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Acoustics — Method for calculating loudness —

Part 1:
Stationary sounds

Acoustique — Méthode de calcul du niveau d'isosonie —

Partie 1: Bruits stationnaires

[Revision of first edition (ISO 532:1975)]

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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.

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ISO 532-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*.

ISO 532-1 is the first part of a new standards series ISO 532-x, which replaces ISO 532:1975, *Acoustics – Method for calculating loudness level*. ISO 532-x consists of the following parts, under the general title *Acoustics — Methods for calculating loudness*:

— *Part 1: Stationary sounds*

— *Part 2: Time-varying sounds*

Introduction

Loudness and loudness level are two perceptual attributes of sound describing absolute and relative sensations of sound strength perceived by a listener under specific listening conditions. Due to inherent individual differences among people, both loudness and loudness level have the nature of statistical estimators characterized by their respective measures of central tendency and dispersion determined for a specific sample of the general population.

The object of this standard is to specify calculation procedures based on physical properties of sound for estimating loudness and loudness level of sound as perceived by listeners with otologically normal hearing under specific listening conditions. This procedure seeks single numbers that can be used in many scientific and technical applications to estimate the perceived loudness and loudness level of sound without conducting separate human observer studies for each application. Because loudness is a perceived quantity, the perception of which may vary among people, any calculated loudness value represents only an estimate of the average loudness as perceived by a group of individuals with otologically normal hearing

This part of ISO 532 is limited to calculation of loudness and loudness level of stationary sounds and the calculations are based on the spectral properties of a sound. This calculation method is based on Moore-Glasberg loudness calculation algorithms [11, 15, 17]. Part 2 of ISO 532 [1)] covers the procedures for calculation of loudness and loudness level of arbitrary non-stationary (time-varying) sounds including stationary sounds as a special case.

The standard describes the calculation procedures leading to estimation of loudness and loudness level and provides an executable computer program. The software provided with this International Standard is entirely informative and provided for the convenience of the user. Use of the provided software is not required for conformance with the International Standard.

The method in the current standard differs from the methods included the previous ISO 532:1975 [3]. The former ISO 532:1975, A method (Stevens loudness [18]), was removed as this method was not often used and its predictions were not accurate for sounds with strong tonal components. The former ISO 532:1975, B method (Zwicker loudness), was removed as this method, and the revised version of that method in the German standard DIN 45631:1991 [12], both predict equal-loudness level contours that are not in accordance with those in ISO 226:2003 [1]. The method described in the current standard also improves precision of calculated loudness at low frequency range and allows for calculation of loudness under conditions where the sound differs at the two ears.

NOTE Equipment or machinery noise emissions/immissions may also be judged by other quantities defined in various International Standards (see e.g. ISO 1996-1 [4], ISO 3740ff [5], and ISO 9612 [6]).

1) Under preparation

Acoustics — Method for calculating loudness —

Part 1:
Stationary sounds

1 Scope

This part of ISO 532 specifies a method for estimating the loudness and loudness level of stationary sounds as perceived by otologically normal adult listeners under specific listening conditions. The document provides an algorithm for the calculation of monaural or binaural loudness for sounds recorded using a single microphone, using a head and torso simulator, or for sounds presented via earphones.

NOTE 1 Problems of binaural calculations are discussed in Annex A.

The method is based on the Moore-Glasberg algorithm and starts by converting a specified signal spectrum into a series of sinusoidal components representing that spectrum. This series is then transformed into a specific loudness pattern by applying four consecutive transformations, each of which is directly related to physiological and psychological characteristics of the human hearing system. Loudness is calculated from the specific loudness pattern.

NOTE 2 Users who do not wish to understand the details of the calculation method can still apply the standard by using an executable computer program which is entirely informative and provided with the standard for the convenience of the user.

This method can be applied to tones, broadband noises, and to complex sounds with sharp line spectral components, e.g., transformer hum or fan noise. It has been shown that this method provides a good match to the contours of equal loudness level as defined in ISO 226:2003 [1] and the reference threshold of hearing as defined in ISO 389-7 [2].

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61260:1995, *Electroacoustics — Octave-band and fractional-octave-band filters*

IEC 61672-1:2002, *Electroacoustics — Sound level meters — Part 1: Specifications*

IEC/TR 60959, *Provisional head and torso simulator for acoustic measurements on air conduction hearing aids*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
sound pressure level
L_p
ten times the logarithm to the base 10 of the ratio of the square of the sound pressure, p, to the square of a reference value, p_0, expressed in decibels

$$L_p = 10 \lg \frac{p^2}{p_0^2} \text{ dB} \quad (1)$$

where the reference value, p_0, in gases is 20 μPa

NOTE 1 Because of practical limitations of the measuring instruments, p^2 is always understood to denote the square of a frequency-weighted, frequency-band-limited or time-weighted sound pressure. If specific frequency and time weightings as specified in IEC 61672-1 and/or specific frequency bands are applied, this should be indicated by appropriate subscripts; e.g. $L_{p,\text{AS}}$ denotes the A-weighted sound pressure level with time weighting S (slow). Frequency weightings such as A-weighting should not be used when specifying sound pressure levels for the propose of loudness calculation using the current procedure.

NOTE 2 This definition is technically in accordance with ISO 80000-8:2007, 8-22 [8].

3.2
frequency band
continuous set of frequencies lying between two specified limiting frequencies

NOTE 1 A frequency band is characterized by two values which define its position in the frequency spectrum, for instance its lower and upper cut-off frequencies.

NOTE 2 Frequency is expressed in Hz.

[IEV 702:1995, 702-01-02 [13]]

3.3
filter
any device or mathematical operation which, when applied to a complex signal, passes energy of signal components of certain frequencies while substantially attenuating energy of signal components of all other frequencies

3.4
cut-off frequency
the lowest (f_l) or the highest (f_h) frequency beyond which the response of the device specified by the given bandwidth does not exceed -3 dB relative to the response measured at the centre frequency (f_c)

3.5
band-pass filter
filter that passes signal energy within a certain frequency band and rejects most of the signal energy outside of this frequency band

3.6
filter bandwidth
Δf
for a band-pass filter the difference between f_h and f_l

3.7
one-third-octave band
the frequency band with the width of one-third of an octave as specified in IEC 61260

3.8
band-reject filter
filter that rejects signal energy within a certain frequency band and passes most of the signal energy outside of this frequency band

NOTE A narrow band-reject filter is also called a notch filter.

3.9
band level
L_{pb}
sound pressure level of sound contained within a restricted frequency band (b), expressed in decibels

3.10
one-third-octave-band level
L_T
sound pressure level of sound contained within a frequency band with the width of one-third of an octave, expressed in decibels

3.11
sound spectrum
distribution of sound energy of a particular sound as a function of frequency

3.12
spectrum density level; spectrum level
level of the limit, as the width of the frequency band approaches zero, of the quotient of a specified quantity distributed within a frequency band, by the width of the band, expressed in decibels

NOTE 1 The words "spectrum level" should be preceded by a descriptive modifier describing the measured quantity.

NOTE 2 For illustration, the sound pressure spectrum level L_{ps} at the midband frequency is obtained practically by

$$L_{pbs} = 10 \lg \left[\left(p_b^2 / \Delta f \right) / \left(p_0^2 / \Delta_0 f \right) \right] \text{ dB} \tag{2}$$

where p_b^2 is the time-mean-square sound pressure measured through a filter system, p_0 the reference sound pressure, Δf the bandwidth of the filter system, and $\Delta_0 f$ the reference bandwidth of 1 Hz. For computational purposes, with L_{pb} for the band sound pressure level observed through the filter, the above relation becomes

$$L_{pbs} = L_{pb} - 10 \lg \left[\Delta f / \Delta_0 f \right] \text{ dB} \tag{3}$$

3.13
auditory filter
a filter within the human cochlea describing the frequency resolution of the auditory system, whose characteristics are usually estimated from the results of masking experiments

3.14
auditory filter bandwidth
bandwidth of an auditory filter

3.15
equivalent rectangular bandwidth of the auditory filter for otologically normal persons
ERB_N
auditory filter bandwidth determined by measuring tone detection thresholds in wideband noise passed through band-reject (notch) filters of various bandwidths.

NOTE The subscript N indicates that the value applies for listeners with otologically normal hearing.

3.16
loudness level
sound level of a given sound that is judged by otologically normal persons as loud as the sound pressure level of a reference sound being a frontally incident, sinusoidal plane progressive wave, presented binaurally at a frequency of 1 000 Hz

NOTE 1 Loudness level is expressed in phons.

3.17
calculated loudness level
L_N
loudness level calculated according to the procedure specified in this International Standard.

3.18
loudness
perceived magnitude of a sound, which depends on the acoustic properties of the sound and its manner of presentation to the listener, as estimated by otologically normal listeners

NOTE 1 Loudness is expressed in sones.

NOTE 2 Loudness depends primarily upon the sound pressure although it also depends upon the frequency, waveform, bandwidth, and duration of the sound.

NOTE 3 One sone is the loudness of a sound whose loudness level is 40 phon.

NOTE 4 A sound that is twice as loud as another sound is characterized by double the number of sones.

3.19
calculated loudness
N
loudness calculated according to the procedure specified in this International Standard

3.20
excitation
E
the output of an auditory filter centred at a given frequency, specified in units that are linearly related to power

NOTE 1 An excitation of 1 unit is produced at the output of an auditory filter centred at 1 000 Hz by a tone with a frequency of 1 000 Hz with a sound pressure level of 0 dB presented in a free field with frontal incidence.

NOTE 2 Since excitation E is specified relative to the reference value specified in NOTE 1, it is a dimensionless quantity.

3.21
excitation level
L_E
ten times the logarithm to the base 10 of the ratio of the excitation at the output of an auditory filter centred at the frequency of interest to the reference excitation E_0

$$L_E = 10 \lg \frac{E}{E_0} \text{dB} \tag{4}$$

where the reference excitation, E_0 is the excitation produced by a 1 000 Hz tone with a sound pressure level of 0 dB presented in a free field with frontal incidence

3.22
specific loudness
N'
the loudness evoked over a frequency band that is one-ERB_N wide and centred on the frequency of interest

NOTE Specific loudness is expressed in sones per ERB_N.

4 General

The method described in the main part of this document specifies a method for calculating loudness and loudness level based on the Moore-Glasberg procedure.

The procedure involves a sequence of stages. Each stage is described below and the executable software implementing the procedure is included (see Annex C). The description of the procedure is provided so that the user can understand how the procedure works. However, it is envisaged that those wishing to calculate loudness using this procedure will use the computer program (see Annex C) provided with this document that implements the described procedure. It is not expected that the procedure will be implemented "by hand." Such computations would be very time consuming.

NOTE 1 The computational procedure described in this document is an updated version of procedures published earlier elsewhere [11, 14, 16, 17].

NOTE 2 Uncertainties are addressed in Clause 8.

5 Input of signals

5.1 Specifications

5.1.1 General

The spectrum of the signal whose loudness is to be determined shall be specified at each ear in order to calculate loudness. The signal spectrum can be specified in several ways as described below. The spectrum can be specified exactly (methods of 5.1.2 to 5.1.4), or approximately using one-third-octave-band levels (method of 5.1.5). The first three methods may be of interest for synthetic signals or signals analysed by Fast Fourier Transformation. 5.1.5 will be the method usually used for practical purposes. If the spectrum is specified exactly, the predicted loudness will be more accurate than when the spectrum is approximated using one-third-octave-band levels.

5.1.2 Complex tone

This is a sound whose spectrum consists of discrete sinusoidal components. The spectrum can be specified in terms of frequency components that are either harmonically or non-harmonically spaced. The frequency and sound pressure level of each component shall be specified.

5.1.3 Noise consisting of bands of pink or white noise of defined width

The number of noise bands and their widths shall be specified. Each band can be composed of either white noise (with a constant spectrum level within the passband) or pink noise (whose spectrum level within the passband decreases with increasing centre frequency at a rate of 3 dB/octave). For each band, the following shall be specified: the lower cut-off frequency, the upper cut-off frequency and the spectrum level. In the case of pink noise, the frequency at which the spectrum level is determined shall also be specified. Within the procedure, the spectra of bands of noise are approximated by a series of discrete sinusoidal components. When the bandwidth of the noise exceeds 30 Hz, the components are spaced at 10 Hz intervals, and the level of each component is set 10 dB higher than the spectrum level at the corresponding frequency. When the bandwidth of the noise is less than 30 Hz, the components are spaced at 1 Hz intervals, and the level of each component is set equal to the spectrum level at the corresponding frequency.

EXAMPLE A band of white noise extending from 200 Hz to 500 Hz with a spectrum level of 50 dB would be approximated by sinusoidal components with frequencies 205 Hz, 215 Hz, 225 Hz, 235 Hz …. 475 Hz, 485 Hz, 495 Hz, each component having a sound pressure level of 60 dB.

NOTE The spacing of the components (10 Hz or 1 Hz) is not a property of the input signal. The spacing is chosen to approximate the spectrum of the signal with sufficient accuracy for the purpose of the computation of loudness.

5.1.4 Mixture of discrete sinusoidal components and bands of pink or white noise

5.1.2 specifies the former and 5.1.3 specifies the latter.

5.1.5 Sound specified in terms of the sound pressure levels in 29 adjacent one-third-octave bands

The nominal centre frequencies of the 29 adjacent one-third-octave bands are as defined by IEC 61260 within the range 25 Hz to 16 000 Hz. Within each band, the spectrum is assumed to be flat, and, as described for noise bands in 5.1.3 above, the spectrum is approximated as a series of sinusoidal components spaced at 10 Hz intervals or (for centre frequencies of 125 Hz and below) at 1 Hz intervals. The level of each component is calculated as follows. Let the width of a one-third-octave band at a given centre frequency be W (e.g. 230 Hz for a centre frequency of 1 000 Hz). The sound pressure level in that band, L_T, is converted to the spectrum level in that band as: $L_T - 10\lg(W/1\text{ Hz})$ dB. The level of each component in the approximation is then set 10 dB above the spectrum level, i.e., to $L_T - 10\lg(W/1\text{ Hz})\text{ dB} + 10\text{ dB}$.

EXAMPLE Consider the one-third-octave band centred at 1 000 Hz, and assume that the band sound pressure level is 63 dB. The spectrum level is then 63 dB – 10lg(230) dB = 39,4 dB. The spectrum of that one-third-octave band would thus be approximated by components at 890 Hz, 900 Hz, 910 Hz, 920 Hz … 1 080 Hz, 1 090 Hz, 1 100 Hz, 1 110 Hz, each with a sound pressure level of 49,4 dB.

5.2 Instrumentation

If the one-third-octave-band sound pressure levels as described in 5.1.5 are determined in a sound field this shall be done through the use of a sound acquisition system that conforms to IEC 61672-1 in conjunction with one-third-octave filters that conform to IEC 61260. Equipment used to present the one-third-octave spectrum in real time has to meet the requirements of IEC 61672-1:2002, class 1, or IEC 61260:1995, class 1. The microphone(s) shall have an omnidirectional characteristic or a free-field characteristic. If a head and torso simulator is used it shall conform to IEC/TR 60959. However, the procedure described in this part of ISO 532 applies to the sound that has been already acquired.

6 Description of the method

6.1 Introduction

The method of calculating loudness consists of the following discrete steps:

(1) transformation of the recorded sound spectrum into the sound spectrum at the tympanic membrane for each ear;

(2) transformation of the sound spectrum at the tympanic membrane into the sound spectrum at the oval window;

(3) transformation of the sound spectrum at the oval window into an excitation pattern on the basilar membrane;

(4) transformation of the excitation pattern into a specific loudness pattern;

