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NOISE CONTROL FOR A BETTER ENVIRONMENT

Proposal of a procedure assessing the annoyance of low-frequency noise and infranoise

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ABSTRACT

It is well known that low-frequency noise is strongly annoying a part of the people even at levels near the hearing threshold. Upcoming with the wind turbines, complaints are increasingly focused on noise in the infrasound range. Also noise with an especially annoying character by amplitude modulation is more in the discussion. The aim of the proposed procedure is to combine proven procedural steps in assessing low-frequency noise with new ones. These extend the covered infrasound range and extend the processing and assessing of special sound characteristics. The characteristics are spectrally and temporally defined. 23 experienced listeners appraised 101 wide-varied stimuli and rated the more or less increased annoyance caused by the special characteristics. The outcome are additional psychoacoustically based noise quantities, which can be calculated from acoustical measurands. The result is checked by data (measurements and comments) collected during investigations of complaints.

Keywords: Low-frequency Noise, Infrasound, Regulation, Guidelines, Assessment
I-INCE Classification of Subject Number: 79

1. INTRODUCTION

Guidelines for low-frequency sound are often criticised by those affected as insufficient. A review of the current directive can actually reveal that they have weak points. In the German DIN 45680, for example, components below a hearing threshold are classified as irrelevant at the outset, although in combination they can definitely lead to annoyance. The increased annoyance caused by tonal components is taken into account, but in a separate evaluation routine whose call can depend on smallest level differences, but which can result in significantly different evaluations. On the other hand, modulation of the noise, which did not become a problem with the wind turbines, but can also occur, for example, with several asynchronously running motors, is not taken into account at all. These are just a few examples that are reason enough to consider further development of the directive. In order to achieve accepted results, there are some guidelines for the considerations:

-The assessment is based on standardised measured values.

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-The calculation and thus the influence of noise characteristics on the result is comprehensible, which facilitates effective noise reduction in the sense of the directive.
- The result should give no room for interpretation, therefore two experts should come to the same result.

What could a new directive look like? In a report by Müller BBM [1], a proposal is made to evaluate the annoyance of noise by means of a base value and supplements that take into account the special property. Special properties are listed:

- Tonality
- Frequency modulation
- Amplitude modulation
- Impulsiveness
- Information content.

However, no guidance was given on how these surcharges should be determined. To have a clue, the author compiled a set of 101 stimuli, which were evaluated by 23 experts. In addition, the colleague Dr. Timpop (IFL, Düsseldorf, GER) evaluated complaint cases which were processed and documented by experts. In addition to the penalties, the questions of which base value is suitable and how the extension into the infrasound range down to 1 Hz can look like apply.

2. PROPOSAL FOR PENALTIES

2.1 Analysis of complaints and listening test

Twenty-seven documented cases were investigated to analyse which circumstances and details led to comprehensible inadequate or correct assessments in the currently valid version of DIN 45680 [2]. In addition to steps that are not discussed here, it is above all the interpretation of tonality. The determination of tonality (present / not present) is sometimes dependent on the smallest level differences in spectral components, which are actually irrelevant for perception. The consequence, however, is that noises classified as broadband are assessed much less critically.

The evaluation of the borderline cases at hand was very helpful in orienting a procedure that does not know such binary decisions. It should be noted at this point that it was not easy to obtain the information, as such cases are usually not archived by the authorities, especially those that were found to be unjustified.

A further limitation was that only the third-octave spectra were available as usable information. This was sufficient for an evaluation of the tonality, but not for further approaches. For this reason, the above-mentioned auditory examination was carried out, which had to remain very limited in its effort, but is nevertheless very informative.

The material for the listening test consisted of 101 stimuli, which varied widely in type and interpretation:

- Sinus tones of 20 Hz, 40 Hz, 60 Hz, 80 Hz
- Frequency modulation of the sinusoidal tones with a deviation of 1 Hz, 5 Hz and 10 Hz at modulation frequencies of 1 Hz, 4 Hz and 10 Hz
- Amplitude modulation of the sinusoidal tones with a degree of 1%, 50% and 100% at modulation frequencies of 1 Hz, 4 Hz and 10 Hz

- White noise of different width and centre frequency
- Brown noise of different width and centre frequency, partially combined with sine tones of different frequency and strength
- Various bass runs, limited to 100 Hz
- Pulse sequences, low-pass filtered with different cut-off frequencies with different steep slopes

A circle of experts of experts was offered to download the stimuli. Since the reaction was of interest at the limit of perceptibility, they should listen to the stimuli clearly, but not loudly. It was assumed that the penalty were largely independent of level.

A total of 23 experts took part in the hearing test. For each stimulus in each of the above categories, they could assign a penalty of 0 dB, 3 dB or 6 dB. Multiple assignments were therefore also possible, because an amplitude-modulated sinusoidal signal can be annoying because of its tonal quality and also because of the level fluctuation.

As the evaluation showed, the original subdivision of the categories was too far-reaching and also not clear. For example, some frequency-modulated stimuli received a penalty for amplitude modulation because it was not the frequency change that was perceived, but rather the volume that varied as a result. For this reason, the assessments were grouped into two categories: one for spectral and one for temporal special qualities . An evaluation of the information content category was omitted, where only the bass - comprehensibly - received significant penalties here. However, it was already the leader in the other categories in terms of penalties.

2.2 Annoying spectral sound characteristic

This category includes judgments on particular annoyance caused by tonality and frequency modulation. From the point of view of signal processing, the degree of uneven distribution of the components in the spectrum corresponds to this. A known and variously used measure of this is the logarithm of the quotient of the arithmetic and geometric mean of the spectral components, which can be modified as follows:

$$X = 10\,\lg\frac{\sum_{i=1}^{N} S_i}{(\prod_{i=1}^{N} S_i)^{1/N}} = 10 * \left[lg \sum_{i=1}^{N} S_i - lgN - \frac{1}{N}\lg\prod_{i=1}^{N} S_i\right]$$

$$= lg \sum_{i=1}^{N} S_i - lgN - \frac{10}{N}\sum_{i=1}^{N} \lg S_i \qquad (Equation\ 1\ to\ 3)$$

With the third octave level values Leq,i, it follows over the context

$$S_i = 10^{L_{eq,i}/10} \qquad (Equation\ 4)$$

from this

$$X = L_{eq} - 10\lg N - \frac{1}{N}\sum_{i=1}^{N} L_{eq,1} \qquad (Equation\ 5)$$

The measure X is therefore determined from the difference between the energetic mean of the noise, reduced by the arithmetic mean of the energetic mean values of the individual third octave components in the range e.g. from 8 Hz to 100 Hz, which comprises N third octave components.

In order to align this measure with the data discussed in 2.1, various operations are necessary. First of all, it has to be taken into account that the pitch perception decreases strongly towards low frequencies. This can be compensated by lowering the level values of the thirds. Here, for example, the difference to the hearing threshold would be a suitable measure. It should also be excluded that level values far below the hearing threshold still have an influence on this measure, which can occur through arithmetic averaging. Differences smaller than -10 dB should therefore be fixed at this value.

The measurement X must ultimately be carried over a characteristic curve which was obtained by evaluating the documented complaints, what finally gives the spectrally determined penalty KST with

$$KST = 4.2 * X/(1 + 0.14 * X)\ dB \qquad (Equation\ 6)$$

Figure 1 shows the relationship between the sum of the penalties assigned for the hearing examination and KST.

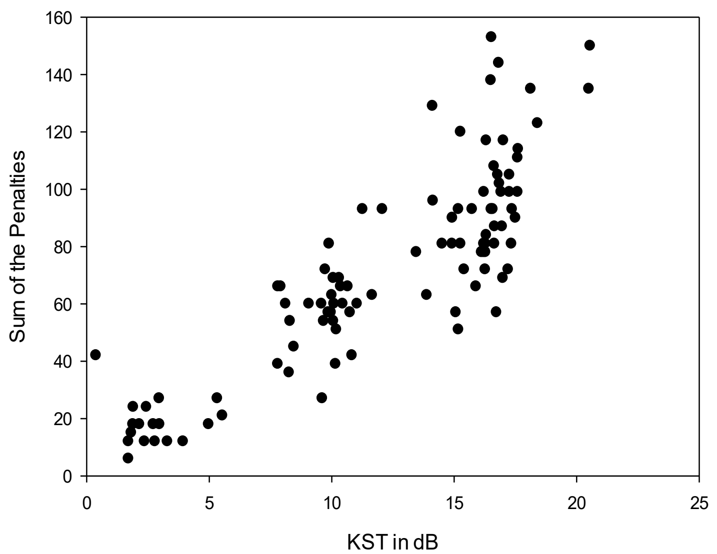

Figure 1: Sum of the penalties assigned by the experts for tonality and frequency modulation vs. the calculated penalty KST for spectral conspicuity.

The regression analysis confirms a close relationship with a r^2= 0.74. However, the slope clearly deviates from one. This is due to the fact that the KST penalty, together with the base value still to be discussed, was placed in relation to existing orientation values when adjusting to the data of the complain documents. Accordingly, the slope also depends on these parameters.

Table 1 lists measurements and results from a number of complains. It should be added that the orientation values for strong annoyance are currently 25 dB at night and 35 dB during the day. The cases marked with * appear to be slightly underestimated in relation to the judgement. These are noises from punches. In this case, the temporally induced surcharge would still come into play, but could not be determined from the available measured values.

Table 1: Some complaints with the assessment by an expert and by the procedure (basic value plus penalty KST)

Assessment of the noise level in dB	Classification by experts in three strength grades	Statement on annoyance by expert	Remarks
36,4	2	distinct	during the day in a quiet environment during
17,1	0	not annoying	turbines off
21,3	0	not annoying	turbine 1 on
33,8	1	strongly annoying	turbine 3 on
42,4	2	strongly annoying	all turbines on
25,0	0	not annoying	during the day
30,4	0	not annoying	during the day
40,9	2	distinctly annoying	during the day
28,2	1	annoying?	expert no complainant yes
33,4	1	annoying	during the day
33,3 *	2	very annoying	punching machine
22,7	0	not annoying	thermal power station
38,3	1	not really annoying	during the day
34,3	1	not annoying	during the day

2.3 Annoying temporal sound characteristic

The temporally conditional penalty is also to be determined from the third octave values. In this way, the evaluation of the noise can be limited to the low frequency range without the need for an extra filter to be defined and implemented. This has the advantage that the one-third octave filters are defined and often already present, but requires a certain time resolution for the one-third octave signals in order to be able to uncover relevant details over time. It should be a time resolution between 10 ms and 20 ms in order to be able to evaluate modulations. In addition, the loss of phase information can be compensated for to a certain extent. The computational effort required for octaves with very low centre frequencies can be reduced by downsampling without further loss of information. The necessity of an increased storage capacity is also no problem.

At the first attempt, the temporal penalty was determined on the basis of [3] as follows:

- Within a time window of 1 second, the maximum A-weighted level value is determined separately in each third octave.

- At the end of the 1-second time window, determine the energetic mean value for all thirds from the maximum values.
- Repeat this five times within a 5-second window.
- In this 5-second window, select the largest 1-second maximum value, which results in a maximum 5-second value.
- Determine the arithmetic mean of the maximum level values (!) from all 5-second maximum values that result over the measurement period.
- The $L_{A,eq}$ is subtracted from the result.

The result is shown in Figure 2, where the total of the penalties given by the experts under the categories amplitude modulation and impulsiveness is plotted over the penalty KTT determined in this way.

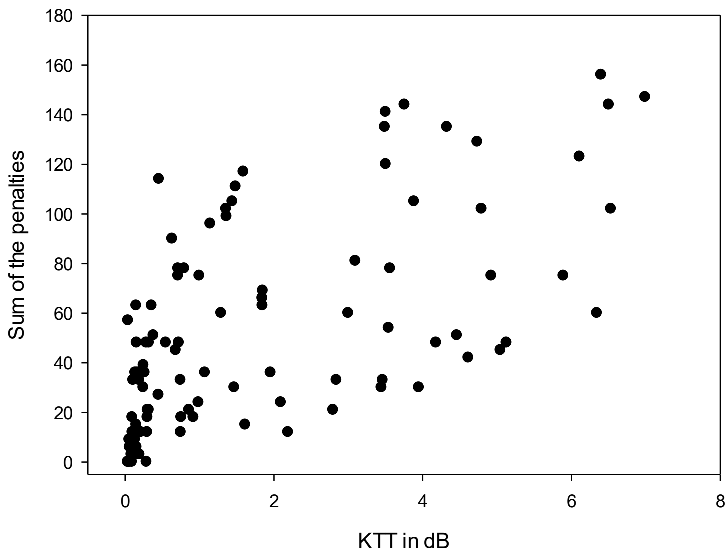

Figure 2. Results of the first approach for KTT

The variance of the values is quite large, which can be explained. At the upper edge it is primarily the modulated stimuli that are underestimated, at the lower edge it is primarily the noisy stimuli that are overestimated. The underestimation is obviously due to the fact that the modulation can no longer be resolved, especially at 4 Hz. At this frequency the human being reacts particularly sensitively. The overestimation of the noise-like noises results in long time windows. Even the intermediate maximum value search is too long, as the spectral composition of a noise signal can change considerably within one second. The use of only the maximum values results in a systematic increase in the assumed noise peaks, which were not present in reality, which is why the experts rated the noises less critically.

Based on this knowledge, the evaluation was modified:
- The linear third-octave values are summed directly.
- The resulting sum signal is evaluated in parallel in two branches
- In a branch, the maximum value is determined in a time window of 250 ms. The level values thus obtained over the measurement period are averaged.
- In the other branch, the sum signal is passed through a filter that raises components that can preferably be traced back to a modulation with 4 Hz. Then

the maximum value is determined within a 5-second grid. The resulting sequence of level values is averaged over the measurement period.
- Finally, the output signals of both branches are weighted, summed and $L_{A,eq}$ subtracted.

By the way, the A-weighting is used to convert the variation of the volume at a frequency modulation into an adequate signal. Figure 3 shows the effect of this modification. The estimation is significantly improved.

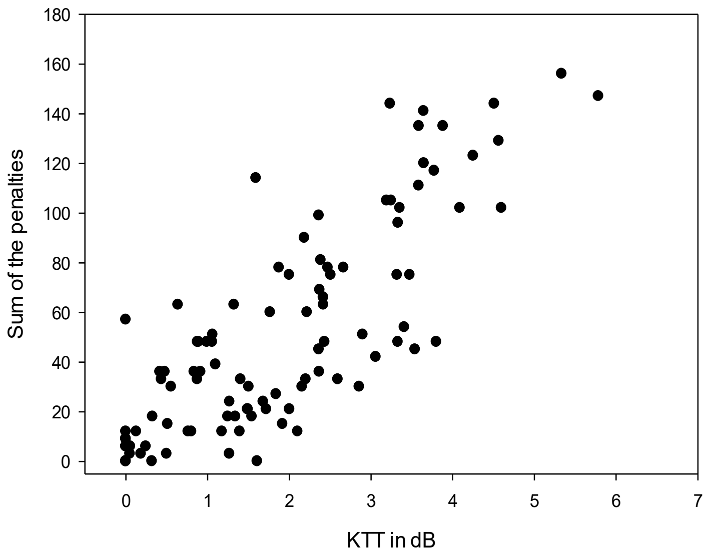

Figure 3: Improved approach for KTT

3. PROPOSAL FOR BASIC VALUE AND FREQUENCY EXTENSION

In both cases, methodes from the Danish guideline [4] are set to established.

3.1 Basic value

The $L_{A,eq}$ is used as the base value, initially limited to the frequency range from 8 Hz to 100 Hz. It is already used elsewhere in the evaluation and can be determined as usual from the third-octave values.

3.2 Extension in the infra sound range

From the discussion of an earlier draft the demand developed to extend the frequency range up to 1 Hz. This requirement is to be met. However, there are only a few regulations for this frequency range. One of them is the limitation to 85 dB(G). In the corresponding Danish guideline, however, the infrasound range is evaluated separately. This can be unfavorable if a noise in relevant proportions extends from the infrasonic range to the low-frequency range. A comprehensive evaluation would be more appropriate. What can a connection look like?

One is also shown in [5], the 85 dB(G) curve and the 20 dB(A) curve intersect at about 20 Hz, the limit to the infrasound range. A level of 20 dB(A) is identical to a level of 70.5 dB, which is pretty much equal to the hearing threshold value at 20 Hz in DIN 45680. This gives a reference value. An overarching weighting is sought that converts an unweighted level value identical to 85 dB(G) into a value of 20 dB in the infrasound range. From 20 Hz and at frequencies above, the weighting should convert a level value of 20 dB(A) into 20 dB, so that the weighting is trivially identical to the A weighting. Table 2 shows the weighting resulting from this for the normalized third-octave centre frequencies in the range from 1 Hz to 100 Hz. At 16 Hz, there is a small deviation from the definition described here. This results from a minimal rounding off of the transition between the two ranges. The Figure 4 shows the graphical implementation of the weighting curve, where the slight bend can be seen. The composite weighting is marked with dB(AG).

Table2: Values for the AG weighting

third-octave centre frequency in Hz	Weighting in dB
1	-107,4
1,25	-102,0
1,6	-97,0
2	-92,7
2,5	-88,5
3,15	-84,4
4	-80,4
5	-76,4
6,3	-72,4
8	-68,4
10	-64,4
12,5	-60,4
16	-55,2
20	-50,5
25	-44,7
31,5	-39,4
40	-34,6
50	-30,2
63	-26,2
80	-22,5
100	-19,1

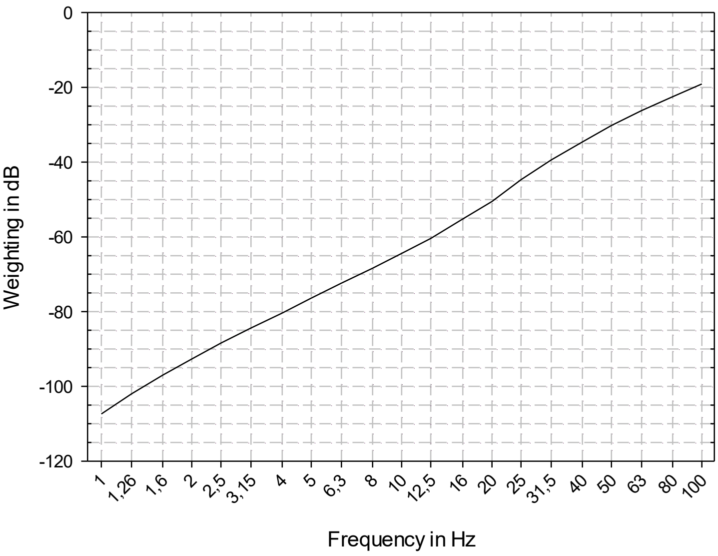

Figure 4: AG-weighting curve

4. CONCLUSIONS

The method presented is suitable for eliminating the weak points of the currently applicable DIN 45680 guideline and for evaluating the characteristics of noises, which are known to lead to increased annoyance, in a more problem-oriented manner. Care was taken to build largely on established parameters and measurement methods. The evaluation in the form of a base value and penalties makes these more transparent and facilitates a targeted reduction of the annoyance. However, it should be remembered that the evaluation does not provide a measure proportional to the level of annoyance, but rather indicates a level at which the annoyance can be classified as significant in all probability. In further investigations with additional material, the safety of such a statement should be further examined in order to eliminate or to keep within limits any shortcomings.

With the extension into the deep infrasound range, the method is also prepared to detect those noise components which are increasingly said to have a annoying effect. So far, these components have been completely ignored. However, their consideration can only be regarded as a first step, because the knowledge about annoyance in this frequency range is still quite scarce. Qualitative statements are therefore hardly possible, not least because of the needed sophisticated data acquisition. Nevertheless, an approach to a qualitatively new gain of knowledge is given.

5. REFERENCES

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