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Influence of structural variability upon sound perception: Usefulness of fractional factorial designs

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Abstract

The present paper introduces an efficient and time-saving approach for the evaluation of the consequences of structural uncertainties on sound perception. Its aim is to validate the use of fractional factorial designs for perceptual assessment of a model system. A test bench was used, which allowed to accurately control the variability of several structural design parameters. Sounds emitted by the bench were recorded with a dummy head and submitted to listeners during two experiments, in which they had to evaluate the dissimilarity of each sound to a reference, representing the nominal state of the device. In the first experiment, six factors, assumed to be independent, were used to define a fractional factorial design. As an analysis of variance showed that two interactions between factors should have been taken into account, a second experimental design was developed to quantify these interactions. These two experiments allowed to define an accurate model of sound perception, describing the effect of each factor on the perceived dissimilarity. Thus, it was possible to relate the variability of the structure to the perception of the sound emitted with few experimental effort.

Keywords: Structural uncertainties; Sound perception; Fractional factorial designs; Taguchi tables; Listening test; Dissimilarity

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1. Introduction

Because of mechanical variability affecting its structure, an object resulting from an industrial production can exhibit considerable variability in its vibratory and acoustical behavior [1–4]. For instance, Bernhard and Kompella [1] showed that, on a large panel of cars, the frequency response functions due to air-borne and structure-borne excitations could exhibit non-negligible amplitude fluctuations and resonance frequencies shifts.

The general problem is to determine whether structural dispersions may also give rise to perceptual dispersions. In other words, can the perception of the sound emitted by an object be significantly modified by variability affecting its structure? Even though consequences of uncertainties on the radiated sound have been studied [3,4] and can be objectively predicted, it is not yet possible to link the consequences of these uncertainties to the perceptual aspect. The aim of this paper is to present a tool to evaluate the acoustical outcomes of structural uncertainties on sound perception.

It might be assumed that the knowledge of just noticeable differences (JNDs) should allow to predict that influence. JNDs are the perceptual thresholds above which a listener can perceive a variation of a sound feature. However, though the loudness' JNDs are well known (see [5] for a review on the topic), this is not the case for some other psychoacoustic metrics such as roughness and fluctuation strength. Moreover, it is not possible to predict the sound features that will be used by listeners to evaluate differences between complex sounds. The knowledge of JNDs alone does not provide information about the type of indicators that are used to differentiate stimuli. But they provide complementary information about the possible relevancy of the psychoacoustic metrics used by listeners for the differentiation task.

Therefore, the only way of measuring a small perceptual difference between complex sounds is an adequate listening test. In order to obtain statistically significant results, studies about structural uncertainties generally involve a large number of recordings. As an example, in [1], the sample group was composed of 99 cars. For a perceptual study, such a large number of sounds is far too high. To evaluate the influence of relevant variability parameters with a reasonable number of sounds, efficient fractional factorial designs can be used. In such experimental designs, which are often used in many industrial applications [6,7], several factors are varied simultaneously according to a special experimental layout. The goal is to use a systematic approach for experimentation such that each experiment provides relevant information.

Fractional factorial designs have been used in a lot of studies aiming to improve processes and to spare measurement time [8,9]. However, their main application is the field of physical measurement. Up to now, published studies using fractional factorial designs for perceptual purposes involved a few number of factors [10] and disregarded any possible interaction. In [11], fractional factorial designs have been used to correlate the sound quality of a vacuum cleaner to the spectral content of sounds. If the presence of significant interactions is presumed, full factorial designs are preferred [12]. Fractional factorial designs have not yet been used so far to evaluate the consequences of structural uncertainties on sound perception, which was the main purpose of this study.