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Acoustics — Methods for calculating loudness —

Part 2: Moore-Glasberg method

Acoustique — Méthode de calcul d'isosonie —

Partie 2: Méthode Moore-Glasberg

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Foreword

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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).

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This document was prepared by Technical Committee ISO/TC 43, *Acoustics*.

A list of all parts in the ISO 532- series, published under the general title *Acoustics — Methods for calculating loudness*, can be found on the ISO website.

Introduction

Loudness and loudness level are two perceptual attributes of sound describing absolute and relative sensations of sound strength perceived by a person 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 the ISO 532- series is to specify calculation procedures based on physical properties of sound for estimating loudness and loudness level of sound as perceived by persons with otologically normal hearing under specific listening conditions. Each 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

ISO 532-1 and ISO 532-2 specify two different methods for calculating loudness which may yield different results for given sounds. Since no general preference for one or the other method can presently be stated, it is up to the user to select the method which appears most appropriate for the given situation. Some major features of each of the methods are described below to facilitate the choice.

This document 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 [14-17]. It 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.

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

The Moore-Glasberg method is limited to stationary sounds and can be applied to tones, broadband noises and complex sounds with sharp line spectral components. The method in this document differs from those in ISO 532:1975. Method A of ISO 532:1975 (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 method described in this document also improves the precision of calculated loudness in the low frequency range and allows for calculation of loudness under conditions where the sound differs at the two ears. It has been shown that this method provides a good match to the contours of equal loudness level as defined in ISO 226:2003 and the reference threshold of hearing as defined in ISO 389-7:2005.

The Zwicker method in ISO 532-1 can be applied for stationary and arbitrary non-stationary sounds. The method for stationary sounds in ISO 532-1 differs slightly from the methods included in the previous ISO 532:1975, method B, by specifying corrections for low frequencies and by restricting the description of the approach to numerical instructions only, thus allowing a unique software description. For reasons of continuity, the method given in ISO 532-1 is in accordance with ISO 226:1987 instead of the later revised version, ISO 226:2003.

NOTE Equipment or machinery noise emissions/immissions can also be judged by other quantities defined in various International Standards (see e.g. ISO 1996-1, ISO 3740, ISO 9612 and ISO 11200).

Acoustics — Methods for calculating loudness —

Part 2:
Moore-Glasberg method

1 Scope

This document specifies a method for estimating the loudness and loudness level of stationary sounds as perceived by otologically normal adult persons under specific listening conditions. It 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. The method is based on the Moore-Glasberg algorithm.

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

NOTE 2 Users who wish to study the details of the calculation method can review or implement the source code, which is entirely informative and provided with this document for the convenience of the user.

This method can be applied to tones, broadband noises and complex sounds with sharp line spectral components, for example transformer hum or fan noise.

NOTE 3 It has been shown (see Reference [15]) that this method provides a good match to the contours of equal loudness level as defined in ISO 226:2003 and the reference threshold of hearing as defined in ISO 389-7:2005.

The evaluation of the harmful effect of sound events is outside the scope of this document.

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.

IEC 61260-1:2014, *Electroacoustics — Octave-band and fractional-octave-band filters — Part 1: Specifications*

IEC 61672-1:2013, *Electroacoustics — Sound level meters — Part 1: Specifications*

IEC/TS 60318-7, *Electroacoustics — Simulators of human head and ear — Part 7: Head and torso simulator for the measurement of hearing aids*

3 Terms and definitions

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

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

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

— IEC Electropedia: available at http://www.electropedia.org/

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

$$L_p = 10 \lg \frac{p^2}{p_0^2} \text{ dB}$$

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

Note 1 to entry: 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* (3.2) are applied, this should be indicated by appropriate subscripts, for example $L_{p,\text{AS}}$ 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 purpose of *loudness* (3.17) calculation using the current procedure.

Note 2 to entry: This definition is technically in accordance with ISO 80000-8:2007, 8.

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

Note 1 to entry: A frequency band is characterized by two values that define its position in the frequency spectrum, for instance its lower and upper cut-off frequencies.

Note 2 to entry: Frequency is expressed in Hz.

[SOURCE: IEC 60050-702:1992, 702-01-02]

3.3
filter
device or mathematical operation that, 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
lowest (f_l) or highest (f_h) frequency beyond which the response of the *filter* (3.3) to a sinusoidal signal does not exceed −3 dB relative to the maximum response measured between (f_l) and (f_h)

3.5
one-third-octave band
frequency band (3.2) with the centre frequency f_T and the width of one-third of an octave

Note 1 to entry: The subscript T instead of c is used to specify the centre frequency in the special case of a one-third-octave band.

Note 2 to entry: Width of one-third of an octave as specified in IEC 61260-1.

3.6
band-reject filter
filter (3.3) that rejects signal energy within a certain *frequency band* (3.2) and passes most of the signal energy outside of this frequency band

Note 1 to entry: A narrow band-reject filter is also called a notch filter.

3.7
band level
$L_{p\text{b}}$
sound pressure level (3.1) of sound contained within a restricted frequency band (b)

3.8
one-third-octave-band level
L_T
sound pressure level (3.1) of sound contained within a *frequency band* (3.2) with the width of one-third of an octave

3.9
sound spectrum
representation of the magnitudes (and sometimes of the phases) of the components of a complex sound as a function of frequency

3.10
spectrum density level
spectrum level
level of the limit, as the width of the *frequency band* (3.2) 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 to entry: The words "spectrum level" should be preceded by a descriptive modifier describing the measured quantity.

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

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

where p_b^2 is the time-mean-square sound pressure measured through a *filter* (3.3) 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* (3.1) observed through the filter, the above relation becomes

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

3.11
auditory filter
filter (3.3) within the human cochlea describing the frequency resolution of the auditory system, with characteristics that are usually estimated from the results of masking experiments

3.12
otologically normal person
person in a normal state of health who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise, exposure to potentially ototoxic drugs or familial hearing loss

[SOURCE: ISO 226:2003, 3.1]

3.13
equivalent rectangular bandwidth of the auditory filter for otologically normal persons
ERB_n
auditory filter (3.11) bandwidth determined by measuring tone detection thresholds in wideband noise passed through band-reject (notch) filters of various bandwidths

Note 1 to entry: The subscript n indicates that the value applies for persons with otologically normal hearing.

Note 2 to entry: The multi-letter abbreviated term presented in italics and with a subscript is used here instead of a symbol to maintain an established notation and to avoid confusion.

Note 3 to entry: Bandwidth is measured in Hertz (Hz).

3.14
equivalent rectangular bandwidth number scale
ERB_n-number scale
transformation of the frequency scale constructed so that an increase in frequency equal to one ERB_n leads to an increase of one unit on the ERB_n-number scale

Note 1 to entry: ERB_n is measured in Hertz (Hz).

Note 2 to entry: The unit of the ERB_n-number scale is the Cam. For example, the value of ERB_n for a centre frequency of 1 000 Hz is approximately 132 Hz, so an increase in frequency from 934 Hz to 1 066 Hz corresponds to a step of one Cam. The equation relating ERB_n-number to frequency is given in 7.4.

3.15
loudness level
sound pressure level (3.1) of a frontally incident, sinusoidal plane progressive wave, presented binaurally at a frequency of 1 000 Hz that is judged by otologically normal persons as being as loud as the given sound

Note 1 to entry: Loudness level is expressed in phons.

3.16
calculated loudness level
L_N
loudness level (3.15) calculated following the procedure of a predictive model

3.17
loudness
perceived magnitude of a sound, which depends on the acoustic properties of the sound and the specific listening conditions, as estimated by otologically normal persons

Note 1 to entry: Loudness is expressed in sones.

Note 2 to entry: Loudness depends primarily upon the *sound pressure level* (3.1) although it also depends upon the frequency, waveform, bandwidth, and duration of the sound.

Note 3 to entry: One sone is the loudness of a sound with a *loudness level* (3.15) of 40 phon.

Note 4 to entry: A sound that is twice as loud as another sound is characterized by doubling the number of sones.

3.18
calculated loudness
N
loudness (3.17) calculated following the procedure of a predictive model

3.19
excitation
E
output of an *auditory filter* (3.11) centred at a given frequency, specified in units that are linearly related to power

Note 1 to entry: 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* (3.1) of 0 dB presented in a free field with frontal incidence.

3.20
excitation level
L_E
ten times the logarithm to the base 10 of the ratio of the *excitation* (3.19) at the output of an *auditory filter* (3.11) centred at the frequency of interest to the reference excitation E_0

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

where the reference excitation, E_0, is the excitation produced by a 1 000 Hz tone with a *sound pressure level* (3.1) of 0 dB presented in a free field with frontal incidence

3.21
specific loudness
N '
calculated loudness (3.18) evoked over a *frequency band* (3.2) with a bandwidth of one ERB_n (3.13) centred on the frequency of interest

Note 1 to entry: Specific loudness is expressed in sones/Cam.

Note 2 to entry: The definition together with the stated unit are different from those in ISO 532-1.

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. 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. The source code provided in Annex C gives an example of the implementation of the method. Other implementations using different software are possible.

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

NOTE 2 Uncertainties are addressed in Clause 9.

5 Specifications of signals

5.1 General

The spectrum of the signal whose loudness is to be determined shall be specified at each ear. The spectrum can be specified exactly using the methods described in 5.2, 5.3 and 5.4 for the case of a complex tone, noise consisting of bands of pink or white noise of defined width, or sounds having a mixture of discrete sinusoidal components or bands of pink or white noise. The sound spectrum can be specified approximately using one-third-octave-band levels specified in the method described in 5.5. For this, one-third-octave bands according to IEC 61260-1:2014 should be used. The methods described in 5.2 to 5.4 may be of interest for synthetic signals or signals analysed by discrete Fourier transform techniques. The method described in 5.5 will be usually used for practical signals. 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.

5.2 Complex tone

This is a sound with a spectrum that 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.

5.3 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 filtered white noise (with a constant spectrum level within the passband) or filtered pink noise (with a spectrum level within the passband that 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 1 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.

EXAMPLE 2 A band of pink noise having lower and upper cut-off frequencies of 100 Hz and 115 Hz, respectively, with a spectrum level of 65 dB would be approximated by sinusoidal components with frequencies 101 Hz, 102 Hz, 103 Hz, 104 Hz .... 113 Hz, 114 Hz, 115 Hz, with the components having sound pressure levels increasing progressively from 64,7 dB at 101 Hz to 65,3 dB at 115 Hz.

NOTE The spacing of the components (10 Hz as in Example 1 or 1 Hz as in Example 2) is not a property of the input signal. The 1 Hz spacing is used to ensure sufficient accuracy in the computation of loudness when the bandwidth of the spectrum of the signal is narrow, i.e. less than 30 Hz. For signals with wider bandwidth, i.e. 30 Hz or greater, then a 10 Hz spacing will result in sufficient accuracy for the purpose of the computation of loudness.

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

For the case of mixtures of sounds, which each have a spectrum consisting of discrete sinusoidal components, 5.2 is applied for each discrete sinusoidal component that the mixed sound comprises. For the case of a mixture of bands of pink or white noise, the spectrum of each component of the mixture can be specified exactly using 5.3. This method is mainly applicable to synthetic signals, although it could be applicable to signals with strong line components in a noise background.

5.5 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 61260-1:2014 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 5.3, 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 $L_T - 10\lg(W/1\text{ Hz})$ dB + 10 dB.

NOTE The 1/3 octave filters, as defined by IEC 61260–1:2014, to analyse the spectrum of the input signal can have errors in their outputs of up to ± 0,7 dB. In a worst-case scenario, if all filter outputs were 0,7 dB higher than the correct values, this would lead to an error in the estimated loudness (in sones) of approximately +4 % for a typical broadband sound. If all filter outputs were 0,7 dB lower than the correct values, this would lead to an error in the estimated loudness of approximately −4 % for a typical broadband sound.

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.

6 Instrumentation

For the input signals used in 5.2 to 5.4 instrumentation is not necessarily required as these levels can be specified without the use of measurement instrumentation. If the input signals from these three methods are acquired with instrumentation, or if one-third-octave-band sound pressure levels as described in 5.5 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

