OBJECTIVE EVALUATION OF ACOUSTIC QUALITY BASED ON A RELATIVE APPROACH

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1. INTRODUCTION

Aurally-adequate recording and analysis technology has been available to acoustic engineers working to measure and analyze sound in a way analogous to human hearing since the early eighties. Aurally-adequate measurement technology, using the Artificial Head for recording sound and applying psychoacoustic calculation for analysis, is vital in achieving acoustic quality and good sound design. However, today's acoustic engineers cannot limit themselves to using objective acoustic quality measurement, but also have to take into account users' demands. This means that sound and product must harmonize (design aspect) and meet customers' requirements (cognitive aspect).

Human hearing is able to detect slight differences between two auditory events based on A-B comparison tests. However, in everyday life, the human ear must be able to evaluate acoustic quality directly without reference to a reference sound. Human hearing is not able to analyze a sound event in absolute terms by listening directly to the sound. A sound source classified as annoying because of various attributes in the time and frequency domain will still be evaluated as such even if the sound level is attenuated. Thus, human hearing is not able to take account of absolute level, loudness and so on, but creates its own reference sound image based on the sound event and classifies the sound in relation to this reference sound.

2. A DEFINITION OF ACOUSTIC QUALITY

Acoustic quality is 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).

Interpretation of acoustic quality 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 "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.

3. AN APPROACH FOR DETERMINING ACOUSTIC QUALITY

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. Temporal structures and spectral patterns are more important factors in deciding whether a sound makes an annoying or distrubing impression. On the basis of these considerations, a procedure has been developed which, 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).

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

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.

4. PRACTICE-RELATED EXAMPLE
ELECTRIC MOTOR APPLICATION: 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.

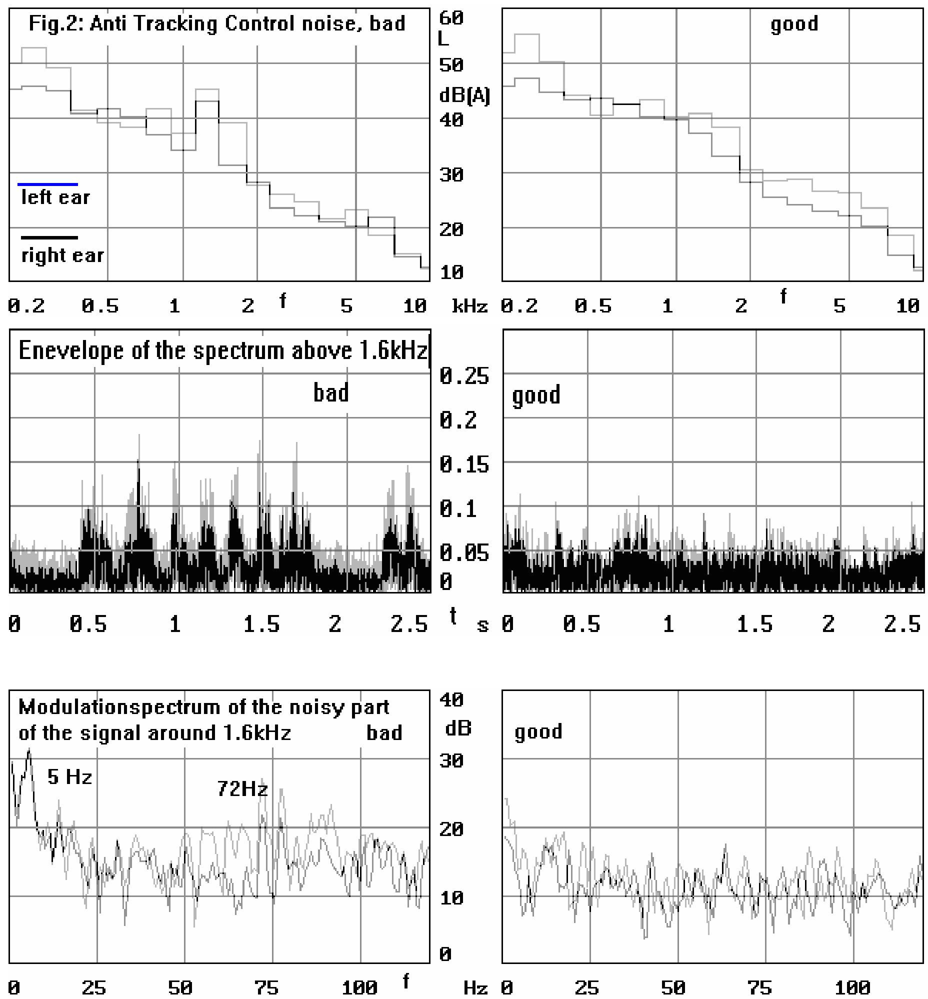

Fig. 1: Comparison of two anti-tracking control systems built into the same car: Poor acoustic quality, but better dB(A) and loudness (left) for the ”bad” device in comparison with the "good" device (right)

In Fig. 1 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 Section 3 could now be applied to this sound comparison. Fig. 2 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.

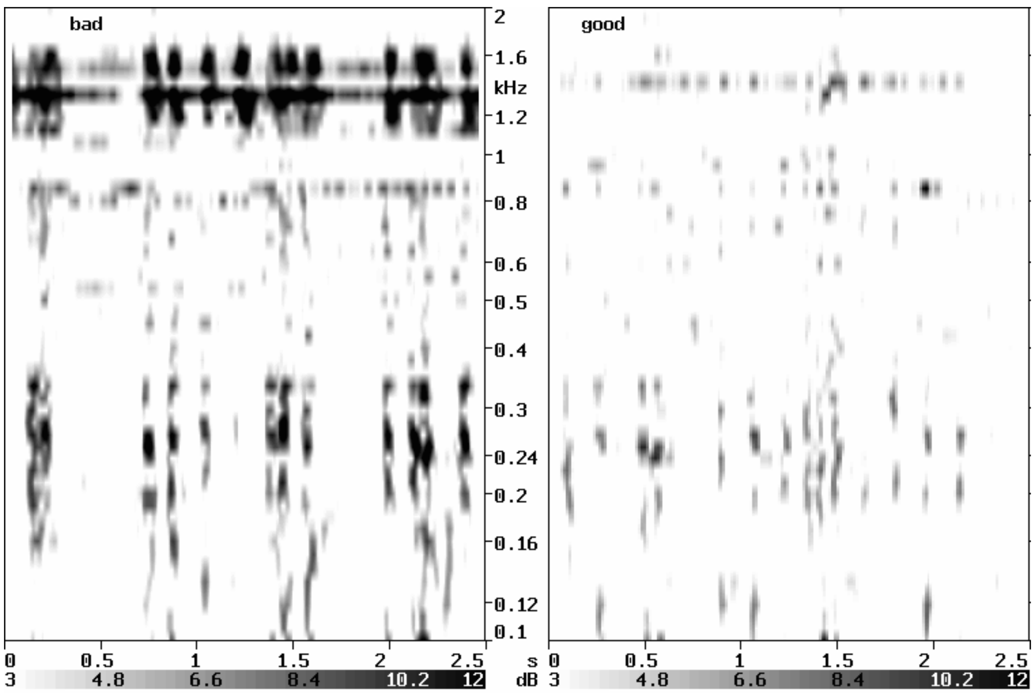

Fig. 2: Acoustic quality calculation according to equation (1). Left: ”bad” anti tracking control system as shown in Fig. 1; right the "good" device.

5. SUMMARY

The acoustic quality of sound events cannot be sufficiently described using basic physical measurement techniques, such as A-weighted SPL determination or third-octave analysis. Moreover, use of the frequently applied psychoacoustic calculation techniques is also limited because of the following disadvantages:

a) The mathematical description of psychoacoustic variables is currently based exclusively on investigations using basic test signals in an anechoic environment. Their application in the case of complex sound situations including spatially distributed sound sources is limited.
b) Currently available psychoacoustic calculation techniques take neither the adaptive behavior of human hearing nor its binaural characteristics into account.
c) A further disadvantage is due to a lack of standardization of psychoacoustic calculation variables, which compromises the comparability of measurement results.

For these reasons a new approach has been developed, based on relative level variations within a given critical band over time, or within a time window in the frequency range related to formation of a sliding mean value. This new approach allows appropriate acoustic quality evaluation analogous to the signal processing encountered in human hearing. The advantage of this technique is that acoustic quality can be determined without reference to a reference sound. Moreover, the technique takes account of the adaptive behavior of the human ear, and also functions on the basis of basic level variables and weighting factors without recourse to currently non-standarized psychoacoustic variables.