Evaluation of the influence of various dispersions on acoustical perception using experiment designs

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Introduction

Some previous studies [1] showed that mechanical variabilities could have a critical impact on structural and acoustical characteristics of an industrial object.

The aim of this study was to know if these variabilities could have an influence on the perception of sounds and how that influence could be measured.

To evaluate the influence of relevant dispersions with a relative low number of measurements, experimental designs were used. The underlying goal was to determine whether this approach, already improved for the understanding of vibro-acoustic data [2], could be consistent with the analysis of perceptive data and could generate a reliable tool for perceptive tests.

Method

Experimental setup

The test bench used for this study was an electric machine on which dispersions, caused by typical defects of rotating machines, were simulated. Six parameters, considered as relevant ones and taking three levels each, were selected:

A: Axial misalignment	D: Outer ring inclination
B: Distance between gears	E: Dynamic unbalance
C: Angular misalignment	F: Magnetic brake torque

This gave 729 different possibilities for the test bench. Experiment designs were used, according to Taguchi's tables, in order to quantify the effects of each factor with a low number of measurements. Assuming that there was no interaction between factors, the L_{18} table, as referenced by Taguchi [3], should enable to know all the effects with only 18 measurements.

Measurement procedure

The noise stemmed from the test bench was recorded using an acoustic dummy head (see Figure 1). According to this scheme, all sounds from the experiment design plus 4 additional validation sounds had to be recorded.

Perceptive tests

The task of the listeners was to evaluate the dissimilarity between each sound and a reference one, for which the 6 controlled factors were left at level 1, corresponding to the nominal state of the bench. 30 listeners were involved in this test.

Figure 1: Acoustic dummy head placed near the test bench in order to record the 18 samples according to the experiment table.

Data analysis

Each sound was given a "dissimilarity score", which corresponded to the mean value of the listeners answers. The lowest it was, the more the sound was perceived as similar to the reference. As shown on figure 2, the low standard deviation excluded the hypothesis of sub-samples within the panel and allowed to process the mean values.

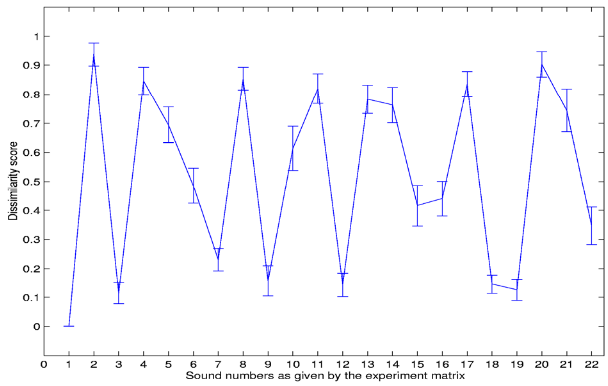

Figure 2: Dissimilarity scores in their 95 % confidence interval for the 22 tested sounds (1 to 18 according to the table and 19 to 22 for validation).

An analysis of variance gave the following contributions for each factor:

A	B	C	D	E	F
10,32%	51,47%	0,42%	6,22%	2,34%	10,28%

Table 1: Factors Contribution to the total variance.

Obviously some factors had much more influence than others. B contributed to more than 50% of the total variance, while a strong part (18,93%) remained unexplained.

Since factors were considered as independant, the theoretical score of any factors combination could be recomputed using the following additive model:

$$Dissimilarity\ score = \bar{M}_{1\to 18} + E_A + E_B + \ldots + E_F \quad (1)$$

Where $\bar{M}_{1\to 18}$ was the overall average dissimilarity score for sounds 1 to 18. E_A, E_B, etc... were the corresponding factors effects for the desired configuration.

First results and discussion

The additional sounds, that were not used to process data, would then allow to evaluate the accuracy of the model described by equation 1 and to confirm if this method could be a reliable one for prediction or not.

Knowing the recording configuration for those measurements, the theoretical score was recomputed and compared to the one given by the panel of listeners. It appeared that the validation was unsuccessful, which proved that the hypothesis of independence between factors was wrong.

Seek for interactions

According to the procedure described in [4], a cross-analysis of variance was done to find out significant interactions between factors.

Two interactions with significant effects were so highlighted, between A and E and between B and F.

The relevance ratio of those interactions was given by the tabulated test variable F.

Quantification of interactions

Following the same scheme as previously, recordings, perceptive tests and data processing were carried out in order to obtain the effects of those interactions on listeners' answers.

First of all, the need was to design new experiment matrices to limit the necessary measurements. Two L_9 tables, enabling to quantify an interaction between two 3-level factors [3], were chosen. Again, four additionnal sounds were recorded for later validation, completing the sample up to 22 sounds.

Once the effects of the interactions were known, it was only necessary to add them to the previous model to take these interactions into account.

$$Dissimilarity\ score = \bar{M}_{1\to 18} + E_A + E_B + \ldots$$
$$\ldots + E_{AE} + E_{BF} \quad (2)$$

E_{AE} and E_{BF} were, as described previously, the effects of interactions in the corresponding configuration of the test bench.

Final validation

As done previously, the dissimilarity score of each additional sound was recomputed using equation 2 and compared to the listeners' answers.

In this case the measured and computed values were very close to one another, and the validation was in concordance with the confidence interval of the measurements.

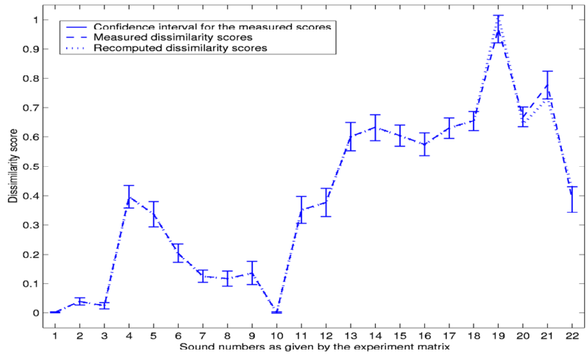

Figure 3: Dissimilarity scores in their 95 % confidence interval and recomputed scores (19 to 22 are additional sounds).

Assuming that the predicted results were accurate enough, it was concluded that no other effect or interaction took any significant part in the response. The model for the dissimilarity score was then satisfyingly described.

Summary

Experiment designs allowed to quantify all effects taking part in the sensation of dissimilarity related to the evaluated object with only a few measurements. This method has been very helpfull to reduce the number of measurements needed for perceptive studies and can constitute a reliable tool for predictions.

The weakness of this method is that it doesn't give any continuous representation of the factors' effects. Effects are clearly known at each level, but many assumptions remain about what happens between two consecutive levels. The other restriction inherent to this approach is to have a small number of controlled factors and clearly identified interactions.

References

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