PSYCHOACOUSTICS – IMPORTANCE AND APPLICATION IN PRACTICE

PACS REFERENCE: 43.66 Yw

Genuit, Klaus
HEAD acoustics GmbH
Ebertstrasse 30a
52134 Herzogenrath
Germany
Tel.: +49-2407-577 20
Fax: +49-2407-577 99
E-mail: klaus.genuit@head-acoustics.de

ABSTRACT

Psychoacoustics deals with the perception of acoustic noise by the human hearing. For more than 20 years the main practical applications of psychoacoustic perceptions have been located in the range of the automotive industry, and here in particular in the analysis of vehicle internal sound. However, investigations of environmental and employment noises in the viewpoint of psychoacoustics are at least of equal importance. Due to its acoustic energy, noise may not only directly damage the human ear, but in most cases it indirectly provokes by means of certain temporal structures and spectral distributions an annoyance, which cannot be answered without any knowledge in psychoacoustics in combination with the cognitive context.

INTRODUCTION

At present time, customers often do not differentiate products because of their technical specifications but because of the implied association. In this context, the terms „sound quality" or „sound design" are used more and more in acoustical engineering. This paper not only gives a kind of definition that can be used for industrial purposes. It also describes a suitable measurement and analysis technology.

The first question is: How does noise talk to us?

a) Noise is informative, that means it gives the listener information about quality, functionality, danger and other environment.
b) Noise implies a certain image of the product maybe luxury, sportive, sheep and so on.
c) Noise may identify the product similar to the optical impression.

That means a corporate sound of a product fits to the expectation to the listener.

The second is: What kind of tasks are related to the psychoacoustics?

a) The description of the perception of sound events how does the hearing perceive sound, what kind of analysis we should use comparable to the human inner-ear and what kind of signal processing and sound evaluation are be done by the human hearing?
b) To get an objective description of subjective perceived sound quality.
c) Describe the transformation of a sound event into a hearing event.

BINAURAL MEASUREMENT TECHNOLOGY AND PSYCHOACOUSTICS

Aurally-equivalent sound measurement technology is concerned with objectively definable parameters that relate to human perception. Evaluation of a sound event by the "communications receiver" in human hearing is influenced by numerous parameters [1]. A sound event cannot be evaluated on the basis of a single dimension. Level is one of numerous parameters which play a part in the evaluation of a sound event by a person. These parameters are basically of two kinds: subjective (psychological) and objective (physical and psycho-acoustic).

Regulations for fixing noise levels are based on A-weighted SPL measurements obtained using a single microphone only. Such a simple measurement procedure has limited utility for quantifying the annoyance in sound events or even sound quality in general. For many years A-weighted SPL measurement has been used to estimate the psychoacoustic parameter of loudness. A loudness measurement which takes better account of the spectral and temporal structure of a sound event than the A-weighted SPL has been shown to have advantages. However, loudness has not been universally successful for quantifying sound quality. This is because complex sound events evaluated by loudness measurement equipment are not easily compared with the evaluations made by the human ear.

The difference can be explained by the evaluation of sound signals in the hearing process. While evaluations by means of conventional acoustic measuring techniques are made with simple A-weighting, human hearing has more complicated level-dependent evaluation mechanisms. A sound impression is not only determined by the sound pressure level, but also by psychoacoustic parameters, such as loudness, sharpness and roughness, and further parameters. Due to the so-called pre-, post- and simultaneous masking effects of human hearing, different sound impressions may be created at the same A-weighted sound pressure level, depending on the temporal order of the signals and their spectral distribution.

The measurement procedure for loudness takes into account the distribution of critical bands in human hearing. Thus, the masking effects and tonal components of a sound can be registered better. Loudness not only depends on the sound pressure level, but also on the spectral composition of the sound. The measurement of loudness (unit: sone) is a considerable step towards human hearing equivalent sound measurement. Sharpness (unit: acum) depends on the spectral composition. A sound is judged to be sharper and thus more annoying if the high-frequency spectral components are more prominent than low-frequency ones. Roughness (unit: asper) or fluctuation (unit: vacil) of signals with strong temporal structure are caused by amplitude and frequency modulations, i.e. fast changes in level and frequency. Due to the filtering properties of the outer ear, each change in frequency simultaneously results in a more or less strong change in amplitude.

Another characteristic of the human hearing are two auditory channels. It allows spatial discrimination essential for pattern recognition in conjunction with directional hearing, selectivity and suppression of noise. In a complex sound situation with various spatially distributed sound sources radiating different signals with the same acoustic power, the elimination of a single sound source leads to a very insignificant reduction of level as measured with a single microphone. In contrast, human binaural hearing is able to perceive considerable changes, depending on the temporal structures of the signals. This binaural signal processing is essential for everyday life, for example, speech communication in a noisy environment is only possible through binaural signal processing.

Prior to introduction of binaural measurement technology, almost all acoustic measuring technology consisted only of single-channel sound event analysis in which measurements were carried out using a single microphone with a spherical directional pattern. Aural evaluation of sound events changes however, when there are several sound sources and when the ear is exposed to sound from several different directions. If each signal source would emit correlation signals of opposite phase from a position exactly geometrically symmetrical with respect to the center point, they would cancel each other and no sound pressure level would be measurable. Due to the spatial separation between the ears at the human head and the resulting interaural level and phase differences, human hearing perceives only slight attenuation of low-frequency components, while the high-frequency spectral components impact the human ear almost uncorrelated. For frequencies above 300 Hz, therefore, no further difference is measurable. Whether the signals are emitted in opposite or simultaneous phase, the sound pressure level remains unchanged. The psychoacoustic effects such as simultaneous, pre- and postmasking change when the masker and the signal to be masked are located at different angles of incidence to the ear.

Human hearing is a highly sensitive system, but has only a limited longtime memory. Consequently, when human hearing has experienced a sound event judged to be unpleasant and annoying, these parameters will continue to obtain, even when the noise is reduced by 2 or 3 dB or even more. When human hearing has been sensitized with respect to a given sound event pattern, it is not able to make an objective evaluation when the sound quality or noise component as a whole is modified. In consequence, for the classification of sound not only have to be considered the sound pressure level and psychoacoustic parameters, but also the duration of exposure, the spectral composition, the time structure and also the number and spatial distribution of the sound sources. Aurally-equivalent sound measuring technology is therefore not an alternative to, but an important extension of existing sound measurement techniques. In complex sound situations, which cannot be defined in terms of A-weighted sound pressure level alone, aurally-equivalent measurements can be used for gathering additional data, necessary for an objective evaluation of the sound event. It became obvious that a human hearing equivalent analysis of sound quality of noise is only possible if all properties of human hearing are taken into consideration. An Artificial Head measurement system is needed having transfer functions comparable to human hearing. The analyzer is not just a simple 1/3-octave or fast Fourier transform analyzer, but an analyzer with high resolution in the time and frequency domains and with a high dynamic range comparable to human hearing.

The problem of human hearing equivalent sound evaluation described here have been known for a long time. The dB(A) measurement has been used since 1950 - first because it could be made relatively simple and second because confusion resulting from different measurement procedures could be avoided. Forty years ago the ISO and the predecessor to ANSI did standardize the dB(A) measurement, while indicating that a human hearing equivalent measurement procedure needed standardization.

The completely known psychoacoustic measurement procedures [2], in particular the loudness meter, were not completely satisfactory since they only took into account a part of human hearing equivalent sound analysis. Because binaural signal processing was neglected, there were often doubts as to whether simple loudness based on recordings with one microphone produced better results than measurements of the A-weighted sound pressure level. Now, the results obtained through aurally-adequate binaural measurement technology provide significant improvements in the ability to produce measurements appropriate to sound quality evaluation and engineering. The combining of these techniques with simultaneous capture and analysis of mechanical or other information about the system, adds more capability for refining the task of efficiently and economically improving product sound quality.

THE MEANING OF SOUND QUALITY

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) and therefore is a multidimensional task as shown in Fig. 1. 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“.

A sound event can create an unpleasant impression without impairing the auditory faculty or being experienced as noise. However, in general it can be said that acoustic quality is negative when the sound event produces an auditory event perceived as unpleasant, annoying or disturbing, it implies negative associations, or it is incompatible with the product. On the other hand, acoustic quality is positive if a sound is no longer perceived as an auditory event (or at least not a disturbing one), produces a pleasant sound impression, or creates positive associations in relation to the product.

A good example for the importance of sound quality is the automotive industry. 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 traveling. The requirements which expensive cars have to meet are higher than those more favorable cars have to meet [3].

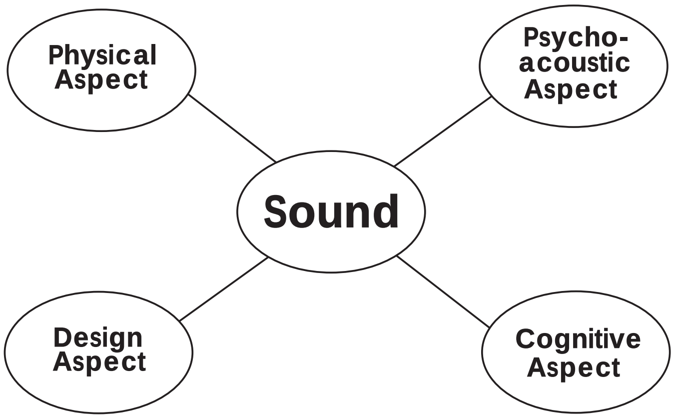

Fig. 1.- The multidimensional character of sound events

As mentioned before, human hearing functions adaptively, i.e. cannot determine absolute measurement values in the same way as an acoustic measuring device. It detects patterns while simultaneously considerably reducing the data received. If certain patterns result in a negative evaluation of acoustic quality, to a certain extent this evaluation is independent of absolute level or absolute loudness as proved if the same sound is listened to again later but with only the level modified. This situation results in special problems involved in carrying out auditory A/B comparison tests. Because of the way human auditory short-term memory functions, in a direct A/B comparison auditory test human hearing is able to detect the slightest differences between two sound events in terms of loudness or A-weighted SPL. However, if there is a relatively long lapse of time between listening to two recordings, the human ear is only able to identify if the patterns are different. If sound events are similar in terms of their temporal structures and spectral patterns and are only different in relation to absolute level or absolute loudness, the human ear is almost completely unable to detect slight differences. Particularly with regard to investigations regarding acoustic quality, the absolute variable, loudness or A-weighted SPL, is almost without significance.

On the basis of these considerations, a procedure has been developed which [4], in addition to the existing psychoacoustic variables, is especially appropriate in the aurally-accurate determination of acoustic quality. This objective is achieved by continuous formation of a reference signal from the sound event as an average in the time and frequency domain, thus deriving an appropriate anchor sound from the sound event which can serve as reference for transient spectral or temporal variations in the signal curve. Acoustic quality evaluation in terms of a single value can be determined, for example, by applying the following equation (1).

$$Q = f(N,S) + f\left(\sum_{i=1}^{24}\left[\left|F_G(i-1) - F_G(i)\right| \cdot w_1(i,F_G(i)) + \sum_{n=1}^{T}\left|F_G(i,n) - F_G(i,n+1)\right| \cdot w_2(i,F_G(i))\right]\right) \quad (1)$$

where F_G (i) is a mean value of the critical band level over a period T of 2 to 4 seconds, F_G (0) = F_G (1), F_G (i, n) is a mean value of the critical band level over a much shorter period (approx. 2 msec), n is the current (time-dependent) value. The weighting factors $w_1(i,F_G(i))$, $w_2(i,F_G(i))$

depend on the critical band level F_G (i). The function f describes an auditive factor, dependent on loudness N and sharpness S.

As can be seen from the equation of acoustic quality Q, an analysis of temporal behavior occurs within a critical band and is combined with an analysis of frequency response.

APPLICATION:
COMPARISON AND JUDGEMENT OF NOISE EMITTED BY ANTI-TRACKING CONTROL

The hearing-related comparison of two different anti-tracking control devices installed in the same vehicle resulted in significant hearing-related differences. Initially, these differences were not identifiable, either by conventional broadband SPL measurement or loudness measurement: The "good" device had an A-weighted SPL 1.8 dB higher, was 1.4 sone louder and 0.1 acum sharper.

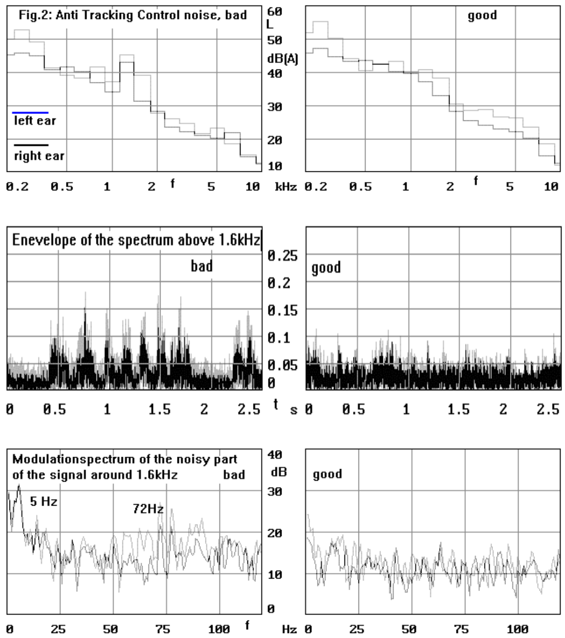

Fig. 2.- Comparison of two anti-tracking control systems built into the same car: Poor acoustic quality, but better dB(A) and loudness (left) for the ”bad” device in comparison with the "good" device (right)

In Fig. 2 the left-hand diagrams relate to the "bad" device, while the right-hand diagrams relate to the "good" one. The diagrams show third-octave analysis (upper), the envelope of the disturbing spectral range around 1400 Hz (middle) and the modulation spectrum (lower), in each case for left and right ear signals recorded at the driver's position. Various analysis procedures, better adapted for identifying temporal structures or tonal components in a sound, make it possible to measure objectively clear differences, which correlate sufficiently well with the subjective sound classification. Alongside kurtosis, tonality and pulse parameters, modulation spectral analysis of the high-pass filtered signals can be seen as particularly meaningful. High-pass filtering is required to eliminate the low-frequency influence, caused for example by the excitation of vehicle wheels, since human hearing also functions selectively. Modulation spectral analysis shows itself to be particularly appropriate in analyzing sound events emitted by small-size electric motors because the rotating excitation produces modulations or periodic excitation of structure resonances. This analysis method, in comparison with roughness analysis, generally makes it easier to draw conclusions about the reasons for negatively evaluated acoustic quality. In the example shown this is caused partly by the characteristic temporal structure with a periodic 5 Hz excitation of a structural resonance around 1400 Hz due to the pump valve, and partly due to modulations with a basic frequency around 72 Hz and corresponding harmonics due to electric drive in operation.

The technique described in formula (1) could now be applied to this sound comparison. Fig. 3 shows a spectrographic display contrasting the variations in both the time and spectral domain in relation to an averaged spectrum for both alternative devices. In the case of the "bad" device, the relevant structures and patterns for acoustic quality are clearly apparent. These are clearly less apparent in the case of the "good" device. This kind of display is independent of the absolute level of loudness and sharpness of the sound event and provides results about the acoustic quality differences from which the conclusions are sufficiently clear, even to the untrained observer.

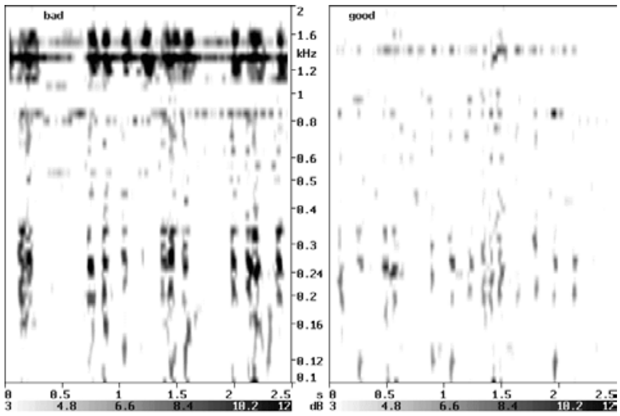

Fig. 3.- Acoustic quality calculation according to equation (1). Left: ”bad” anti tracking control system; right the "good" device.

SUMMARY

Binaural measurement technology and psychoacoustic knowledge have proven their suitability considering the characteristics of human hearing and subjective judgement. For the actual demands by customers referring to product sounds an enlargement of these basics is necessary. Several approaches have been presented that may help acoustic engineers to solve sound quality related tasks and to create a „corporate identity“ or „product identity sound“. On this background it is possible to give a practical meaning to the term „sound quality“ that is not easy to define precisely.

BIBLIOGRAPHICAL REFERENCES

[1] K. Genuit, M. Burkhard;
Subjective Measurement of Noise and Vibration Using Objective Techniques
Zeitschrift Sound & Vibration, Mai 1995, S. 28-34

[2] E. Zwicker, H. Fastl;
“Psychoacoustics, Facts and Models“,
Springer Verlag, Berlin, Heidelberg, New York, 1990

[3] K. Genuit;
Sound Engineering of Vehicle Noise
Inter-Noise’94, 29.-31.08.1994, Yokohama, Japan

[4] K. Genuit;
Objective Evaluation of Acoustic Quality Based on a Relative Approach
Inter-Noise’96, 30.07.-02.08.1996, Liverpool, England