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THE FUTURE OF SOUND QUALITY OF THE INTERIOR NOISE OF VEHICLES

K. Genuit

HEAD acoustics GmbH, Ebertstraße 30a, 52134, Herzogenrath, Germany

Tel.: +49-(0)2407-577 20 / Fax: +49-(0)2407-577 99 / Email: klaus.genuit@head-acoustics.de

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ABSTRACT
Working on sound quality requires a multi-dimensional view and fundamental expert knowledge. Although discussing this topic may seem easy, the derivation of suitable descriptors and task-oriented analyses always means a challenge. To simplify the solution process several tools are available described in this paper. It has to be considered that they only support expert's work − but they cannot replace it. In the future, the integration of sound quality evaluation into the development process means an important requirement and includes the need of engineers which can handle the several domains of sound perception. The basics for a better understanding of sound quality were investigated by the EU-project OBELICS (Objective Evaluation of Interior Car Sounds) [10].

1 - INTRODUCTION
For several years the sound quality inside vehicles can be measured by means of binaural recordings and analyses based on psychoacoustic parameters. The subjective classification of the sound quality inside vehicles depends not only on psychoacoustic parameters, but on the personal expectation of the driver, too. That means, two cars with identical psychoacoustic parameters could be classified differently, depending on the listener's personal attitude. For the further development of tools to predict sound quality we have to investigate whether the existing psychoacoustic parameters are suitable to describe the complete signal processing of human hearing. Especially for cars with low loudness levels not only absolute parameters like loudness, roughness and so on are important, but more the dynamic behavior of these parameters depending on rotation, speed and load. A further important question is the design of listening tests to get the right answers with respect to the question for the best sound quality. Furthermore, we have to find solutions for the complete new sound quality inside electric motor driven cars. This will be a great task for the acoustical engineers in the future.
Already in the late seventies a new binaural Artificial Head Measurement System [1] was developed which met the requirements of the automobile industry in terms of measurement technology. In addition to a calibratable Artificial Head Measurement System which is compatible with standard measurement technologies and has transfer characteristics comparable to human hearing, software analysis system with psychoacoustic evaluation is also available. This software permits the analysis of binaural signals regarding physical and psychoacoustic procedures [2]. Moreover, the signals to be analyzed can be simultaneously monitored through headphones and manipulated in the time and frequency domain so that those signal components being responsible for noise annoyance can be found. Thus, parameters relevant to sound quality are determined aurally-accurately.
Especially in complex sound situations with several spatially distributed sound sources, standard, one-channel measurements methods cannot adequately determine sound quality, the acoustic comfort or annoyance of sound events.
Numerous examples show that binaural measurement technology increases the possibilities of evaluating sounds of cars [3, 4]. Nevertheless, there are a lot of questions which are still open. The further development is aiming at finding suitable evaluation algorithms for judgement and at integrating them in the software. The prospects that the most important factors of acoustic judgement can be used for

the objective evaluation are very good. Thus, it will be much easier to precisely define goals than up to now.

2 - ACOUSTIC DEMANDS ON A MODERN CAR

It would be wrong to think that a low noise level is enough to meet the customers' wishes as to comfort. On the contrary! This is because, on the one hand, the noise components are becoming increasingly perceptible due to a reduced noise level. In other words: the quieter a car, the more audible are disturbing individual components. On the other hand, the acoustic demands on different cars are varying. A sports car driver expects a different sound than somebody who wants to buy a limousine for travelling. The requirements which expensive cars have to meet are higher than those more favorable cars have to meet. Conventional measurement and analysis techniques are not able to objectively determine sound comfort. Important elements which influence the subjective impression are masking effects, sound impression, spatial distribution and complex phase relations and are taken into consideration only in a limited way or not at all. Therefore, the subjective judgement is very essential for development. There are, however, some problems.

Firstly, the judgements of the engineers who have to evaluate vary, depending on the form they are in and their states of mind. Secondly, we have an acoustic short-term memory. Noise patterns such as voices of certain persons can be stored over longer periods, but we are not able to store acoustic details. As the changes and steps made during developments can frequently not be reproduced, the engineers are often not sure when judging which leads to wrong decisions.

2.1 - The need of product sound quality

The acoustic characteristics of a product today mean an integral part of product identity. They influence significantly customer's decision. Due to the reached technical state of art the reduction of sound pressure level at consumer products often does not lead to subjectively perceived improvements. For current and future needs the product sound must act as a criterion for distinction that supports the positive image of a product. In this context the following characteristics of sound are useful:

- sound is informative, it includes information of quality, functionality, etc.
- sound implies a certain image, such as luxury, sportive or cheap
- sound may identify similar to the optical impression.

2.2 - The attempt of sound quality definition

Sound quality can be defined as the degree to which the totality of the individual requirements made on an auditory event are met. Acoustic quality comprises three different kinds of influencing variables: physical (sound field), psychoacoustic (auditory perception), and psychological (auditory evaluation) [5] and therefore is a multidimensional task. Physical and psychoacoustic measurement procedures alone do not allow a general and unequivocal definition of acoustic quality. This is because listeners primarily classify perceived auditory events in terms of their experience, expectations and subjective attitudes. Although the term "noise" has been clearly defined in DIN 1320 ("Noise is sound occurring within the frequency range of human hearing which disturbs silence or an intended sound perception and results in annoyance or endangers the health"), no such type of definition can be given for the term "sound quality" or "acoustic quality".

2.3 - Sound quality perception

The perception of sound (quality) includes several domains as represented in fig. 1. The physical and psychoacoustical domain may be described more or less by using known analysis methods. Amongst others these are sound pressure level, loudness, roughness, sharpness and so on. The design domain implies that the sound must agree with products characteristics. If for example the main product characteristic is solidity, high sharpness values normally will not correspond with this product.

Another domain that has to be considered is the cognitive one. It is the most difficult with respect to objective analysis. Our attitude to particular sounds depends on the situation in which we hear it. Two sounds of exactly the same physical shape may cause total different judgement for the same listener depending on the situation.

2.4 - Requirements for product sound quality

There exists a certain relation between sound quality, subjective noise judgement and the individual expectation as represented in fig. 2: If the subjective judgement is better than the individual expectation then the customer is very satisfied, meaning a high sound quality is realised. Obviously, this can be

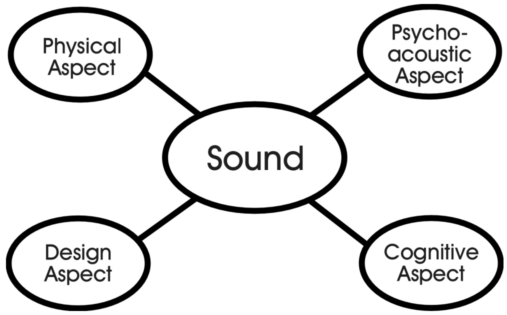

Figure 1: Domains of sound quality perception.

transferred for the opposite case: If customer's expectation is higher than the subjective judgement than the resulting sound quality is poor.

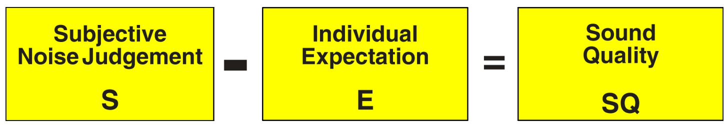

Figure 2: Relation between sound quality, subjective judgement and individual expectation [6].

Product sound quality has to consider customer's expectations as described above. If he wants to drive a sportive car it does not make sense to realise a sound design that is suitable for an upper range family car. Or: If the customer wants to buy a powerful washing machine, any high frequent operation noises should be avoided. Finally, product sound quality has to consider the influence on the environment. That means, it has to correspond not only with the expectation of the customer but of those peoples being exposed to the product. This is probably important with respect to vehicles due to their social context: Sportive cars and sportive sound primarily based on high loudness levels and booming noise probably will embarrass citizens of a city. Here, a more restrained sound characteristic giving the driver the feedback of high performance during acceleration phases may be more suitable. The task of acoustical engineers is to find the best solution for the requirements by manufacturers, customers and society.

3 - METHODS FOR DESCRIPTION AND EVALUATION OF SOUND QUALITY

In the following jury testing, the derivation of sound quality descriptors and the set-up of sound libraries will be described. This gives only an overview of possible methods. It does not claim to be complete, but includes most of the proceeding used in engineering practice.

3.1 - Jury testing

Paired comparison tests often are used to receive a ranking of the sounds under investigation. Here, two selected samples are compared with each other step by step until each sample was compared to all others. This test method allows a reliable decision about ranking. With respect to sound quality it shows some disadvantages: We normally do not judge the sound quality of one product directly compared to another, but we derive a judgement based on our overall acoustical impression. This fact can not be represented by A/B tests [7].

3.2 - The integration of vibration simulation

Realism of virtual environments can be significantly enhanced by the integration of feedback channels not addressing the ears, but the whole body [8]: very low frequency airborne sound as well as structure vibration. For that purpose the binaural technology as described above has to be extended. Examinations have shown a trade-off phenomena between sound and vibration when the vibration level is in the range of perception threshold: The loudness is judged higher when vibrations are present in this case [9]. The experience when dealing with complaints in vehicles have shown that normally the consideration of vibrations at passenger's seat and of the rotational vibrations at the steering wheel is sufficient for a first approach. The mentioned vibrations represent the major part of relevant influences for the judgement.
Introductory research tests within the European research project OBELICS (BRPR CT96-0242) [10] have shown that the use of combined vibroacoustic playback systems leads to more reliable judgements of sound characteristics and sound quality. Based on this, a suitable vibro-acoustical playback system

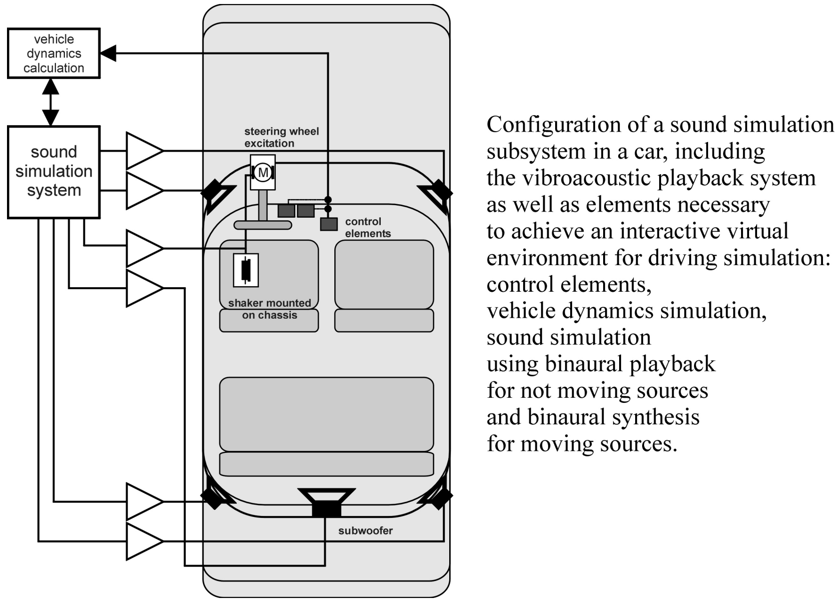

Figure 3: Sound simulation subsystem.

may consist of airborne sound via head phone(s), low frequent sound (20 - 150 Hz) via subwoofer(s), and vibrations at steering wheel and seat via excitation devices. The set-up of such a system is shown in fig. 3.
The main advantages of the "SoundCar" are:

- playback of a combined vibro acoustical situation in a realistic environment;
- comparison of several vibro-acoustical situations without time delays;
- a fast and cost saving judgement that is more reliable.

3.3 - Sound quality descriptors
The acoustic world mostly asks for a single-value descriptor for sound quality that may be handled at least as easy as the A-weighted sound pressure level, describes SQ sufficiently and can be used "globally". The problem is that normally neither the term "SQ" nor the characteristics that have to be described are defined precisely in advance. Additionally, the global definition of a sound quality descriptor is not possible because the judgement of sound quality is amongst others context-sensitive and includes cognitive aspects.
One possible proceeding is shown in fig. 4. The sound event under investigation is analysed objectively using conventional or advanced analysis technique. The most important issue in this context is to represent visually the main characteristics of the sound. That means for example that an average FFT is not sufficient if the sound event consists of a temporally structured signal (i.e. rattle noise). By filtering annoying or characteristic signal components and correlating them with the subjective judgement it is possible to select the relevant ones and to create for example a time-dependent level curve as target. This may be used as a suitable descriptor for the sound quality of one particular product.

3.4 - Sound libraries
As mentioned before, the term sound quality often stays diffuse. The same is valid for the use of verbal descriptions for sound events. Examples are shown in fig. 5. The term "rattling" may mean two different sounds for two different people. It is also possible that for other sounds exists no verbal description. These issues are background for the creation of sound libraries. Such libraries enable the involved partners to talk in the same (acoustical) language, to determine unambiguously annoying noise shares, to describe evaluation characteristics and in consequence to work in a task-orientated way on acoustic solutions using the available resources efficiently.
A suitable set-up of such a library should consist at least of

- a survey of sound recordings with work descriptions,

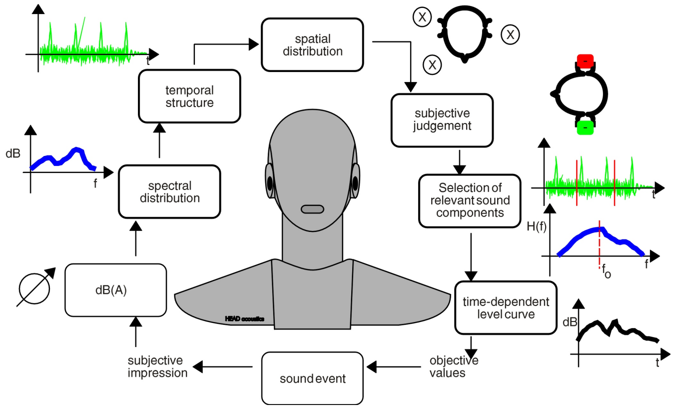

Figure 4: Proceeding for the objectivation of subjective judgement.

Figure 5: Some verbal descriptors of sound events.

- a description of operational conditions at which the sound event appears,
- description of sound characteristics and suitable analysis methods
- links to theoretical knowledge.

If such a library is accepted it simplifies the work on sound quality.

REFERENCES

1. **K. Genuit**, A special calibratable Artificial-Head-Measurement-System for subjective and objective Classification of Noise, In *Inter-Noise*, pp. 1313-1318, 1986

2. **K. Genuit**, Investigation and Simulation of vehicle noise using the binaural measurement technique, In *SAE*, pp. 97-104, 1987

3. **K. Genuit, H.W. Gierlich**, Investigation of the Correlation between objective noise measurement and subjective Classification, In *SAE*, pp. 295-303, 1989

4. **K. Genuit, E. David**, A new method for determining the subjective effects of sounds and vibration using on objective procedure, In *SAE*, 1993

5. **K. Genuit**, Binaural Technique for the objective measurement of subjectively perceived sound quality, In *Noise-Con* , 1991

6. **K. Genuit, J. Friedlein**, Estimation of car noise quality by using binaural measurement technology, In *Noise* , 1993

7. **K. Genuit**, Objective Evaluation of Acoustic-Quality Based on a Relative Approach, In *Inter-Noise*, 1996

8. **K. Genuit, J. Poggenburg**, The Influence of Vibrations on the Subjective Judgement of Vehicle's Interior Noise, In *Noise-Con*, 1998

9. **W. Krebber, H.W. Gierlich, K. Genuit**, Virtual Acoustic Environments: Basics and Applications for Interactive Simulations, *Signal Processing*, 1999

10. **W. Krebber, M. Adams, F. Brandl, N. Chouard, K. Genuit, T. Hempel, R. v. Hofe, G. Irato, P. v. d. Ponseele, B. Saint.Loubry, B. Schulte-Fortkamp, R. Sottek, R. Weber**, Objective Evaluation of Interior Car Sound - the OBELICS project, In *DAGA*, 2000