International Standard

ISO 16254

Second edition
2024-12

Acoustics — Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation — Engineering method

Acoustique — Mesurage du bruit émis par les véhicules routiers de catégories M et N à l'arrêt et en fonctionnement à basse vitesse — Méthode d'expertise

Reference number
ISO 16254:2024(en)

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Published in Switzerland

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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 document 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*, Subcommittee SC 1, *Noise,* in collaboration with ISO/TC 22, *Road vehicles*.

This second edition cancels and replaces the first edition (ISO 16254:2016), which has been technically revised.

The main changes are as follows:

— addition of multiple microphones at each measurement location;

— revised signal processing to improve correlation to human perception;

— further development of tonal loudness as an alternate method to identify frequencies and to assure frequencies so identified are audible to pedestrians.

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.

Introduction

The advent of road transport vehicles that rely, in whole or in part, on alternative drive trains (e.g. electromotive propulsion) is serving to reduce both air and noise pollution and their adverse impacts on citizens throughout the world. However, the environmental benefits achieved to date by these “hybrid or pure electric” road vehicles have resulted in the unintended consequence of removing a source of audible signal that is used by various groups of pedestrians (e.g. in particular, blind and low vision persons) to detect the approach, presence and/or departure of road vehicles.

Therefore, this document has been developed to provide a method to measure the sound emission of road vehicles at standstill and low speed operation, as well as to quantify the characteristics of any external sound-generation system installed for the purpose of conveying acoustic information about the approach, presence and/or departure of the vehicle to nearby pedestrians.

This document incorporates additional sensor locations and provisions to reduce the measurement variation of reported results and to introduce a metric for determining the frequency of tonal components that does not rely on prior knowledge of the sound signal. Tonal loudness calculates the audibility of the given signals considering how the sounds are perceived by people, providing an optional metric to assess detection and to identify frequency content.

This document was developed in cooperation with the Society of Automotive Engineers (SAE) Vehicle Sound for Pedestrians Subcommittee and the SAE Advanced Driver Assistance Committee.

Acoustics — Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation — Engineering method

1 Scope

This document is derived from ISO 362-1[2] and specifies an engineering method for measuring the sound emitted by M and N category road vehicles at standstill and low speed operating conditions. The specifications reproduce the level of sound which is generated by the principal vehicle sound sources consistent with stationary and low speed vehicle operating conditions relevant for pedestrian safety. The method is designed to meet the requirements of simplicity as far as they are consistent with reproducibility of results under the operating conditions of the vehicle.

The test method requires an acoustic environment which is only obtained in an extensive open space. Such conditions usually exist during the following:

— measurements of vehicles for regulatory certification;

— measurements at the manufacturing stage;

— measurements at official testing stations.

The results obtained by this method give an objective measure of the sound emitted under the specified conditions of test. It is necessary to consider the fact that the subjective appraisal of the annoyance, perceptibility, and/or detectability of different motor vehicles or classes of motor vehicles due to their sound emission are not simply related to the indications of a sound measurement system. As annoyance, perceptibility and/or detectability are strongly related to personal human perception, physiological human condition, culture, and environmental conditions, there are large variations and therefore these terms are not useful as parameters to describe a specific vehicle condition.

Spot checks of vehicles chosen at random rarely occur in an ideal acoustic environment. If measurements are carried out on the road in an acoustic environment which does not fulfil the requirements stated in this document, the results obtained might deviate appreciably from the results obtained using the specified conditions.

In addition, this document provides an engineering method to measure the performance of external sound generation systems intended for the purpose of providing acoustic information to pedestrians on a vehicle's operating condition. This information is reported as objective criteria related to the external sound generation system's sound pressure level, frequency content, and changes in sound pressure level and frequency content as a function of vehicle speed.

This document adds a metric related to the human perception of tonal loudness, the psychoacoustic tonality. The psychoacoustic tonality can be used to estimate audible frequency shifts of the sounds by identifying the most audible component in each auditory frequency band (critical band), as well as to determine if the band(s) so identified meet audibility criteria.

Annex A and Annex C contains background information relevant in the development 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.

ISO 3745:2012, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for anechoic rooms and hemi-anechoic rooms*

ISO 10844, *Acoustics — Specification of test tracks for measuring sound emitted by road vehicles and their tyres*

ISO 26101-1, *Acoustics — Test methods for the qualification of the acoustic environment — Part 1: Qualification of free-field environments*

IEC 60942, *Electroacoustics — Sound calibrators*

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

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

IEC 61672-3, *Electroacoustics — Sound level meters — Part 3: Periodic tests*

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

ECMA-418-2, *Psychoacoustic metrics for ITT equipment: models based on human perception*

3 Terms and definitions

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

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

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

3.1
front reference plane
vertical plane tangent to the leading edge of the vehicle

3.2
rear reference plane
vertical plane tangent to the trailing edge of the vehicle

3.3
external sound generation system
system that provides an acoustic signal to the external environment of the vehicle for the purpose to provide information to pedestrians

3.4
component
external sound generation system (3.3) intended to emit sound information which can be tested separately from the vehicle

3.5
kerb mass
complete shipping mass of a vehicle fitted with all equipment necessary for normal operation plus the mass of the following elements for M1, N1 and M2 having a maximum authorized mass not exceeding 3 500 kg:

— lubricants, coolant (if needed), washer fluid;

— fuel (tank filled to at least 90 % of the capacity specified by the manufacturer);

— other equipment if included as basic parts for the vehicle, such as spare wheel(s), wheel chocks, fire extinguisher(s), spare parts and tool kit

Note 1 to entry: The definition of kerb mass can vary from country to country, but in this document, it refers to the definition contained in ISO 1176[4].

Note 2 to entry: M and N vehicle categories are defined in SAE J2889-1[8] and ISO 362-1[2].

3.6
mass in running order
nominal mass of an N2, N3 or M2 vehicle having a maximum authorized mass greater than 3 500 kg, or an M3 vehicle as determined by the following conditions:

a) the mass in running order is taken as the sum of the unladen vehicle mass and the driver's mass;

b) in the case of category M2 and M3 vehicles that include seating positions for additional crewmembers, their mass is incorporated in the same way and equal to that of the driver

Note 1 to entry: The driver's mass is calculated in accordance with ISO 2416[5].

Note 2 to entry: Unladen vehicle mass is defined in ISO 362-1[2].

3.7
full vehicle operation
operation of a vehicle with all systems and *components* (3.4) operating according to the manufacturer's specification for normal road use

3.8
simulated vehicle operation
operation of a vehicle with some systems or *components* (3.4) disabled to reduce noise interference during testing which may include external signals applied to the vehicle to simulate actual in-use signals

3.9
lowest frequency of interest
frequency below which there is no signal content relevant to the measurement of sound emission for the vehicle under test

3.10
critical band
filter within the human cochlea describing the frequency resolution of the auditory system with characteristics that are usually estimated from the results of masking experiments

3.11
tonality
characteristic of sound containing a single-frequency component or narrow-band components that emerge audibly from the total sound

3.12
specific tonality
tonality (3.11) in a single *critical band* (3.10)

4 Symbols and abbreviated terms

Table 1 — Symbols and abbreviated terms and the paragraph in which they are first used

Symbol	Unit	Subclause	Explanation
AA′	—	6.1.2	Line perpendicular to vehicle travel which indicates the beginning of the zone to record sound pressure level during test.
BB′	—	6.1.2	Line perpendicular to vehicle travel which indicates end of the zone to record sound pressure level during test.
CC′	—	6.1.2	Centreline of vehicle travel.
δ_1 - δ_7	dB	D.2	Input quantities to allow for any uncertainty in A-weighted sound pressure level.
δ_8 - δ_{14}	dB	D.3	Input quantities to allow for any uncertainty in one-third octave band A-weighted sound pressure level.

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
δ_{15} - δ_{21}	Hz	D.4	Input quantities to allow for any uncertainty in frequency measurement used for the determination of frequency shift.
$f_{i,\text{speed}}$	Hz	7.2.5.3.1	Single frequency component of external sound generation system at a given vehicle speed.
$f_{i,\text{ref}}$	Hz	7.2.5.3.1	Single frequency component of external sound generation system at reference vehicle speed.
$\Delta f_{percent}$	%	7.2.5.3.1	Frequency shift expressed in percent of a reference frequency.
Δf	Hz	7.2.3	Frequency resolution of narrowband analysis used to measure frequency spectra for the purpose of determining frequency shift information.
F_s	Hz	5.1.1	Sampling frequency used by digital signal processing system
i	—	6.3.2	Index for left or right microphone locations
j	—	7.1.6.1	Index for single test run within stopped or slow speed cruise test conditions
$L_{\text{st,fwd}}$	dB	7.1.7.2	Vehicle A-weighted sound pressure level in stationary forward condition.
$L_{\text{st,rev}}$	dB	7.1.8	Vehicle A-weighted sound pressure level in stationary reverse condition.
$L_{\text{crs,10}}$	dB	7.1.9	Cruise vehicle A-weighted sound pressure level at a vehicle speed of 10 km/h.
$L_{\text{test},j}$	dB	7.1.6.1	A-weighted sound pressure level result of j^{th} test run.
L_{bgn}	dB	6.3.1	Background noise A-weighted sound pressure level.
$L_{\text{bgn,L},i}$	dB	6.3.1	Background noise A-weighted sound pressure level, left side of vehicle, i^{th} microphone location.
$L_{\text{bgn,R},i}$	dB	6.3.1	Background noise A-weighted sound pressure level, right side of vehicle, i^{th} microphone location.
$L_{\text{bgn\_BAND}}$	dB	6.3.2	Background noise one-third octave A-weighted sound pressure level. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{bgn\_BAND,L},i}$	dB	6.3.2	Background noise one-third octave A-weighted sound pressure level, left side of vehicle, i^{th} microphone location. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{bgn\_BAND,R},i}$	dB	6.3.2	Background noise one-third octave A-weighted sound pressure level, right side of vehicle, i^{th} microphone location. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
L_x	dB	D.2	A-weighted sound pressure level for any stationary or cruise condition for use in assessment of measurement uncertainty.
$L_{x,\text{band}}$	dB	D.3	A-weighted sound pressure level per one-third octave band for any stationary or cruise condition for use in assessment of measurement uncertainty.
$L_{x,\text{meas}}$	dB	D.2	A-weighted sound pressure level for any stationary or cruise condition for use in assessment of measurement uncertainty.
$\text{MicLeft}_{\_i}$	—	7.1.1	ith Microphone situated at left side of vehicle
$\text{MicRight}_{\_i}$	—	7.1.1	ith Microphone situated at right side of vehicle
MicLeft_1	—	7.1.1	Microphone situated at left side of vehicle, with height of 0,8 m above ground
MicLeft_2	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,0 m above ground
MicLeft_3	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,2 m above ground

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
MicLeft_4	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,4 m above ground
MicLeft_5	—	7.1.1	Microphone situated at left side of vehicle, with height of 1,6 m above ground
MicRight_1	—	7.1.1	Microphone situated at right side of vehicle, with height of 0,8 m above ground
MicRight_2	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,0 m above ground
MicRight_3	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,2 m above ground
MicRight_4	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,4 m above ground
MicRight_5	—	7.1.1	Microphone situated at right side of vehicle, with height of 1,6 m above ground
$L_{\text{MicLeft\_}i\text{\_BAND},j}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicLeft__i location for the *j*th measurement run. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicRight\_}i\text{\_BAND},j}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicRight__i location for the *j*th measurement run
$L_{\text{MicLeft\_BAND},j}$	dB	7.1.6.4.2	Maximum one-third octave results for each band over the entire measurement interval for all MicLeft__i locations for the *j*th measurement run. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicRight\_BAND},j}$	dB	7.1.6.4.2	Maximum one-third octave results for each band over the entire measurement interval for all MicRight__i locations for the *j*th measurement run. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicLeft\_i\_BAND}}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each MicLeft__i location.
$L_{\text{MicRight\_i\_BAND}}$	dB	7.1.6.2	Maximum one-third octave results for each band over the entire measurement interval for each $\text{MicRight\_}_\text{i}$ location. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{\text{MicLeft\_}i\text{\_OA},j}$	dB	7.1.6.3.2	Maximum overall sound pressure level result over the entire measurement interval for each MicLeft__i location for the *j*th measurement run
$L_{\text{MicRight\_}i\text{\_OA},j}$	dB	7.1.6.3.2	Maximum overall sound pressure level result over the entire measurement interval for each MicRight__i location for the *j*th measurement run
$L_{\text{MicLeft\_OA},j}$	dB	7.1.6.2	Maximum overall sound pressure level result over the entire measurement interval for all MicLeft__i locations for the *j*th measurement run
$L_{\text{MicRight\_OA},j}$	dB	7.1.6.2	Maximum overall sound pressure level result over the entire measurement interval for all MicRight__i locations for the *j*th measurement run
$L_{\text{MicLeft\_i\_OA}}$	dB	7.1.5.3.1	Maximum overall sound pressure level result over the entire measurement interval for each MicLeft__i locations averaged over all *j* runs
$L_{\text{MicRight\_i\_OA}}$	dB	7.1.5.3.1	Maximum overall sound pressure level result over the entire measurement interval for each MicRight__i locations averaged over all *j* runs

Table 1 *(continued)*

Symbol	Unit	Subclause	Explanation
$L_{MicLeftBAND}$	dB	7.1.7.3	Maximum one-third octave sound pressure level over the entire measurement interval for all MicLeft$_i$ locations averaged over all *j* measurement runs. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{MicRightBAND}$	dB	7.1.7.3	Maximum one-third octave sound pressure level over the entire measurement interval for all MicRight$_i$ locations averaged over all *j* measurement runs. This result is reported as a frequency spectrum between 160 Hz and 5 000 Hz,
$L_{MicLeftOA}$	dB	7.1.7.2	Maximum overall sound pressure level result over the entire measurement interval for all MicLeft$_i$ locations
$L_{MicRightOA}$	dB	7.1.7.2	Maximum overall sound pressure level result over the entire measurement interval for all MicRight$_i$ locations
N	—	7.2.3	Block size of digital sample used for discrete Fourier transform or autopower spectrum analysis.
PP′	—	6.1.2	Line perpendicular to vehicle travel which indicates location of microphones.
v_{ref}	km/h	7.2.5.2	Reference vehicle velocity used for calculating frequency shift percentage.
v_{test}	km/h	7.2.5.3.1	Target vehicle test velocity.
$f_{band,speed}$	Hz	J.4.6	Main frequency of tonal component in a critical band belonging to a certain frequency shift and speed
$f_{band,speed,filtered}$	Hz	J.4.6	Valid frequencies from the tonality analysis over time in a critical band belonging to a certain frequency shift and speed
T'_{bgn}	tu_{HMS}	8	Specific tonality of the background noise in a critical band
$T'_{speed,shift}$	tu_{HMS}	J.4.4	Specific tonality in critical band belonging to a certain frequency shift and speed
z	$Bark_{HMS}$	J.4.6	Critical-band rate
$Z_{speed,shift}$	$Bark_{HMS}$	J.4.4	Critical-band rate corresponding to a certain frequency shift and speed

5 Instrumentation

5.1 Instruments for acoustic measurement

5.1.1 General

The apparatus used for measuring the sound pressure level shall be a sound level meter or equivalent measurement system meeting the requirements of class 1 instruments (inclusive of the recommended windscreen, if used). These requirements are described in IEC 61672–1.

The entire measurement system shall be checked by means of a sound calibrator that fulfils the requirements of class 1 sound calibrators in accordance with IEC 60942.

Measurements shall be carried out using the time weighting “F” of the acoustic measurement instrument and the “A” frequency weighting also described in IEC 61672–1. When using a system that includes a periodic monitoring of the A-weighted sound pressure level, a reading should be made at a time interval not greater than 30 ms.

When no general statement or conclusion can be made about conformance of the sound level meter model to the full specifications of IEC 61672-1, the apparatus used for measuring the sound pressure level shall be a sound level meter or equivalent measurement system meeting the conformity requirements of Class 1 instruments as described in IEC 61672-3.

NOTE The tests of IEC 61672-3 cover only a limited subset of the specifications in IEC 61672-1 for which the scope is large (temperature range, frequency requirements up to 20 kHz, etc.). It is economically not feasible to verify the whole IEC 61672-1 requirements on each item of a computerized data acquisition systems model. Apparently, until today, no computerized data acquisition system available complies with the full specifications of IEC 61672-1. It is beyond the possibilities of the users of these systems to prove conformity of the instrumentation required by the test code.

When measurements are carried out for one-third octaves, the instrumentation shall meet all requirements of IEC 61260–1, class 1.

When measurements are carried out for frequency shift, the digital sound recording system shall have at least a 16 bit quantization. The sampling rate, F_S, and the dynamic range shall be appropriate to the signal of interest.

5.1.2 Daily verification and adjustment

At the beginning of every measurement session, the entire acoustic measurement system shall be checked and adjusted, if possible, by means of a sound calibrator as described in 5.1.1. At the end of every measurement session, the entire acoustic measurement system shall be checked by means of a sound calibrator as described in 5.1.1.

Without any further adjustment, the difference between the readings at the beginning and the end shall be less than or equal to 0,5 dB. If this value is exceeded, the results of the measurements obtained after the previous satisfactory check shall be discarded.

NOTE 1 A bi-yearly IEC 61672-3 calibration permits the use of a daily sensitivity check and adjustment.

NOTE 2 The purpose of the check at the beginning of the measurement session is twofold:

a) To ensure the measurement system is in good working order, and

b) To adjust the level consistent with the environmental conditions of the day.

The purpose of the check at the end of the measurement session is also twofold:

— To ensure the measurement system remains in good working order, and

— To verify the adjusted level remains within expected tolerances for a repeatable and reproduceable measurement.

5.1.3 Conformity with requirements

Conformity of the sound calibrator with the requirements of IEC 60942 shall be verified once a year. Conformity of the instrumentation system with the requirements of IEC 61672–1 shall be verified at least every 2 years using IEC 61672-3. All conformity testing shall be conducted by a laboratory, which is authorized to perform calibrations traceable to the appropriate standards.

NOTE The tests of IEC 61672-3 cover only a limited subset of the specifications in IEC 61672-1 for which the scope is large (temperature range, frequency requirements up to 20 kHz, etc.). It is not feasible to verify the whole IEC 61672-1 requirements on each item of a computerized data acquisition system. Computerized data acquisition system available comply with the necessary specifications of IEC 61672-1 and testing specifications of IEC 61672-3 as required for this document.

5.2 Instrumentation for speed measurements

The road speed of the vehicle shall be measured with instruments meeting specification limits of at least ±0,5 km/h when using continuous measuring devices.

NOTE A continuous measuring device will determine all required speed information with one device.

5.3 Meteorological instrumentation

The meteorological instrumentation used to monitor the environmental conditions during the test shall meet the specifications of the following:

— ±1 °C or less for a temperature measuring device;

— ±1,0 m/s for a wind speed-measuring device;

— ±5 hPa for a barometric pressure measuring device;

— ±5 % for a relative humidity measuring device.

6 Acoustic environment, meteorological conditions, and background noise

6.1 Test site

6.1.1 General

The specifications for the test site provide the necessary acoustic environment to carry out the full vehicle or component tests documented in this document. Outdoor and indoor test environments that meet the specifications of this document provide equivalent acoustic environments and produce results that are equally valid.

6.1.2 Outdoor testing

The test site shall be substantially level. The test track construction and surface shall meet the requirements of ISO 10844. Figure 1 gives information on test site dimensions.

Within a radius of 50 m around the centre of the track, the space shall be free of large reflecting objects, such as fences, rocks, bridges or buildings. The test track and the surface of the site shall be dry and free from absorbing materials, such as powdery snow or loose debris.

In the vicinity of the microphones, there shall be no obstacle that can influence the acoustic field and no person shall remain between the microphone and the noise source. The meter observer shall be positioned so as not to influence the meter reading.

NOTE 1 Buildings outside the 50 m radius might have significant influence if their reflection focuses on the test track.

The term “substantially level” is intended to convey that the test site shall not have slopes or discontinuities that would render invalid the assumption the site provided free-field acoustic propagation. This is not to limit slopes on the test site necessary for water management, drainage, etc. Engineering judgement is expected to be applied to determine the effect on the site of any obstacle. The test track itself is subject to the requirements specified.

For the purpose of this document, test track constructions and surfaces according to ISO 10844 will also provide satisfactory results for vehicle speeds of up to 20 km/h.

NOTE 2 Government regulations can require specific surface requirements.