Impulsive Noise

Objective Method for the Measurement of Prominence of Impulsive Sounds and for Adjustment of L_{Aeq}

Torben Holm Pedersen

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 added to the measured L_{Aeq}, if prominent impulses are present in the noise, to compensate for the extra annoyance due to the impulses.

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

Impulsive sounds are characterised by a sudden onset, which means that they are noticed more than continuous noise types, which may mean that they are perceived louder and that the sound source is identified more easily.

This 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 of the impulses. The audibility of the impulses shall exceed a certain limit before the impulses are prominent. Below this limit no adjustment is made to L_{Aeq}. When the prominence rises, the adjustment increases. The adjustment is calculated from a logarithmic measure for the prominence of the impulses based on 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. Definitions

2.1 General Presumption

Sound pressure levels, L_{pAF}, mentioned in the definitions are A-weighted levels with time weighting F.

2.2 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 auditive 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.

2.3 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.

2.4 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.

2.5 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 found from the level range $L_e - (L_e - L_s)/2$ to L_e.

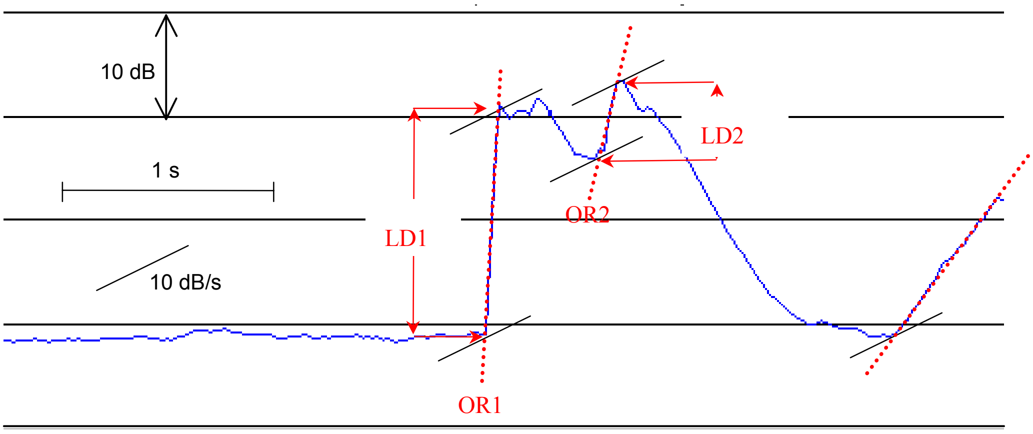

Figure 1
Time history of the A-weighted sound pressure levels with time weighting F. The figure illustrates the onset ratio (OR) and the level difference (LD) for the two most prominent impulses. Gradients of 10 dB/s are indicated with short line segments.

3. Measurements

Measurements shall be made on the basis of L_{pAF}, the A-weighted sound pressure level with time weighting F conforming with Class 1 as specified in IEC 61672 or IEC 651. Either digital or analogue methods or combinations of these may be used for the measurements.

3.1 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_{eq}-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 formula:

$$L_{pAF,n} = 10 \cdot \lg\left[\left(\left(\frac{\tau}{\Delta t} - 1\right) \cdot 10^{\frac{L_{pA,F,n-1}}{10}} + 10^{\frac{L_{Aeq,n}}{10}} \right) / \left(\frac{\tau}{\Delta t}\right) \right]$$

$L_{Aeq,n}$ 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 LAeq-value, LAeq,n

τ Time constant for the time weighting. For F: τ = 125 ms

Δt Time between the L_{Aeq}-values (and the integration time)

lg is the logarithm with base 10

From a successive series of sound pressure levels with time weighting F, $L_{pAF,n}$, 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: $L_{s+1} - L_s > 10/f$.

2) The end point e is the first point after the starting point where the slope is less than 10 dB/s: $L_{e+1} - L_e < 10/f$.

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 starting point s1 shall be neglected if the following conditions are met:

   $(L_{e1} - L_e)/(t_{e1} - t_e) > 10$ dB/s and $(L_{s1} - L_s)/(t_{s1} - t_s) > 10$ 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 $L_e - L_s$, and the onset rate is found from the "least-squares method" (linear regression analysis) of the points from s to e (incl.).

Note 1: For pass-bys of vehicles, aircraft ... the onset rates shall be determined over the level range $L_e - (L_e - L_s)/2$ to L_e.

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.

3.2 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 re-commended.

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.

4. 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:

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

where the "onset rate" in dB/s and the "level difference" in dB are defined in clauses 2.4 and 2.5. lg 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: $P = k_1 \cdot \log$ (onset rate) $+ k_2 \cdot \log$ (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 [1].

5. Adjustment to L_{Aeq}

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

$$K_I = 1.8 \cdot (P - 5), \text{ for } P > 5, \quad K_I = 0 \text{ for } P \leq 5 \qquad (2)$$

It is suggested that this adjustment is made to $L_{Aeq,30min}$ 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:

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

where:

T is the duration of the reference time interval

ΔtN is the durations of the measurement time intervals, 0.5 hour

$L_{Aeq,N}$ is the equivalent noise level of the time periods Δt_N

$K_{I,N}$ 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 depend on the 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.

6. 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.

7. 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:

- Recording and analysis equipment, type, make and model
- 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 the standard
- Measured values of level differences and onset rates
- Calculation results of the prominence, P, and the adjustment, K_I, and associated uncertainties

8. References

The background of the method is described in:

1. Pedersen, T. H., *Audibility of impulsive sounds in environmental noise*. Inter-Noise 2000 CD-ROM proceedings.

2. Pedersen, T. H., *Impulsive noise. An objective measuring method for the prominence of impulsive sounds and for the adjustment of* L_{Aeq}. AV 1005/00. DELTA report, 2000. (Report in Danish with expanded English summary)

3. Andersson, H., et al., *Round Robin Test of an objective measuring method for the determination of the prominence of impulsive sounds and for the impulse adjustment of* L_{Aeq} .SP Rapport 2000:xx, Acoustics, Borås 2000.