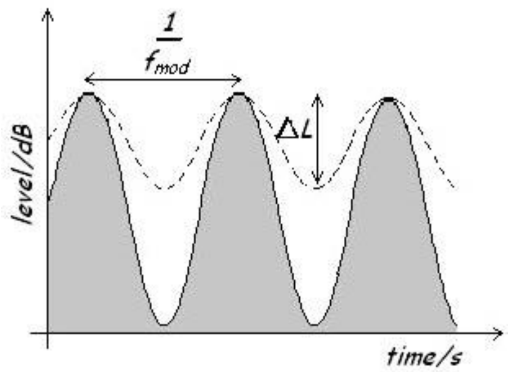


Figure 3. Weighting factor for sharpness as a function of critical-band rate [1].

- *Roughness:* quantifies the subjective perception of rapid amplitude modulations contained in a signal (15 – 300 Hz).



$$R = cal \cdot \int_{0}^{24\,Bark} f_{mod} \cdot \Delta L \cdot dz$$

Figure 4. Roughness representation.

- *Fluctuation Strength:* quantifies the subjective perception of the slow amplitude modulations contained in a signal (~20Hz), presenting the maximum sensitivity at 4 Hz. It will be given by the following expression:

$$F = \frac{0.008 \cdot \int_0^{24\,Bark} \Delta L \cdot dz}{\frac{f_{mod}}{4} + \frac{4}{f_{mod}}}$$

RESULTS

Subjective Test

From the tests performed with production personnel, the following defects are detected in the samples by means of subjective methods:

Defect	Description
Vibration Level	High vibration level.
Scraping Noise	Dirty sound, like sand scraping.
Impact Noise	Impulsive noise apparition
Discontinuity	Discontinuous vibration. Fluctuating signal.

Table 1. Subjective defects catalogue.

Defect Signals

Each defect listed in the above table will be associated to a particular type of signal such as shown in the following figures:

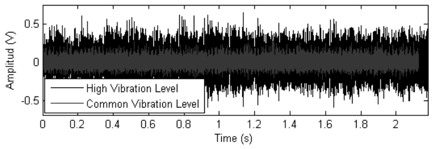


Figure 5. High vibration level signal.

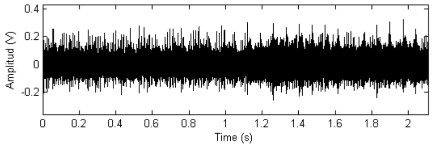


Figure 6. Scraping noise signal.

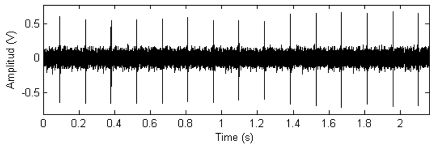


Figure 7. Impulsive noise signal.

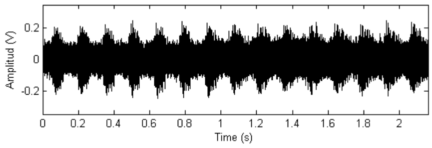


Figure 8. Discontinuous vibration signal.

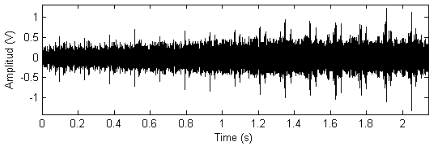


Figure 9. Low frequency modulated signal.

Vibration Measurement for Correct Samples

Next figures represent the results obtained for each proposed parameter from the samples analysis done.

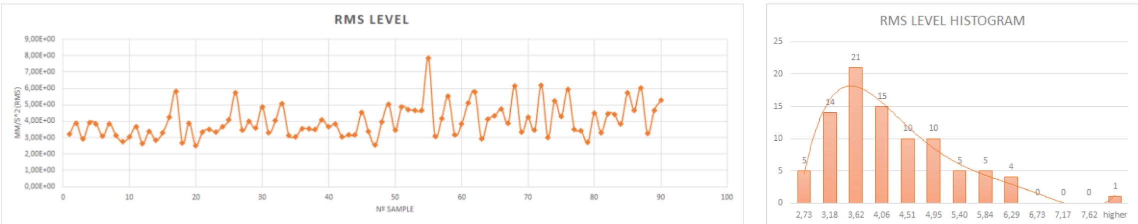


Figure 10. RMS Level. Gearhead with no load.

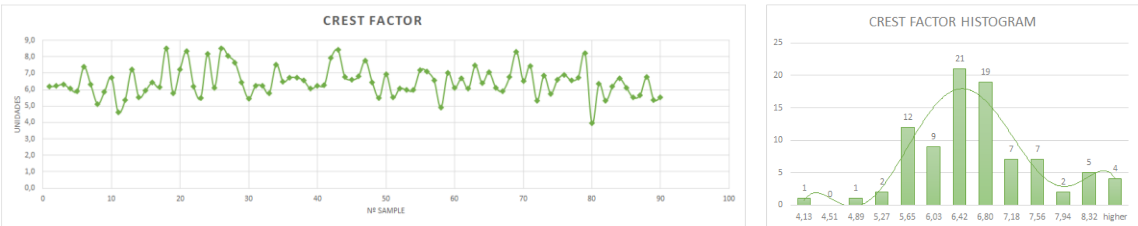


Figure 11. Crest Factor values. Gearhead with no load.

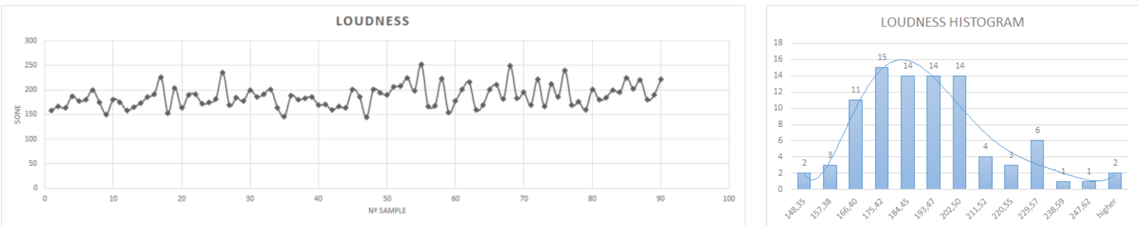


Figure 12. Loudness values. Gearhead with no load.

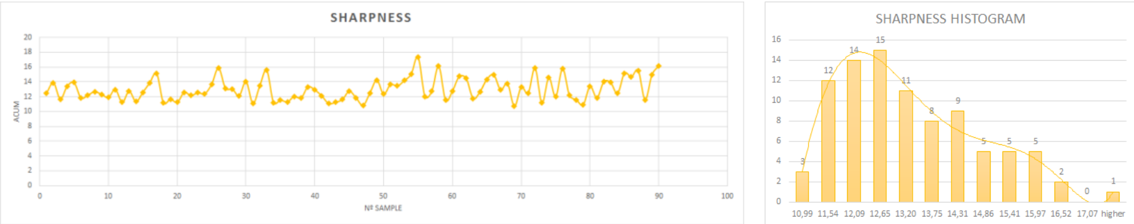


Figure 13. Sharpness values. Gearhead with no load.

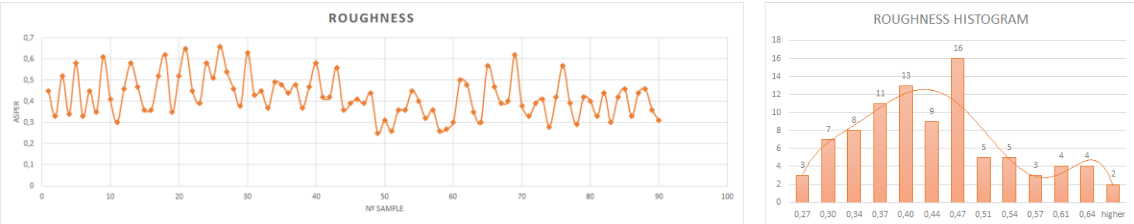


Figure 14. Roughness values. Gearhead with no load.

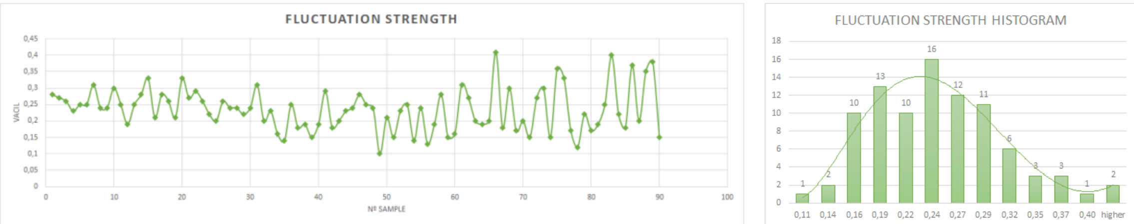


Figure 15. Fluctuation Strength values. Gearhead with no load.

The representation of the results in a histogram form results in a Gaussian distribution in most parameters. The definition of statistical unequivocally makes possible the delimitation of values in which the correct samples will range.

			PSYCHOACOUSTIC PARAMETERS			
STATISTIC	**RMS Level**	**Crest Factor**	**Loudness**	**Roughness**	**Sharpness**	**Fluctuation Strength**
Mean	4,00E+00	6,48	186,78	0,42	13,00	0,24
Median	3,83E+00	6,37	184,23	0,42	12,67	0,24
Mode	3,89E+00	6,18	174,11	0,36	11,84	0,25
Percentile 95%	5,99E+00	8,32	230,11	0,62	15,87	0,36
Percentile 90%	5,70E+00	7,92	221,69	0,58	15,18	0,33
Standard Deviation	1,01E+00	0,90	22,99	0,10	1,50	0,06
Minimum Value	2,51E+00	3,94	143,84	0,25	10,71	0,10
Maximum Value	7,84E+00	8,51	252,13	0,66	17,35	0,41

Table 2. Statistic parameters. Gearhead with no load.

In order to establish margins to ensure a maximum defects detection, the 95% percentile is set as the boundary value for the gap between correct and defective elements.

Comparison between Correct and Defective Samples

From the characterization of the right samples and the measures realized on defective items, it is possible to establish a comparison observing the behaviour of the psychoacoustic parameters in each case. The results obtained are shown:

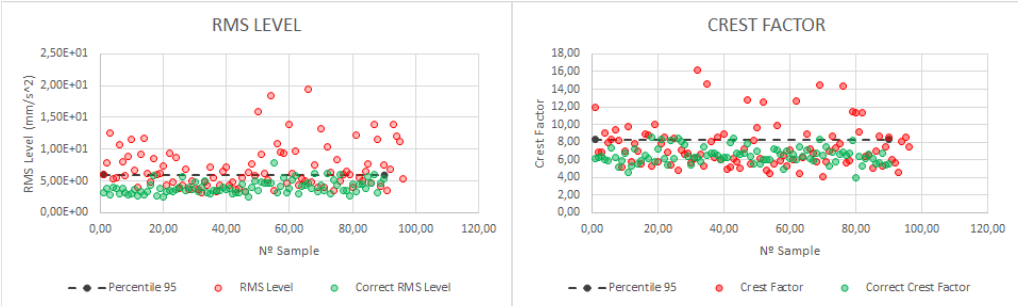


Figure 16. Comparison Correct/Defective Gearhead. RMS Level and Crest Factor.

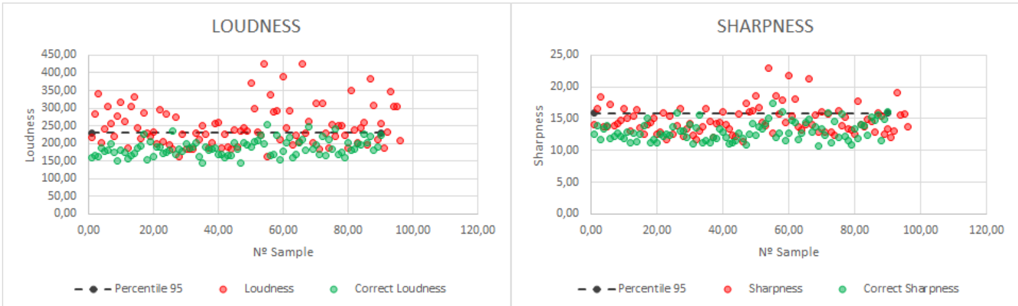


Figure 17. Comparison Correct/Defective Gearhead. Loudness and Sharpness.

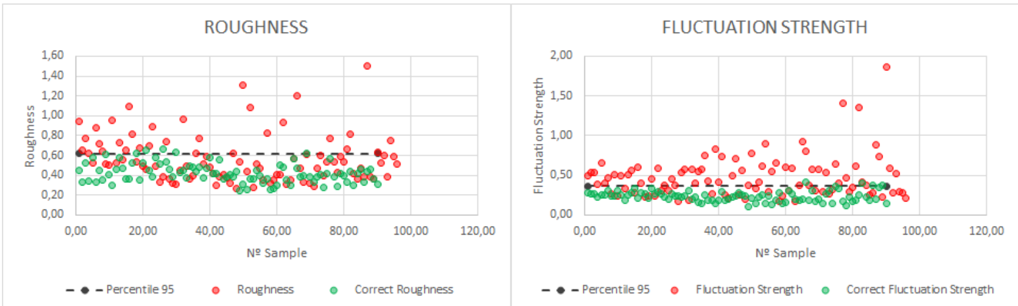


Figure 18. Comparison Correct/Defective Gearhead. Roughness and Fluctuation Strength.

The above figures show in green those items which performance is framed within the standards set by the subjective analysis. Red dots represent the samples with a lower quality specification.

Those samples whose behaviour is considered defective provide values above the range set by the 95% percentile. The most indicative parameter for each defect is defined in the following table:

Parameter	Associated Defect
RMS Level	High vibration level
Crest Factor	Impact noise
Loudness	High vibration level
Roughness	Discontinuity/Impact Noise
Fluctuation Strength	Discontinuity/Fluctuation

Table 3. Significant parameters.

Therefore, each defect identified subjectively has its correspondence in a psychoacoustic parameter. Likewise, all of them can be associated to the failure of a particular component into the machinery, being able to identify problems such as imbalances or breaks as indicative way.

Parameters like Crest Factor can be visualized more clearly in a time-frequency analysis. Vertical lines in the representation correspond to impulsive signals, identified as tapping on the subjective analysis of the samples. The following figure shows an example for this type of depiction.

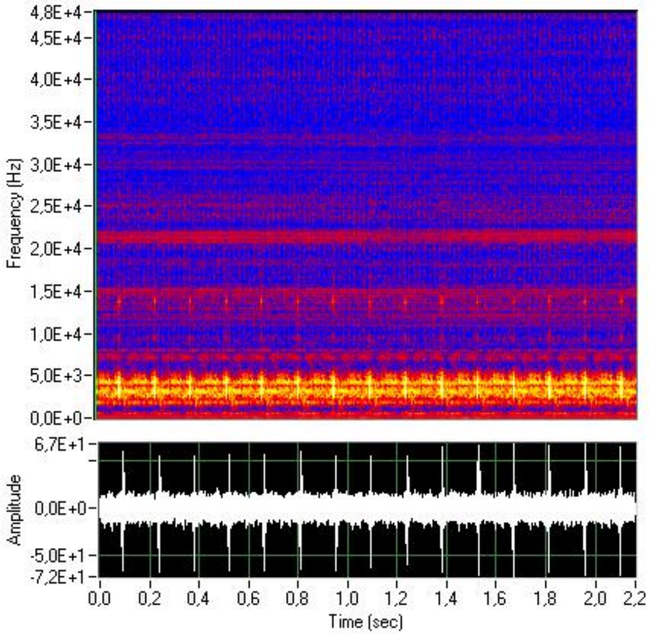


Figure 19. Time-frequency representation.

CONCLUSIONS

From the analysis carried out, a high correlation is obtained between the subjective perception of certain noises and the values provided by classical psychoacoustic parameters used on vibration signal. Subjective defects such as discontinuities are present in the vibration signal as modulation, being easily identified by the roughness or fluctuation strength. Thus, the use of psychoacoustic parameters provides a useful tool in the quality control of electrical motors and machinery.

Note the importance of rigorously establishing a measuring point to carry out the measures. The suitability of this point ensures the achievement of satisfactory results.

Similarly, the selection of the type of transducer is extremely important in the process. The existence of defects associated with very low frequency components makes the assay particularly sensitive to noise.

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[3] “An Introduction to Sound Quality Testing”. University of Salford. Manchester.