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Round Robin Test of an Objective Method for the Determination of the Prominence of Impulsive Sounds and for the Impulse Adjustment of $L_{Aeq}$

Nordtest Project 1516-00
Abstract

Within the frame of a Nordtest project an objective method for the determination of the prominence of impulsive sounds and for the impulse adjustment of $L_{Aeq}$ has been tested by four Nordic laboratories. The method is based on measurements of the onset rate of the impulse and the level difference between the maximum sound pressure level and the starting point of the onset. Based on these parameters the impulse adjustment to add to the measured $L_{Aeq}$ to account for the extra annoyance of impulsive noise is calculated. The results indicate that the impulse adjustment can be determined with a mean standard deviation of the reproducibility of 0.5 dB. The adjustments calculated are in good qualitative agreement with those given in ISO 1996 for a number of specified impulse sources.

Key words: Impulsive sound, noise, assessment

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Preface

This project has been supported by Nordtest, project no 1516-00

The project has been carried out by a group consisting of

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Conclusions

It is objectively possible to predict the prominence of different types of impulsive noise with good reproducibility and to use the result to calculate an adjustment, $K_a$, to add to the measured $L_{seq}$ to account for the extra annoyance of impulsive noise. The predicted prominence correlates well with subjective listening tests.

The impulse adjustment of $L_{seq}$, $K_a$, can be determined with a mean standard deviation of 0.5 dB, using the proposed method. The adjustments calculated are in good qualitative agreement with those given in ISO 1996 for a number of specified impulse sources.

The main contributor to the standard deviation is the measurement of onset rate. The standard deviation of the onset rate can be decreased for short impulses by limiting the permitted range of sampling of $L_{pa,F}$ to 10-25 ms.

Taking into account
- that three of the participants used the method for the first time in this Round Robin test
- that the method was changed slightly after one of the participants made his measurements
- that one of the participants made a consequent deviation from the method
- that different equipment and sampling procedures (5-32 ms) were used by the four participants

the mean standard deviation is acceptable in comparison with the other uncertainties seen in environmental noise measurements.
1 Introduction

1.1 Background

Noise with prominent impulses is more annoying than continuous types of noise (without impulses or tones) with the same equivalent sound pressure level. Therefore an adjustment is often added to the measured $L_{Aeq}$, if prominent impulses are present in the noise, to compensate for the extra annoyance due to the impulses.

In ISO 1996, [1], the adjustment is prescribed to be 5 dB if the noise is “regular impulsive” and 12 dB if the noise is “highly impulsive”. The only guideline to judge which category a sound applies to is a number of examples of impulsive sound sources.

Therefore, DELTA [2] has proposed an objective measuring method for the prominence of impulsive sounds and for adjustment of $L_{Aeq}$. The method is based on the judgement of 17 listeners of the objective prominence of 47 different impulsive sound samples. The proposed formula for calculating the predicted prominence is:

$$P = 3 \lg(\text{onset rate [dB/s]}) + 2 \lg(\text{level difference [dB]})$$

where onset rate and level difference are defined in Annex A. The formula was found to predict the prominence with good correlation with the listening tests ($R^2=0.74$). The predicted prominence is transformed into an adjustment in the range 0-12 dB to $L_{Aeq}$, using the formula:

$$K_I = 1.8 \cdot (P - 5), \text{ for } P > 5 \quad K_I = 0 \text{ for } P = 5$$

1.2 Aim

The aim of this project is to test the proposed method and to determine the measurement uncertainty by carrying out comparison measurements between 4 different Nordic laboratories using different measuring set ups.

1.3 Authors

The Annex A, Nordtest Method Proposal has been written by Torben Holm Pedersen. The other parts of this report has been written by Håkan Andersson.

1.4 Work in project group

The project group had two meetings. At the first meeting the DELTA member described the work and the proposed method, the carrying out was discussed and a detailed time schedule was settled. After that the measurements were carried out and SP evaluated the result. Based on the experience of the measurements some minor changes to the method were introduced. The result was sent to all the group members and a second meeting was held where the result and the method were discussed.
2 Method

The measuring method and the definitions in this report are found in Annex A.

3 Round Robin test

3.1 Test signals

DELTA provided a CD with 54 impulse sound samples, used at their listening tests. 11 of them were chosen to be included in the project.

The other members of the group were invited to contribute with additional sound samples, typical for their countries. SP distributed an additional CD with in total 10 impulse sounds, 5 of them only optional to analyse, recorded by KILDE and SP.

The impulse sound samples are listed in table 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Source</th>
<th>Recorded by</th>
</tr>
</thead>
<tbody>
<tr>
<td>2L</td>
<td>Hammerblows on metal</td>
<td>DELTA</td>
</tr>
<tr>
<td>5L</td>
<td>Air release</td>
<td>DELTA</td>
</tr>
<tr>
<td>7L</td>
<td>Stonecut</td>
<td>DELTA</td>
</tr>
<tr>
<td>9L</td>
<td>Tyre change</td>
<td>DELTA</td>
</tr>
<tr>
<td>16L</td>
<td>Woodax</td>
<td>DELTA</td>
</tr>
<tr>
<td>2H</td>
<td>Hammerblows on metal</td>
<td>DELTA</td>
</tr>
<tr>
<td>5H</td>
<td>Air release</td>
<td>DELTA</td>
</tr>
<tr>
<td>7H</td>
<td>Stonecut</td>
<td>DELTA</td>
</tr>
<tr>
<td>9H</td>
<td>Tyre change</td>
<td>DELTA</td>
</tr>
<tr>
<td>16H</td>
<td>Woodax</td>
<td>DELTA</td>
</tr>
<tr>
<td>5P</td>
<td>Door slamming and starting car</td>
<td>DELTA</td>
</tr>
<tr>
<td>NT1</td>
<td>Skateboard ramp</td>
<td>KILDE</td>
</tr>
<tr>
<td>NT4</td>
<td>Container truck</td>
<td>KILDE</td>
</tr>
<tr>
<td>NT7</td>
<td>Car in tunnel opening</td>
<td>KILDE</td>
</tr>
<tr>
<td>NT8</td>
<td>Timber sorting machine</td>
<td>SP</td>
</tr>
<tr>
<td>NT9</td>
<td>Church bells</td>
<td>SP</td>
</tr>
</tbody>
</table>

The samples marked with "L" had the same $L_{Aeq}$ for the impulses as for the background noise. The samples marked with "H" had 20 dB higher $L_{Aeq}$ for the impulses than for the background noise. The additional samples are marked with "NT".

The time length of the samples was 30 s.

Some of the noise samples in the Round Robin test are close-up recordings of sounds (distances <30 m). This is not the typical situation for environmental noise problems. This means that the levels are larger and the background noise relatively lower than in the situations relevant for environmental noise. This gives higher level differences. The distortion of the impulse (the spreading of the sound energy in time due to reflections and atmospheric conditions) is also less when the recordings are made close to the sound.
sources. This means higher onset rates. Higher level differences and higher onset rates mean higher values of the prominence $P$ and the adjustment $K_l$.

This is no problem as to the Round Robin test, but the consequence is that the values of $P$ and $K_l$ are larger than you will normally observe in environmental noise situations - also larger than the values agreed upon in the ISO 1996 amd. 2 draft.

On the other hand this effect is in accordance with what you hear: when you are close to an impulsive source you will perceive the impulsive characteristic as more dominating. This effect is not taken into consideration in the ISO-draft.

### 3.2 Measurements

The participants measured and analysed the selected recordings on the CDs. They were initially instructed to perform the measurement according to the “NORDTEST draft 2” method. When the measurements started some questions were raised about how to interpret the definition of “Onset Rate”. A “NORDTEST draft 3” test method with a new definition of “Onset Rate” was sent out. At that time VTT had already carried out their measurements according to the “NORDTEST draft 2” method. The other participants used the “NORDTEST draft 3” method. However, no systematic or significant difference between the VTT result and the others was found.

The “Onset rate” is in the “NORDTEST draft 2” method defined as the slope of the straight line between 10 % and 90 % of the level difference above the background level. The “Onset rate” definition in the “NORDTEST draft 3” method is the same as in the method proposal given in Annex A.

### 3.3 Equipment and method used

#### 3.3.1 DELTA

CD player Sony D-181.
A HHB Portadat type PDR 1000 was used as analogue to digital converter. The digital signals were fed to a PC with NOISELAB analysing software from DELTA.

NOISELAB computes a running true time level recording of the A-weighted sound pressure levels with time weighting $F$. The computed sound pressure levels are sampled every 25th ms.

Based on a visual judgement supported by cursor readings the “worst” impulse from each sound example was selected for a detailed analysis. The “reverberation time” and level difference were measured for the part of the impulse which had a gradient larger than 10 dB/s. The onset rate was computed by means of linear regression.

#### 3.3.2 VTT

CD player JVC XL-V230.
A Norsonic 830 real-time analyser with advanced transient measurement option was set up for transient measurements to measure A-weighted level versus time with time-weighting $F$ and sampling period 32 ms.
For each sound sample, level versus time was printed and one impulse for each sound sample was chosen. For each impulse a straight line representing the impulse was determined. For each impulse level difference and onset rate (based on 10-90 % and 50-95 % of the level difference) was determined along this line.

3.3.3 KILDE

Audio CD player.
A NORSONIC analyser121 was set for A-weighted measurements with time weighting F and sampling period 10 ms.
A NORSONIC Nor-Profile (Software analysing N-121 instrument files) was used to produce graphs on a PC. Using cursors defining start point and end point on graphs, the corresponding time and level data were copied to a spreadsheet, calculating level difference (LD) and onset rate (OR).

All level vs. time graphs were initially inspected visually, pointing out impulses for further analysing, with regard to LD and OR. Up to 6 impulses were analysed for one sound example. The impulse with the highest calculated prominence P was chosen.

The onset rate was calculated as the line between the start point and end point. This method has earlier been proven to give result that differ up to 0.4 dB from the proposed linear regression method.

3.3.4 SP

CD player Sony D-E301.
A Sound Level Meter B&K 2230 was set for A-weighted measurements with time weighting F. The Sound Level Meter DC output was connected to a HP 3562A signal analyser, set to time capture mode. The sampling interval was 5 or 10 ms as given in the table 2. The data was finally transferred to an Excel workbook.

Excel was used to point out start points and end points of the onsets. Up to 6 of the onsets that visually looked “worst” were selected for closer analysis. The onset rate was determined by applying the Excel regression function on the samples between the start points and end points. The Excel regression function is approximating a line with the least square method.

Table 2. Sampling interval used by SP.

<table>
<thead>
<tr>
<th>Sound sample</th>
<th>2L</th>
<th>5L</th>
<th>7L</th>
<th>9L</th>
<th>16L</th>
<th>2H</th>
<th>5H</th>
<th>7H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling interval</td>
<td>5 ms</td>
<td>5 ms</td>
<td>10 ms</td>
<td>10 ms</td>
<td>10 ms</td>
<td>10 ms</td>
<td>10 ms</td>
<td>5 ms</td>
</tr>
<tr>
<td>Sound sample</td>
<td>9H</td>
<td>16H</td>
<td>5P</td>
<td>NT1</td>
<td>NT4</td>
<td>NT7</td>
<td>NT8</td>
<td>NT9</td>
</tr>
<tr>
<td>Sampling interval</td>
<td>10 ms</td>
<td>5 ms</td>
<td>5 ms</td>
<td>5 ms</td>
<td>5 ms</td>
<td>5 ms</td>
<td>5 ms</td>
<td>5 ms</td>
</tr>
</tbody>
</table>
4 Measurement results

4.1 Summary

In figure 1-3 the reported adjustment to $L_{Aeq}, K_I$, for the four different laboratories are shown. We can see in figure 2 that the agreement between the laboratories is almost within ±1 dB.

The deviations from the mean will be explained in chapter 4.3.

![Graph showing adjustment to $L_{Aeq}, K_I$](image)

*Figure 1. Adjustment to $L_{Aeq}, K_I$*
The mean standard deviation of the measured adjustments $K_i$ is 0.6 dB.

An explanation for the standard deviation for some of the sound samples is found in chapter 4.3.1.
4.2 Result of combined measures

4.2.1 Predicted prominence $P$

The adjustment to $L_{Aeq}$ $K_i$, is calculated from the predicted prominence $P$ by the following equation:

$$K_i = 1.8 \cdot (P - 5) \text{ for } P > 5; \quad K_i = 0 \text{ for } P \leq 5$$

The standard deviation of the reported predicted prominence $P$ is shown in figure 4.

![Graph showing standard deviation of predicted prominence $P$](image)

*Figure 4. Standard deviation of predicted prominence $P$*

The mean standard deviation of the predicted prominence $P$ is 0.3.

The predicted prominence $P$ is an objective combined measure calculated from

$$P = 3 \cdot \log(\text{onset rate}) + 2 \cdot \log(\text{level difference})$$
4.2.2 Onset rate

The onset rate is the slope in dB/s of the line that gives the best approximation to the part of the time history of $L_{MAP}$ where the positive gradient exceeds 10 dB/s.

**Figure 5.** Measured $3\lg(\text{onset rate})$

**Figure 6.** Measured $3\lg(\text{onset rate})$ re. arithmetic mean.
Figure 7. Standard deviation of $3 \log$(onset rate).

### 4.2.3 Level difference

The level difference for an impulse is the difference in dB between the maximum and minimum point of the part of the time history of $L_{10,6}$ where the positive gradient exceeds 10 dB/s.

Figure 8. Measured $2 \log$(level difference).
4.3 Measurement uncertainty

4.3.1 Uncertainty sources

4.3.1.1 Standard deviation differences

4 of the tested 16 sound samples had a standard deviation of more than 0.6 dB of the reported $K_I$. 
For all the other sound sources the standard deviations are around 0.5 dB or better, see figure 3.

Sound sample NT9 has the largest standard deviation (1.4 dB). In this case one participant only made the analysis on a very limited number of impulses and “missed” the most prominent one, see discussion in chapter 4.3.1.3. The chosen impulse has also been analysed by SP with a result agreement of 0.4 dB. If the result from this participant is omitted the standard deviation decreases to 0.6 dB.

One of the participants used a method for determining the onset rate that did not fully agree with the method, giving a result difference up to 0.4 dB, further discussed in chapter 4.3.1.4.

4.3.1.2 Sampling interval

With an onset time less than 50 ms and a sampling interval 25 ms the time history of $L_{PA,F}$ of the onset will only include 2 samples. This will give a coarse measurement of the onset rate and level difference.

Sound 2L, which have a onset time of about 100 ms, has repeatedly been analysed by SP using 3 different sampling intervals, 5, 10 and 20 ms respectively. The repeatability of $K_t$ is better than 0.1 dB for the sampling intervals 5 ms and 10 ms. By a sampling interval of 20 ms the mean repeatability is 0.4 dB. The mean value of the measured $K_t$ was 0.4 dB lower at 20 ms sampling interval than at 5 ms and 10 ms respectively.

The conclusion of the tests on sound sample 2L is that about 10 samples per onset is needed to get maximum accuracy.

However, the constants in the calculations of $P$ and $K_t$ are fitted to the listening tests using 25 ms sampling interval and a radically changed interval may need new constants.

In the final method the allowable sampling interval is changed from ≤25 ms to 10-25 ms.

4.3.1.3 Choice of impulse to analyse

Some of the sound samples had very many impulses which made it difficult to pick out and analyse the most prominent one. Most of the project participants made a visual inspection to pick out a limited number of impulses that looked “worst”, which were analysed.

The standard deviation of the Round Robin would decrease if the participants had been able to analyse all impulses, e.g. by using automatic analysis. However, a system for automatic analysis must be designed with most care.

As discussed earlier, the largest standard deviation (NT9) would decrease from 1.4 dB to about 0.6 dB if the correct impulse would be chosen. Also sound sample NT1 was analysed at different impulses by all the participants.

The times of the chosen impulses are found in tables in Annex B.
4.3.1.4 Line approximation of onset rate

The onset rate shall, according to the last version of the proposed method, be determined by linear regression of the time history between the start point and the end point. However, one of the participants determined the onset rate by the straight line between the start point and the end point.

SP has made the analysis using booth methods. The result of the two methods differs up to 0.4 dB. The difference increases with the onset rate and the sign of the difference seems to vary randomly.

4.3.1.5 Equipment

The measuring equipment shall fulfil the requirements of IEC 60651, type 1 and its successor IEC 61672-1, class 1. The main contributor to the measuring uncertainty when measuring short impulses is expected to be the time weighting $F$. To test how variations in the time weighting affects the $K_I$, an impulse was mathematically modelled with a 100 ms tone burst with a level 20 dB above the background noise. The time constant of the time weighting was changed within the tolerance limits of IEC 61672-1, class 1.

When varying the time constant within the tolerance limits, the calculated $K_I$ only changed 0.1 dB.

An explanation to the insensitivity of the time constant of the equipment is that the predicted prominence is the logarithm of the measures.

4.3.2 Result corrected for deviations from the method

By going through the measurements and results relative to the draft in Appendix A the working group could correct a number of deviations from the method in the performed measurements.

The following corrections were made:
- The onset rate of sound sample 7L has been determined by linear regression also by KILDE. Also NT1 has been reanalysed but without any changes of the result.
- The VTT result of sound sample NT9 is omitted as it is not valid for the most prominent impulse.

After this process the standard uncertainty was reduced to 0.5 dB

The text in the method was changed in order to get improvement on these points
4.3.3 Estimated uncertainty of $K_f$

As all the project participants used different equipment and different analysis methods, the standard deviation of the reported adjustment $K_f$ will give a good estimation of the standard uncertainty of the measurements.

By taking the mean value of the standard deviation of the corrected measured $K_f$ of the different sound samples the standard uncertainty is estimated to be 0.5 dB. The expanded uncertainty with a coverage factor 2 is then estimated to be 1.0 dB.

The estimated uncertainty is only dealing with the analysis of the impulse, not the model correlation to listeners judgement and the uncertainties of field measurements.

5 Practical experiences during the measurements

The equipment used by SP showed to produce some ringing in the time history trace if the onset rate and level difference were large. This ringing produced a false end point. When making manual analysis, it is no problem to detect and neglect the false end point if the analysing person is aware of the ringing. However, even if the false end point is neglected it is included in the line approximation of the onset rate. This will cause a minor overestimation of the onset rate.

All participants used different manual analysis methods. The first analysis was time consuming, but after some practicing the analysis went on fast and smoothly. The manual analysis methods also seem useable for practical analyses with longer measurement times.
6 Comparison with examples in ISO 1996

A number of examples of impulsive sound sources are given in ISO 1996-2 Amd.1 1998. They are divided into two groups, "regular impulsive sound" with 5 dB adjustment to $L_{Aeq}$ and "highly impulsive sound" with 12 dB adjustment to $L_{Aeq}$.

Some of the examples were included in the test.

<table>
<thead>
<tr>
<th>Sound source</th>
<th>ISO 1996 adjustment</th>
<th>Nordtest adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car door slam</td>
<td>5 dB</td>
<td>6.4 dB</td>
</tr>
<tr>
<td>Church bells</td>
<td>5 dB</td>
<td>5.6 dB</td>
</tr>
<tr>
<td>Metal hammering (L)</td>
<td>12 dB</td>
<td>7.1 dB</td>
</tr>
<tr>
<td>Metal hammering (H)</td>
<td>12 dB</td>
<td>9.9 dB</td>
</tr>
<tr>
<td>Wood hammering (L)</td>
<td>12 dB</td>
<td>6.7 dB</td>
</tr>
<tr>
<td>Wood hammering (H)</td>
<td>12 dB</td>
<td>10.0 dB</td>
</tr>
</tbody>
</table>

The sources marked with (L) had the same $L_{Aeq}$ for the impulses as for the background noise and represent a distant measurement. The samples marked with (H) had 20 dB higher $L_{Aeq}$ for the impulses than for the background noise and represent a closer measurement.

The result is pointing out the problem with the present ISO 1996 draft, the effect of the background noise and distance from the source is not taken into consideration.

7 References


[3] IEC 60651, Sound level meters

Annex A - Nordtest Method Proposal

Final version 1, prepared by Torben Holm Pedersen

Impulsive noise

Objective method for the measurement of prominence of impulsive sounds and for adjustment of $L_{Aeq}$

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1. Scope

Noise with prominent impulses is more annoying than continuous types of noise (without impulses or tones) with the same equivalent sound pressure level. Therefore an adjustment $K_i$ is added to the measured $L_{Aeq}$ if prominent impulses are present in the noise, to adjust for the extra annoyance due to the impulses.

Impulsive sounds are characterised by a sudden onset, which makes them more prominent than continuous noise types, and makes the sound source identified more easily.

The adjustment to $L_{Aeq}$ for impulses depends on how prominent the impulse characteristic is perceived through the continuous part of the noise.

Measurements according to this Nordtest method gives as the main result a measure for the prominence of impulsive sounds in the immission point. The method aims at predicting the prominence of impulsive sounds in correspondence with average subjective judgements. Based on the predicted prominence, $P$, a graduated adjustment, $K_i$, to the measured $L_{Aeq}$ is defined.

The method is based on the presumption that the annoyance increases with increasing audibility (perceived prominence) of the impulses. The audibility of the impulses is expressed by the prominence, which shall exceed a certain limit before an adjustment is made to $L_{Aeq}$. Below this limit no adjustment is made. When the prominence rises, the adjustment increases.

The prominence $P$ is defined by a logarithmic measure based on the level difference and onset rate of the A-weighted sound pressure level with time weighting $F$. The logarithmic scale together with time weighting $F$ set in practice an upper limit for the adjustment.

2. Field of application

This method is related to the annoyance of noise and is not applicable to evaluation of the risk of hearing damages.

The method is a supplement to environmental noise measurements methods. Guidelines on how to perform such measurements in the field should be found in the relevant standards.

3. References

The following normative documents contain provisions which constitute - through reference in this text - provisions of this Nordtest Method. Parties using this Nordtest Method are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Nordtest as well as members of ISO and IEC maintain registers of currently valid International Standards.

1. IEC Publication 61672, Electroacoustics - Sound level meters
2. IEC Publications 651 and 60651 Sound level meters
3. ISO 1996/1, Acoustics - Description, measurement, and assessment of environmental noise. Part 1: Basic quantities and assessment procedures

1) To be published, replaces IEC 60651 and IEC 60804.
4. Definitions

4.1 Sound pressure level, in decibels, $L_p$

The sound pressure level $L_p$ is given by

$$L_p = 10 \log \left( \frac{p}{p_0} \right)^2$$

$p = $ root mean square sound pressure, in pascals;
$p_0 = $ reference sound pressure (20 μPa).

4.2 Weighted sound pressure level, in decibels, $L_{PAF}$

When the sound pressure $p$ is weighted in accordance with frequency weighting A and time-weighted in accordance with characteristic F (Fast), the weighted sound pressure level is denoted $L_{PAF}$.

4.3 Energy-equivalent A-weighted sound pressure level, in decibels, $L_{eq,T}^{2}$

The value of the A-weighted sound pressure level of a continuous steady sound that has within a specified time period the same mean square sound pressure as a sound whose level varies with time. It is defined as

$$L_{eq,T} = 10 \log \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_0^2} \, dt \quad [dB]$$

$L_{eq,T} = $ energy-equivalent sound pressure level for the time interval T, starting at the time $t_1$ and ending at the time $t_2$, [dB];
$p_0 = $ reference sound pressure (20 μPa);
$p(t) = $ instantaneous value of the sound pressure of the noise signal, [Pa].

4.4 Impulse

The sudden onset of a sound is defined as an impulse.

Note: The definition includes only the onset of a sound, not the sound as a whole. "Sudden" is based on an auditory judgement, which is expressed in terms of physical measurements in this method.

The character and prominence of the impulse in the immission point depends on the character of the emitted sound, the distance and propagation path from the sound source and the background noise. Therefore the impulsiveness of a sound is characterised by the onset of the sound independently of the category of the sound source.

4.5 Onset

For the purpose of this method the onset of a sound is defined as the part of the positive slope of the time history of L_{PAF} where the gradient exceeds 10 dB/s.

The starting point of an onset is the point where the gradient first exceeds 10 dB/s. The end point of an onset is the first point after the starting point where the gradient decreases to less than 10 dB/s. Irregularities (on the onset) shorter than 50 ms are left out of account.

2 The expression "equivalent noise level" has generally been used in the present Nordtest method in order to simplify the text.
4.6 Level difference
The level difference of an impulse is the difference in dB of $L_{PAF}$ between the level of the end point $L_e$ and the level of the starting point $L_s$ of the onset.

4.7 Onset rate
The onset rate is the slope in dB/s of the straight line that gives the best approximation to the onset between the starting point and the end point.

Note: For pass-bys of e.g. road vehicles, trains or aircraft the onset rates shall be determined as the slope in the level range $L_e - (L_s - L_o)/2$ to $L_o$, i.e. the slope of the upper half of the level difference.

![Diagram of Level Difference and Onset Rate](image)

Figure 1. Time history of the A-weighted sound pressure levels with time weighting F (Fast). The figure illustrates the onset ratio (OR) and the level difference (LD) for the two most prominent impulses. Gradients of 10 dB/s are indicated with short line segments.

4.8 Measurement time interval
The time interval within which the squared sound pressure is integrated and averaged to determine the energy-equivalent sound pressure level.

4.9 Reference time Interval
The time interval over which the noise exposure is averaged to determine the energy-equivalent sound pressure level.

4.10 Predicted prominence
The predicted prominence, $P$, is a measure, calculated from onset rate and level difference, which gives a good correlation with listening tests on how prominent impulsive sounds are perceived. $P$ increases with increasing level difference and onset rate.

4.11 Adjustment to $L_{Aeq}$
A term, $K_c$ in dB, that is added to the measured $L_{Aeq}$ to account for the extra annoyance of impulsive noise.
5. Instrumentation

Measurement equipment applied for this measuring method shall be Class 1 as specified by IEC 651, 60651 or 61672. The complete measuring system shall comply with the IEC requirements, be it a sound level meter or a larger system including DAT-recorders or PC-based analysers.

The electric background noise level in the measuring set-up shall be at least 10 dB lower than the acoustic background noise level. Special care shall be taken to ensure that the system is not overloaded during measurement.

The equipment applied for the measurement shall be specified in the report. Special equipment shall be described.

The equipment shall be calibrated according to relevant regulations and guidelines for the actual measurement.

6. Measurements

Measurements shall be made on the basis of $L_{PAF}$, the A-weighted sound pressure level with time weighting F (Fast). The measurements may be performed by either digital or analogue methods or a combination of these.

6.1 Digital recording and signal processing

The A-weighted sound pressure level with time weighting F shall be sampled with time intervals in the range 10-25 ms. (incl.). Measurements made on the basis of short-term $L_{Aeq}$-values (e.g. 10 ms) shall (e.g. by computation) be approximated to time weighting F before the readings are taken.

Note: Measurements based on a series of short-term $L_{Aeq}$-values may be converted to a series of $L_{PAF}$-values by the following formulas:

$$L_{PAF,t} = 10 \cdot \log \left( \left( \frac{\tau}{\Delta t} - 1 \right) \cdot 10^{\frac{L_{PAF,n}}{10}} + 10^{\frac{L_{Aeq,n}}{10}} \right)$$

$L_{Aeq,n}$  The n'th short-term $L_{Aeq}$-value

$L_{PAF,n}$  A-weighted sound pressure level with time weighting F at the time of the n'th $L_{Aeq}$-value, $L_{Aeq,n}$

$\tau$  Time constant for the time weighting. For F: $\tau = 125$ ms

$\Delta t$  Time between the $L_{Aeq}$-values (and the integration time)

$\log$ is the logarithm with base 10

From a successive series of sound pressure levels with time weighting F, $L_{PAF,t,n}$ the starting point s and the end point e of an onset are defined from the procedure1)-4). The symbols used are defined below.

1) The starting point s is the first point where the slope is larger than 10 dB/s:

$$L_{s+1} - L_s > \frac{10}{f} \left[ \frac{\text{dB/s}}{\text{1/s}} \right]$$

2) The end point e is the first point after the starting point where the slope is smaller than 10 dB/s:

$$L_{e+1} - L_e < \frac{10}{f} \left[ \frac{\text{dB/s}}{\text{1/s}} \right]$$

3) A new starting point occurs when condition 1) is met again.
4) If a new starting point s1 occurs within a period of 50 ms after the end point e, then end point e and start point s1 shall be neglected if the following conditions are met:

\[(L_{e1} - L_e)/(t_{e1} - t_e) > 10 \text{ dB/s} \text{ and } (L_{e1} - L_e)/(t_{e1} - t_e) > 10 \text{ dB/s}\]

e1 is the end point after the new starting point s1. If point e is neglected, point e1 takes over the name e.

s+1 denotes the point one sample after point s. \(L_s\) is the level of point s, and \(t_s\) is the time of sampling; \(L_e\) is the level of point e and \(t_e\) is the time of sampling, and so on. f is the sampling frequency.

For each onset the level difference is \(L_s - L_e\), and the onset rate is found from the "least-squares method" (linear regression) of the points from s to e (incl.).

Note 1: For pass-bys of vehicles, aircraft etc. the onset rates shall be determined over the level range \(L_s - (L_e - L_s)/2\) to \(L_e\), i.e. the slope of the upper half of the level difference.

Note 2: In some measuring systems, the onset rate may be determined from the F-weighted samples as \(-60/T\), where T is the reverberation time measured directly on the onset of the sound. Other systems require that the sound samples are reversed before such a measurement can be performed.

6.2 Analogue recordings

By analogue recording care shall be taken that the vertical writing speed (the level) is not limited by the writing system. By recordings in true time a writing speed of at least 1000 dB/s is necessary.

By visual readings of the onset rate from level recordings, the horizontal speed (the time) shall be sufficient to ensure a satisfactory accuracy of the gradient of the onset. A slope of 45° is recommended.

By the approximation of the onset to a straight line, irregularities shorter than 50 ms on the generally increasing curve (even decreasing levels) do not indicate the start of a new onset.

7. Predicted prominence, P

In periods of half an hour a number of impulses with the apparently highest onset rates and level differences shall be selected. For noise with shorter duration the impulses shall be selected during the whole period. For each selected impulse the predicted prominence, P, is calculated from:

\[P = 3 \cdot \log \text{(onset rate/[dB/s])} + 2 \cdot \log \text{(level difference/[dB])} \quad \text{(1)}\]

where the "onset rate" in dB/s and the "level difference" in dB are defined in the clauses 4.6 and 4.7. \(\log\) is the logarithm with base 10. The impulse with the highest value of P gives the final result.

Note: The general form of the expression for P is: \(P = k_1 \cdot \log\text{(onset rate)} + k_2 \cdot \log\text{(level difference)}\). The constants \(k_1\) and \(k_2\) have been estimated from the results of listening tests. It is also taken into account that the relation between P for very sudden and loud impulses and P for slow level changes shall be large. P was furthermore designed to give a maximum around 15. With the constants given in formula (1) the predicted prominence explains 73% of the variance in the answers from the listening test mentioned in [2].

8. Adjustment to \(L_{Aeq}\) (Optional)

For sounds with onset rates larger than 10 dB/s the following adjustment \(K_i\), based on the predicted prominence \(P\), may be applied:

\[K_i = 1.8 \cdot (P - 5) \text{ dB, for } P > 5, \quad K_i = 0 \text{ dB for } P \leq 5 \quad \text{(2)}\]

It is proposed that this adjustment is made to \(L_{Aeq,30\text{min}}\) on the basis of the one event with the highest value of P occurring during the 30-minute period.
Note 1: According to this proposal the rating level $L_{Ar,T}$ over the reference time interval $T$ related to the impulse characteristics is found from:

$$L_{Ar,T} = 10 \log \left( \frac{1}{T} \sum_{N}^{10} 10^{\Delta t_N + K_{IN}} \right)$$

where:
- $T$ is the duration of the reference time interval
- $\Delta t_N$ is the durations of the measurement time intervals, 0.5 hour
- $L_{Aeq,N}$ is the equivalent noise level of the time periods $\Delta t_N$
- $K_{IN}$ is the adjustments to $L_{Aeq,N}$

Note 2: The general form of formula (2) is: $K_i = k_3 \cdot (P - k_4)$, for $P > k_4$, $K_i = 0$ for $P \leq k_4$. The constant $k_3$ gives the inclination of the correlation between $K_i$ and $P$, and $k_4$ defines the lower limit for adjustment to $L_{Aeq}$. The values of the constants $k_3$ and $k_4$ have been determined to give correspondence with the extra annoyance reported in the literature for different kinds of noise sources. As the annoyance depends on the level and characteristics of the noise, the kind of sound source, the context and social factors, and as the adjustment $K_i$ is meant to compensate for the extra annoyance from the impulses, it might be considered to operate with values of $k_3$ and $k_4$ that depends on the category of sound source.

Note 3: The time period of 30 minutes for adjustment of $L_{Aeq}$ is a preliminary choice based on considerations of reasonableness and ease of measurements and administration. There are no systematic investigations behind this choice of period, and the principle should be considered in more detail when investigations of the relevant period are made.

Note 4: In the present Nordic guidelines for environmental noise, an adjustment of 5 dB is made on the basis of subjective judgement, and there are no possibilities of giving a graduated adjustment to $L_{Aeq}$ or making the adjustments in periods of half an hour. Until revisions of these guidelines have been made, this present method may be used as a support of the subjective judgement. It is recommended to give the 5-dB adjustment when $K_i > 3$ and when the impulses are characteristic of the working operations.

9. Accuracy

Although the information about the measurements shall be given in terms of sound pressure levels, the method is not sensitive to the absolute calibration of the measuring equipment.

The working conditions of the source may be more critical than for measurements involving long-term averaging as e.g. measurements of $L_{Aeq}$.

In [3] it was found that the mean standard deviations of the results of 16 different noise examples from 4 laboratories using 4 different measuring set-ups was 0.3 on the prominence $P$ and 0.6 dB on the adjustment $K_i$.

10. Information to be reported

The report shall contain the information required by the relevant guidelines for the noise measurements. Additionally the following information shall be given:

- State that the measurement has been performed in accordance with the specifications in the present Nordic test method
- Type, make and model of Recording and analysis equipment
- Sampling rate for $L_{PAF}$
- Procedure used for the measurement of level difference and onset rate
- The working conditions that cause the impulses and the time of the specific measurements
- Weather conditions as required in relevant guidelines or standards
- Measured values of level differences and onset rates
- Calculation results of the prominence $P_i$ and the adjustment $K_i$ and associated uncertainties

11. Bibliography

The background of the method is described in:


2) Pedersen, T. H., *Impulsive noise. An objective measuring method for the prominence of impulsive sounds and for the adjustment of $L_{Aeq}$* (report in Danish with expanded English summary),

Annex B - Result in tabular form

**KILDE Akustikk AS**

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