The assessment and description of Sound Quality by objective parameters requires tools, which vary in complexity depending on the requirements of the respective problem or situation. Apart from the use of classical psychoacoustic parameters such as loudness or roughness in the description of the Sound Quality of consumer products many product- or problem-oriented quantities have been developed and introduced. Nevertheless, quite often the reference to certain standards is required and advantageous in terms of acceptance of the description. As an example for the objective description of the overall auditory impression the tonal components of sounds can be evaluated applying DIN 45681. This DIN standard for stationary sounds was reviewed and extended also to the application on instationary sounds. In the paper the time-varying tonality is compared to subjective assessments of sounds. Effects of the calculation of tonality applied to different changes of the tonal components in the sounds are discussed. Examples for different types of application are given considering Sound Quality aspects.

A second example is a project with the aim to develop an univocal noise categorization concept for IT-Equipment by using sound power level with additional psychoacoustic-based measurements.

1. INTRODUCTION

The subjective and objective assessment of Sound Quality in psychoacoustics requires quite different categories. General ratings take place in global terms of acceptability (positive) or annoyance (negative). During listening to sounds different test subjects in general give different assessments for their sound impression. Psychoacoustic models taking into account certain characteristics of the hearing system are constructed to describe aspects of Sound Quality. Quite often a large percentage of the subjective assessment of Sound Quality can be explained by the psychoacoustic loudness, e.g. for the psychoacoustic annoyance of any sound it contributes about 80 %. The 20 % rest then must be described by other quantities, such as
roughness or fluctuation strength for the effect of amplitude modulation and sharpness for the influence of the sound timbre. Also the presence of tonal components (tonality) influences the subjective sensation. A procedure to assess the influence of single tones is given in the standard DIN 45 681. Basically it describes the method to calculate the so-called tone adjustment for the assessment of noise immissions in dB between 0 dB (no tonal components) and 6 dB (one or more strong tones), which will be added to the noise rating level. The procedure in DIN 45 681 gives the possibility of a more detailed assessment of the influence of single tones. The level difference \( \Delta L \) between the prominent tonal components in a sound and the masked threshold (as defined in the standard) is used within the work described in this paper to predict the subjectively assessed tonality of that sound. To improve the objective calculation of sound properties and their predictability all tonal harmonic or non-harmonic components, which influence the perception of tonality, should be taken into account. Unfortunately, there exist only few results of investigations describing the tonality of tone complexes\(^5\).

The assessment of time variant sound properties is more challenging, both for subjective and objective assessments. Such problems occur for example in automotive or railway vehicle acoustics (run-ups). In many cases percentile values of psychoacoustic quantities can be used for the description. More recently, in this context the time variant tonality attracted attention in the domain of automotive and railway vehicle acoustics. The procedure described in DIN 45 681 is also extended to the application to non-stationary sounds.

2. SUBJECTIVE ASSESSMENT OF TONALITY OF NON-STATIONARY SOUNDS

Many devices of daily life such as vacuum cleaners, hair dryers, scanners or printers radiate noise with mainly constant or time-invariant tonal components. For stationary sounds subjective assessments of the tonality can be found by standard listening tests (paired comparison test or semantic differential). The tonality of non-stationary sounds now can be calculated (see below), but how is the correlation to the subjective assessments of test subjects?

To clarify this question a psychoacoustic test was designed, in which test subjects had to move a slider on the screen of a PC using the computer mouse. The slider was arranged horizontally and had a length from the left to the right frame of the PC-screen. The test subject had the task to select one sound using prepared software buttons. After a short countdown, the sound was replayed and the position of the slider was written into a text file with a time resolution of 0,01 s. The slider position was divided in 100 steps. The test subject could repeat the sound as often as it was necessary and was asked to use the full available range of the slider. Figure 1 shows an example for the subjective tonality of six test persons (p1 to p6). The median and the interquartile range are marked in bold. The range of the interquartiles seems to be in a typical range for psychoacoustic listening.

The available scale range can be fixed by reference sounds for the highest and lowest scale value.
3. OBJECTIVE ASSESSMENT OF TONALITY OF NON-STATIONARY SOUNDS

The main result of the calculation according to DIN 45 681 is the level-difference $\Delta L$:

$$\Delta L = [L_T - L_G - a_v] \text{dB}$$

(1)

with

- $L_T$ tone level, dB
- $L_G$ masking noise, dB
- $a_v$ masking index, dB, $a_v$ has values between $-2$ dB at low frequencies and $-6$ dB at higher frequencies.

Some results of the application of the calculation procedure according to DIN 45 681 are shown in the form of spectrogram representations in Figure 2. The calculation is based on FFT-analysis with a frequency resolution of 4 Hz. 12 FFTs have been averaged to get a mean spectrum every three seconds according to DIN 45681. The dynamic of the Campbell-scale is fixed with 20 dB. The diagrams show the time varying specific tonality of the three different sounds.

**Figure 1**: Example for the subjective assessment of six test subjects p1 to p6 concerning the instant tonality of a test noise (car interior noise during run-down). The median and the range of the quartiles is marked in bold. The ordinate is scaled linear in steps from 0 to 100 according to the slider positions of the test design.
Figure 2: Specific tonality of three different sound sources. The y-values are given as the calculated level difference $\Delta L$ according to DIN 45 681. Sound was recorded in 1 m distance of each device. The specific tonality is displayed to an upper frequency of 4 kHz.

Figure 2 gives information about the frequency distribution of the tonal components. For a reduction of the calculated data and to derive a single global quantity describing the overall tonality impression, the maximum level difference for each specific tonality spectrum is calculated. The results for the examples in Figure 2 are shown in Figure 3. In addition, the results of a subjective test, following the test procedure as described above in section 2, are compared to the calculated tonality (the results of only one test person are displayed). It turns out, that the calculated level difference and the subjective tonality have similar forms, though the subjective tonality is always delayed. This delay can even be observed when test subjects have the possibility to listen to the sound in pre-tests several times. It has typical values of more than 3 s.

The level difference $\Delta L$ was used as a measurement quantity for the calculated value for the tonality. This allows a more detailed description of the tonality instead of the tonal component adjustment $K_T$ according to DIN 45681 with values between 0 dB and the upper limitation with 6 dB. Similar to the results in$^8)$, the calculated level difference $\Delta L$ easily can reach values of 20 dB and more and proved to be a useful descriptor for the prediction of tonality$^9)$. 

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$^8)$ Reference to the source of the subjective test.

$^9)$ Reference to the study evaluating the usefulness of $\Delta L$.
Figure 3: Specific tonality, calculated according to DIN 45681, of three different sound sources. For the y-value, the calculated level difference $\Delta L$ in dB is used. The subjective data are scaled in the form:

$$a + b \cdot \log(x)$$
4. USE OF SOUND QUALITY PARAMETERS FOR A NOISE CATEGORISATION CONCEPT FOR IT-EQUIPMENT

Regarding noise emissions of IT-Equipment, the current standards ISO 7779 and ISO 9296, respectively the ECMA-74 standard, demand noise measurements only based on the sound power level. Additional sound quality describing measurements for tonal prominence or impulsive noise are optional and not mandatory. Currently there are several approaches to include sound quality describing parameters in order to develop an univocal noise categorization concept for IT-equipment. These rating categories from A (very quiet) to G (very loud / annoying) arise from the well-known EU energy label for household appliances. This concept is currently under development both with the German Federal Institute for Occupational Safety and Health (BauA) and several IT Industry members within the INCE.

In the course of this investigation, in which the development of a classification regarding noise emissions of electronic office equipment is discussed, the tonality of the different noises is also regarded as a necessary input quantity for the classification itself. The basic idea is to measure the sound power level of the device during operation and calculate the tonality. The calculation of the tonality according to DIN 45 681, to ISO 7779 or to other techniques is being discussed at present. The combination of the sound power level, the tonality and the instationary loudness (impulsiveness) then can be used as a basis for the description and quantification of the sound quality.

As shown in Figure 3 the level differences $\Delta L$ can very often have values of more than 12 dB. This leads to a general tone adjustment of 6 dB, because according to the DIN 45381 the level difference reaches or exceeds 12 dB. Here further tests are still necessary to find out the appropriate scaling of the tonality of the noise from electronic office equipment.

5. CONCLUSIONS

The standard DIN 45 681 describes a procedure to calculate the level difference of a tonal component and the level of the masked threshold. This quantity can be used to predict the tonality of sounds. Additionally, this procedure can be applied to describe the tonality of time variant sounds. The agreement with subjective ratings is quite good. The response time of test subjects is to some degree smaller of that of the model. The difference appears only when fast changes occur and should be considered in a refined model.

The application to large variety of technical or artificial sounds show that the calculated level difference $\Delta L$ easy can reach or exceed a value of 12 dB. This would lead to a tone adjustment of 6 dB for almost all devices of the daily life. For future improvements and application of the DIN 45 681 in the Sound Quality process investigations have to be carried out, which deal with the scale level of the subjective rating of time variant sounds. Derivation of an overall tonality from specific tonality considering more than one tonal component (harmonic and non-harmonic tone complexes) including time variant sounds will be part of future work.

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