ISO/TS 20065:2022(E)

ISO TC 43/SC 1~~/WG 45~~

Date: 2022-~~09-28~~xx

Acoustics — Objective method for assessing the audibility of tones in noise — Engineering method

Acoustique — Méthode objective d'évaluation de l'audibilité des tonalités dans le bruit — Méthode d'expertise

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Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part~~-~~ 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part~~ 2 (see www.iso.org/directives~~ 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see ~~www.iso.org/patents~~www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see ~~www.iso.org/iso/foreword.html~~www.iso.org/iso/foreword.html.

This document was prepared by Technical ~~Committee~~ ISO/TC~~-~~ 43, *Acoustics*, Subcommittee SC~~-~~ 1, *Noise*.

This ~~Technical Specification~~first edition of ISO/TS 20065 cancels and replaces ~~the Publicly Available Specification ISO/~~ISO/PAS~~-~~ 20065:~~-~~2016, which has been technically revised~~ primarily editorially to provide a clearer technical specification standard that can be more easily implemented in software~~.

The main changes are as follows:

— ~~Guidance~~guidance on residual sound (~~clause~~ 5.3.1~~)~~);

— ~~A~~a file containing a number of other example audio files and a guidance document can be downloaded from ~~https://standards.iso.org/iso/20065~~https://standards.iso.org/iso/20065 (from “Prominent tones in wind turbine noise Round robin test IEC 61400~~-~~-11, ISO~~-~~/PAS 20065~~”)~~”);

— ~~Editorial~~editorial changes for clarity and to meet the latest ISO standards, including definitions, measures, formulae, ~~alligned~~aligned and streamlined terminology, and additional background information.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at ~~www.iso.org/members.html~~www.iso.org/members.html.

Acoustics ~~–~~— Objective method for assessing the audibility of tones in noise ~~–~~— Engineering method

1 Scope

This document describes a method for the objective determination of the audibility of tones in environmental noise.

This document is intended to augment the usual method for evaluation on the basis of aural impression, in particular, in cases in which there is no agreement on the degree of the audibility of tones. The method described can be used if the frequency of the tone being evaluated is equal to, or greater than, 50 Hz. In other cases, if the tone frequency is below 50 Hz, or if other types of noise (such as screeching) are ~~to be~~ captured, then this method cannot replace subjective evaluation.

~~Note:~~ NOTE The procedure has not been validated below 50 Hz.

The method presented herein can be used in continuous measurement stations that work automatically.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

~~<std>~~ISO 1996-1, *Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures*~~</std>~~

~~<std>~~IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*~~</std>~~

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1996-1 and the following apply.

~~Unless otherwise stated, the reference level for dB values in these definitions is 20 µPa.~~

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at ~~https://www.iso.org/obp~~https://www.iso.org/obp

— IEC Electropedia: available at ~~https://www.electropedia.org/~~https://www.electropedia.org/

NOTE Unless otherwise stated, the reference level for decibels (dB) values in these definitions is 20 µPa.

3.1
tone
sound characterized by a single-frequency component or narrow-band components

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3.2
tone frequency
f_T
frequency of the *spectral line* (3.23) (or mid-band frequency of the narrow-band filter), to the level of which the *tone* (3.1) contributes most strongly

Note 1 to entry: Tone frequency is expressed in hertz (Hz).

3.3
tone level
L_T
energy summation of the *narrow-band level* (3.22) with the *tone frequency* (3.2), f_T, and the lateral lines about f_T, assignable to this tone

Note 1 to entry: Tone level is expressed in decibels (dB).

Note 2 to entry: If the *critical band* (3.5) for the frequency, f_T, under consideration contains a number of tones, then the tone level, L_T, is the energy sum of these tones. This level, L_T, is then assigned to the frequency of the participating tone that has the maximal value of *audibility* (3.4), ΔL.

Note 3 to entry: The method for the determination of the tone level, L_T, of a tone in a critical band is described in 5.3.3.

3.4
audibility
ΔL
Audibility of tones is the arithmetic difference between the *tone level* (3.3), L_T, and the *masking threshold* (3.15), L'_T

Note 1 to entry: Audibility is expressed in decibels (dB).

Note 2 to entry: The method for the determination of the *decisive audibility* (3.24), ΔL_j, of a *narrow-band spectrum* (3.12) is described in 5.3.8.

3.5
critical band
frequency band with a *bandwidth* (3.17), Δf_c within which the auditory system integrates the sound intensity in the formation of loudness and within which it integrates the sound intensity in the formation of the *masking threshold* (3.15)

Note 1 to entry: Critical band is expressed in hertz (Hz).

Note 2 to entry: This characteristic of a critical band (see also References [4] and [5]) holds only for a restricted sound level range. This dependence is neglected here.

3.6
mean narrow-band level of the critical band
L_S
energy mean value of all *narrow-band levels* (3.22) in a *critical band* (3.5), except for the spectral line for the frequency, f_T, under consideration and all lines that exceed this mean value by more than 6 dB

Note 1 to entry: Mean narrow-band level of the critical band is expressed in decibels (dB).

Note 2 to entry: The method for the determination of the mean narrow-band level, L_S, of the masking noise is described in 5.3.2 and Annex D ~~(iterative method)~~.

3.7
critical band level
L_G
level of noise that is assigned to the *critical band* (3.5) that describes the masking characteristic of the noise for one or more tones of the noise in this critical band

Note 1 to entry: Critical band level is expressed in decibels (dB~~.~~).

Note 2 to entry: See *narrow-band level* (3.22) and Annex C for masking.

Note 3 to entry: For the definition formula for L_G, see Formula (12).

3.8
sampling frequency
f_S
number of samples taken per second

Note 1 to entry: Sampling frequency is expressed in hertz (Hz~~.~~).

Note 2 to entry: The analogue data provided continuously are converted into samples through sampling at discrete time intervals for digital processing.

Note 3 to entry: To ensure the reproducibility of a digitized signal, the Shannon theorem requires that the sampling frequency, f_S, is at least 2 times the highest frequency of the signal components used for evaluation in the time signal [$f_S \geq 2 f_N$, see also *aliasing* (3.9), *antialiasing filter* (3.10) and *useable frequency* (3.20)]. Discrete Fourier Transform (DFT) ~~analyzers~~analysers thus need a sampling frequency that is at least 2,56 times the maximum frequency to be analysed.

3.9
aliasing
reflection in the *line spectrum* (3.12) of frequency components from the range above the *sampling frequency* (3.8) divided by two ($f_S/2$) in the range below $f_S/2$

Note 1 to entry: *Antialiasing filters* (3.10) are used to avoid errors through such reflections.

Note 2 to entry: Half the sampling frequency ($f_S/2$) is also known as the Nyquist frequency.

3.10
antialiasing filter
low-pass filter
ideal filter that allows frequencies below half the *sampling frequency* (3.8) to pass through completely (without influencing the signal), but completely block all higher frequencies

Note 1 to entry: To prevent *aliasing* (3.9), the noise under investigation shall be filtered using an antialiasing filter before analogue-to-digital conversion.

Note 2 to entry: Real aliasing filters have a final damping (generally 120 dB/octave) within the blocking range, i.e. signal components in this transition range are reflected (damped). For example, in the transformation of 2 048 (2 k) data points, 1 024 frequency lines are calculated and 800 lines shown. A component in the line number 1 248 is folded back into the line number 800. With a low-pass filter of 120 dB/octave the damping of these components is approximately 75 dB.

Note 3 to entry: The usual commercial DFT ~~analyzers~~analysers have an antialiasing filter, the limit frequency of which can be switched automatically with the selectable sampling frequency. The reflection of simulated *narrow-band levels* (3.22) is suppressed.

3.11
block length
N
block of sampling values that in discrete form represents a time-limited range of the time signal to be analysed

Note 1 to entry: In contrast to frequency analysis with analogue and digital filters, the noise with the Fast Fourier Transform is processed in data blocks. In general, these blocks embrace only a part of the noise recording. The block length, *N*, expresses the number of data points processed at the same time. Regarding the Fast Fourier Transform, the value of *N* generally has the integer of power of 2. It has a value, for example, of $N = 2^{10} = 1\,024$ data points.

3.12
line spectrum
narrow-band spectrum
frequency spectrum
plot of the sound pressure level (*narrow-band level*) (3.22) as a function of the frequency in frequency bands of constant *bandwidth* (3.17) (*line spacing*, Δf) (3.13)

Note 1 to entry: A-weighting of the level is assumed in this document.

Note 2 to entry: DFT analysis delivers a line spectrum, in which each line represents the output of a filter, the mid-frequency of which corresponds to the frequency of the *spectral line* (3.23).

Note 3 to entry: Line spectrum is sometimes referred to as frequency spectrum.

3.13
line spacing
frequency resolution
distance, between adjacent *spectral lines* (3.23), where the line spacing in the DFT is given by

$$\Delta f = f_S / N$$

where

f_S is the *sampling frequency* (3.8);

N is the *block length* (3.11).

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Note 1 to entry: Line spacing is expressed in hertz (Hz~~.~~).

Note 2 to entry: In this document, the line spacing is 1,9 Hz ≤ Δf ≤ 4,0 Hz.

3.14
time window
time data set of the signal segment (*block length*) (3.11) that is multiplied by a weighting function (window function)

Note 1 to entry: In accordance with the definition of the Fourier integral, a prerequisite of the DFT analysis is that the time data set is periodic. If this is not the case (as with stochastic signals), cut-off effects at the edges of the time window will lead to distortion of the spectrum. These distortions are avoided through weighting functions such as the Hanning ~~Function~~function.

Note 2 to entry: For more information on window and weighting functions, see, for example, Reference [~~5~~6] and Annex A.

3.15
masking threshold
L'_{T}
audibility (3.4) threshold for a specific sound in the presence of a masking sound (masker)

Note 1 to entry: Masking threshold is expressed in decibels (dB~~.~~).

Note 2 to entry: See Annex C for more information on the audibility threshold and the masking noise.

3.16
masking index
a_{v}
arithmetic difference between the *masking threshold* (3.15), L'_{T} , and the *critical band level* (3.7), L_{G}, of the masking noise

Note 1 to entry: ~~masking~~Masking index is expressed in decibels (dB~~.~~).

Note 2 to entry: For frequency-dependent masking index, a_{v}, masking and masking noise, see Annex C.

3.17
bandwidth
frequency bandwidth
frequency range of a number of adjacent *spectral lines* (3.23)

Note 1 to entry: Bandwidth is expressed in hertz (Hz~~.~~).

Note 2 to entry: If the width of a frequency band is calculated for which its beginning or end does not correspond to the boundary between two spectral lines, then only the spectral lines that lie in their full width within the calculated frequency range are assigned to the frequency band.

3.18
distinctness
clarity ratio of the prominence of a tone based on a bandpass noise to the prominence of a sinusoidal tone of the same *tone frequency* (3.2), f_{T}, and same *tone level* (3.3), L_{T}

Note 1 to entry: Distinctness is expressed in ~~%.~~percentage (%).

3.19
edge steepness
slope of the level difference between the maximum *narrow-band level* (3.22) of a tone, L_{Tmax}, and the narrow-band levels of the first line below/above the tone to the corresponding frequency difference

Note 1 to entry: Edge steepness is expressed in decibels per hertz (dB/Hz~~.~~).

3.20
useable frequency
f_N
upper limit frequency of the signal components used for evaluation

Note 1 to entry: Useable frequency is expressed in hertz (Hz.).

3.21
investigation range
frequency range within which tones are investigated in the *line spectrum* (3.12)

Note 1 to entry: Investigation range is expressed in hertz (Hz.).

3.22
narrow-band level
averaged level within a *spectral line* (3.23)

Note 1 to entry: Narrow-band level is expressed in decibels (dB.).

3.23
spectral line
frequency band of *bandwidth* (3.17), Δf (*line spacing*) (3.13), in a *line spectrum* (3.12)

Note 1 to entry: Spectral line is expressed in hertz (Hz.).

3.24
decisive audibility
ΔL_j
maximum *audibility* (3.4), ΔL in the individual spectrum, *j*

Note 1 to entry: Decisive audibility is expressed in decibels (dB.).

3.25
mean audibility
ΔL,
energy average of *decisive audibility* (3.24)), ΔLj, calculated for each narrow-band averaged spectrum

Note 1 to entry: Mean audibility is expressed in decibels (dB.).

4 Measurement procedure

4.1 General

The measurement procedure will depend on the aims. The requirements for the measurement and assessment procedure in terms of the choice of measurement point, measurement time and duration of measurement, extraneous noise, etc. shall be satisfied.

The variable for determination of audibility of prominent tones is the sound pressure, $p(t)$. For frequency analysis, the A-weighted equivalent continuous sound pressure level, L_{Aeq}, as given in ISO 1996-1, is toshall be established for the respective spectral lines. If the line spectrum is unweighted (linearLIN or Z), then it shall be corrected to A-weighting in accordance with IEC 61672-1.

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4.2 Measurement instruments

Sound level meters that meet, or exceed, the requirements of Class 1 in IEC 61672-1 shall be used. These have a frequency weighting “A”/“LIN” or “A”/“Z” with a lower limit frequency equal to, or below, 20 Hz.

Additional instruments such as recording instruments (digital or magnetic tape) may also be used. The measured values derived through recording instruments shall lie within the tolerance range given in IEC 61672-1.

Analysis of frequency components in the measurement signals is performed using a frequency ~~analyzer~~analyser. The constant line spacing, Δf, shall lie in the range 1,9 Hz to 4 Hz (inclusive). The use of the Hanning window is mandatory in this document. For further processing, it shall be ensured that the digitalization of the sound pressure signal across the entire dynamic range used has a resolution of at least 0,1 dB.

Before it is processed further, the analogue measurement signal shall be passed through a steep low-pass filter (antialiasing filter) to avoid errors in frequency analysis. The sampling frequency (see 3.8) shall be at least two times the maximum usable frequency present (see 3.20). The Hanning window is to be used as time window to reduce lateral bands (see 3.14).

4.3 Merging the basic spectra

The spectra for the prominent tone assessment shall have an averaging time of approximately 3 s. Due to the line spacing of 1,9 Hz to 4 Hz (see 4.2) and the typical frequency range, f, of a few kHz, the basic spectra given by the frequency ~~analyzer~~analyser will have an averaging time below 1 s. To get the averaging time of approximately 3 s, a number of basic spectra shall be merged. This shall be done line by line with Formula (1):

$$\sout{L_i = 10\,\lg\left(\frac{1}{N}\sum_{j=1}^{N}10^{0,1L_{i,j}/\text{dB}}\right)\text{dB}}\ L_i = 10\,\lg\left(\frac{1}{N}\sum_{j=1}^{N}10^{0,1L_{i,j}/\text{dB}}\right)\text{dB} \qquad (1)$$

where

$L_{i,j}$ is the level of the i^{th} spectral line for the j^{th} spectrum, in dB;

N is the number of merged spectra.

5 Evaluation

5.1 General information

The aim of evaluation is to establish the audibility, ΔL. The procedure is the same for stationary and non-stationary noises. For tones that can only just be perceived, a quaver (eighth note) is to be adopted as a base time that is adequate for hearing. However, comprehensive studies have shown that the lower limit for use of the procedure is reached at averaging times of approximately 3 s. Lower averaging times lead to unjustified values of audibility, ΔL (too high, but also too low). Signals that have very high level and/or frequency dynamics that no longer correspond with a 3-second averaging can, therefore, not be evaluated using this document. The following conditions shall be satisfied for the measurements.

— The extended uncertainty, U, of the audibility, ΔL, with a coverage probability of 90 % in a bilateral confidence interval (see Clause 6) shall not exceed ±1,5 dB. This is generally the case with evaluation of at least 12 time-staggered narrow-band averaged spectra. If there are less than 12 averaged spectra then the uncertainty shall be taken into consideration as given in Clause 6.

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