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BASICS AND USE OF DIN 45681 'DETECTION OF TONAL COMPONENTS AND DETERMINATION OF A TONE ADJUSTMENT FOR THE NOISE ASSESSMENT

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1. INTRODUCTION AND PSYCHOACOUSTICAL BACKGROUND

The German standard DIN 45681 (Draft) [1] describes a calculation procedure for the detection of tonal components and the determination of a tone adjustment for tonal sounds. Its purpose is to improve and to generalize the assessment of tonal noise immissions caused by industrial plants, sports facilities and so on, as tonal sounds can be exceedingly annyoing and disturbing. The amount of the calculated tonal adjustment, which is charged to the A-weighted equivalent sound pressure level, depends on the audibility of tonal components within a composite sound, thus defined in the standard. The calculation procedure uses two essential psychoacoustical quantities to determine the audibility of the tonal components: the critical band level L_G and the masking index a_v. It is well known that the audibility of a tone depends on the level difference between the sound pressure level (SPL) L_T of the tone itself and the SPL L_G which is caused by the masking noise within the particular critical band with the tone frequency as center frequency [2]. The tone is audible if its SPL is not lower than $L_G + a_v$ with $a_v < 0$. The critical bandwidth and the masking index a_v depend on the frequency.

The tone adjustment K_T depends on the level difference ΔL. ΔL is defined as the excess level of the tone above its masked threshold

$$\Delta L = L_T - L_G - a_v \qquad (1).$$

If $\Delta L = 0$ dB the tone is just masked. Under this condition the corresponding level of the tone L_T is designated as the masked threshold of the tone. Fig. 1 shows the masking index as a function of frequency. It is important to realize that tones can be noticed even if the level of the tone L_T is lower than the critical band level L_G of the masking noise.

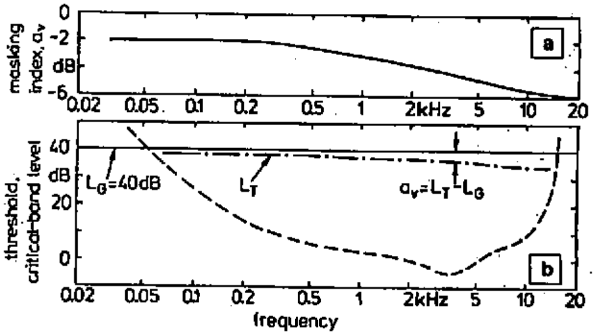

Fig. 1. a. Masking index on an expanded ordinate scale. b. Critical band level L_G of the masking noise (—), masked threshold of a pure tone L_T (– • –) and threshold in quiet (– –) as a function of frequency. Uniform exciting noise as masker. From [2]

Although the masking index is a function of frequency, in DIN 45681 a value of 6 dB was laid down for the masking index, independent of frequency. Therefore, low frequency tones are overestimated. Tab. 1 contains the classification of the tone adjustment K_T in relation to the level difference (excess level) ΔL described above.

ΔL	≤ 0 dB	0..2 dB	2..4 dB	4..6 dB	6..8 dB	8..10 dB	> 10 dB
K_T	0 dB	1 dB	2 dB	3 dB	4 dB	5 dB	6 dB

Tab. 1. Classification of the tone adjustment K_T depending on the excess level ΔL.

2. CALCULATION OF THE TONE ADJUSTMENT - AN EXAMPLE

To detect single tones or tonal components within a composite sound it is necessary to carry out a narrow band signal analysis. The calculation procedure of DIN 45681 requires a FFT-spectrum. If the composite sound is analyzed, the SPLs of the tonal components and the masking noise cannot be measured separately. Therefore, DIN 45681 contains 4 criteria which shall help to separate the spectral lines into such lines which are attached to a tonal component and such lines which are attached to the masking noise. A side band shall be added to the tone if its level is

1. not lower than the maximum level minus 10 dB and
2. not lower than the average level of the masking noise within the particular critical band plus 6 dB.
3. Side bands which meet only one of these two criteria are rejected with regard to the tonal component as well as to the masking noise
4. There must be 10 lines left for the masking noise at least.

The calculation procedure is to be explained by means of an example.The narrow band spectrum of one critical band is given in Tab. 2. In Tab. 2 three spectral lines can be derived which contain tonal energy. However, only the spectral lines at 250 Hz and 255 Hz are added for the tone level.

f_i/Hz	225	230	235	240	245	250	255	260	265	270	275	280	285
L_i/dB	15.4	15.4	15.4	15.4	15.4	22.5	25.5	18.5	15.4	15.4	15.4	15.4	15.4

Tab. 2. Sample spectrum for the critical band with a center frequency of 255 Hz and a bandwidth of 100 Hz from 205 Hz to 305 Hz. Assumption: the missing lines below 225 Hz and above 285 Hz also have a level of 15.4 dB.

The spectral line at 260 Hz contains tonal energy too, because the level difference between the level of this spectral line and the maximum level is less than 10 dB, but the level difference to the average level of the spectral lines of the masking noise L_S (with L_S = 15.4 dB) is less than 6 dB. Therefore, the spectrum contains 21 spectral lines of the masking noise and 2 valid lines of the tonal component in the frequency range from 205 Hz to 305 Hz.

$$L_T = 27.3\ \text{dB} \qquad L_G = L_S + 10\lg(21)\text{dB} = 28.6\ \text{dB}$$

$$\Delta L = L_T - L_G + 6\ \text{dB} = 4.7\ \text{dB} \qquad K_T = 3\ \text{dB}$$

3. PSYCHOACOUSTICAL INVESTIGATIONS

By means of psychoacoustical experiments we wanted to find out how far the tone adjustments, calculated with DIN 45681, correspond to subjective ratings of the tonality of sounds. The dependences on the sound pressure level and the frequency were of particular interest.

Procedure

The synthetically generated sounds should simulate industrial noise immissions. Uniform Masking Noise (UMN) with a level of 50 dB was used as broadband masking sound. Narrow band noise signals (NBN) with a bandwidth of 30 Hz were used as tonal components.. The UMN was presented simultaneously with the NBN signals. Levels of 32, 37, 39, 42, 47, 52, 57, or 62 dB were used for the NBN. The frequencies of these tonal components were between 200 and 800 Hz, separated in intervals of 100 Hz. With this frequency range we covered the range of most of the tonal noise immissions in the neighbouhood of industrial areas - and these are intended for an analysis according to DIN 45681.

Each sound was presented with a duration of 4 s, followed by a silent interval which was equally long. The test sounds were presented diotically via electrodynamical headphones (Beyer DT 48) with free-field equalizer according to Zwicker and Fastl [2] to eight subjects with normal hearing capabilities (hearing losses smaller than 20 dB) at the age of 25 to 38 years. The subjects had the task to rate the test sounds by means of positive numbers which correspond to the perceived tonality of the sound (magnitude estimation without standard (anchor) signal). The subjects were free in choosing the range of the numbers. Each sound was presented four times in the course of the test. The four values of a subject for the same noise were averaged using medians. These medians were referred to the median of the NBN with a center frequency of 800 Hz and a level of 62 dB in order to get normalized values.

Results

Medians and interquartile ranges over all subjects are shown exemplary in Fig. 2. With an increasing level above the masked threshold of the tonal components, an increasing influence of the frequency on the rating of the tonality becomes obvious. Sounds with a tonal component of 800 Hz were estimated as more tonal than sounds with a tonal component of the same level but with a lower frequency.

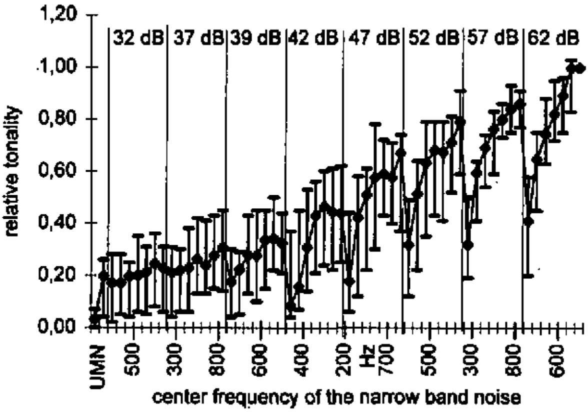

Fig. 2. Medians and interquartile ranges of the relative tonality of NBN of 8 subjects normalized to the tonality of the sound with a tonal component at 800 Hz with 62 dB. The NBN, masked by the UMN, had levels between 32 and 62 dB (numbers in the columns) at frequencies between 200 and 800 Hz (for each NBN level). The first sound on the x-axis represents UMN, the second UMN with humming noise at 50, 100 ... 250 Hz.

Fig. 3 shows the medians of the subjective ratings as solid line together with the results of calculations of the tone adjustment according to DIN 45681 (dotted line) for the same sounds. To make the results comparable, we defined that a tone adjustment of 6 dB corresponds to a subjective rating of 100% on a linear scale. The calculated tone adjustments exceed the subjects' ratings in many cases. Especially for tonal components with levels clearly above the masked threshold it turns out that calculations according to DIN 45681 yield the maximum value for the tone adjustment of 6 dB. However, subjects quote lower values in most of the cases.

3. DISCUSSION

A comparison of the results shows that, concerning the assessments of the subjects and the tonal adjustments which are determined by the

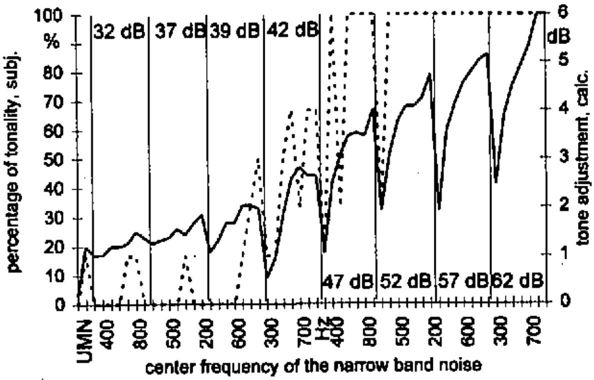

Fig. 3. Comparison of the subjects' ratings and the results of the calculation procedure. Dotted line: calculation results; solid line: medians of the subjects' ratings from Fig. 2. Parameter: sound pressure level of the narrow band noise.

calculation procedure, there is only a tendency of agreement. Particularly the frequency dependence of the calculated tonal adjustments for tonal components with the same level above the masked threshold is not clearly developed. However, subjects show a clear inclination for frequency dependence when rating the sounds. The higher the frequency the more tonal it is rated by the subjects. This frequency dependence could be allowed for by a simple weighting function in the calculation procedure. As adequate weighting function for the investigated frequency range from 200 Hz to 800 Hz, a square root function was found (see Fig. 4). The weighted tonal adjustments are rounded to integers. In Fig. 5 the ratings of the subjects are compared with the results of the calculation procedure utilizing the weighting function.

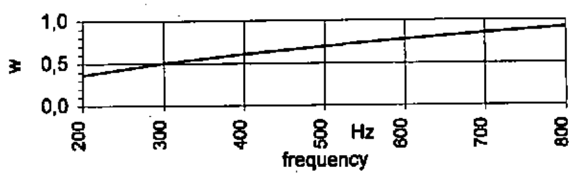

Fig. 4. Weighting function for the frequency range from 200 to 800 Hz

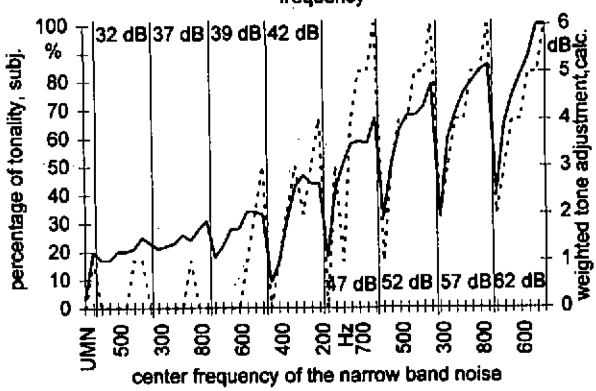

Fig. 5. Comparison of the subjects' ratings and the weighted results of the calculation procedure. Dotted line: weighted calculation results; solid line: medians of the subjects' ratings from Fig. 2. Parameter: sound pressure level of the narrow band noise.

The unweighted results of the calculation procedure produce a deviation of up to 4 dB compared with the results of the subjective ratings. Applying the weighting function, the maximum deviation can be reduced to a value of 2 dB.

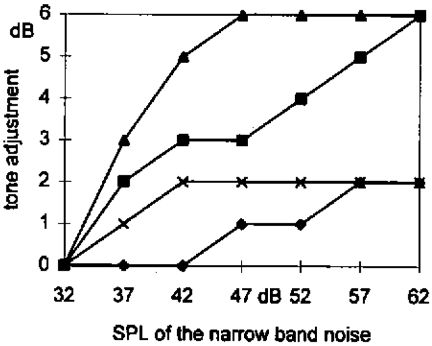

Fig. 6. Tonal adjustment as a function of the SPL of the NBN (tonal component).
- ◆ subjects' ratings for 200 Hz
- ■ subjects' ratings for 800 Hz
- ▲ calculated values according to DIN 45681, unweighted for all frequencies
- X calculated values according to DIN 45681 for 200 Hz, weighted with the function in Fig. 4.

The results are summarized in Fig. 6 in a generalized manner. Fig. 6 shows the dependence of the tone adjustment on the frequency as it was discussed before (symbols ◆ and ■). In addition to that effect it turns out that the weighting function, which was introduced to equalize this frequency dependence (symbol ▲ in comparison with X), must be completed by a function which reduces the tonal adjustment at low excess levels ΔL Subjects do not estimate sounds at low level differences above the masked threshold as tonal as the calculation procedure does. That is what we found in [3] too.

DIN 45681 contains a suitable tool to calculate a tone adjustment for tonal sounds. The range of 6 dB seems to be satisfactory. However, the dependence of the tone adjustment on the spectral distribution and the excess levels of the tonal components should be submitted to further investigation in order to update and improve the calculation procedure.

References

[1] DIN 45681 'Bestimmung der Tonhaltigkeit von Geräuschen und Ermittlung eines Tonzuschlages für die Beurteilung von Geräuschimmissionen', Draft (Beuth, Berlin, February 1995)

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