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TECHNICAL REPORT

Electroacoustics – Measurement microphones – Part 10: Absolute pressure calibration of microphones at low frequencies using calculable pistonphones

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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ELECTROACOUSTICS – MEASUREMENT MICROPHONES –

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FOREWORD

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IEC TR 61094-10 has been prepared by IEC technical committee 29: Electroacoustics. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
29/1113/DTR	29/1124/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61094 series, published under the general title *Electroacoustics – Measurement microphones*, can be found on the IEC website.

Future documents in this series will carry the new general title as cited above. Titles of existing documents in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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ELECTROACOUSTICS – MEASUREMENT MICROPHONES –

Part 10: Absolute pressure calibration of microphones at low frequencies using calculable pistonphones

1 Scope

This part of IEC 61094

- is applicable to laboratory standard microphones meeting the requirements of IEC 61094-1 and other types of measurement microphones,
- describes one possible absolute method for determining the complex pressure sensitivity, based on a device capable of generating a known sound pressure, especially at low frequencies, and
- provides a reproducible and accurate basis for the measurement of sound pressure at low frequencies.

All quantities are expressed in SI units.

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 61094-1:2000, *Measurement microphones – Part 1: Specifications for laboratory standard microphones*

IEC 61094-2:2009, *Electroacoustics – Measurement microphones – Part 2: Primary method for pressure calibration of laboratory standard microphones by the reciprocity technique*
IEC 61094-2:2009/AMD1:2022

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61094-1 and IEC 61094-2 and the following apply.

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

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
pistonphone
device in which sound pressure is generated in a fixed sealed volume of air, by the motion of one or more pistons creating a well-defined volume velocity

3.2
calculable pistonphone
pistonphone where the generated sound pressure can be calculated from physical principles

4 Reference environmental conditions

The reference environmental conditions are the following:

- temperature 23,0 °C;
- static pressure 101,325 kPa;
- relative humidity 50 %.

5 Principles of absolute pressure calibration of microphones using a calculable pistonphone

5.1 General principle

The microphone to be calibrated is exposed to a known or calculable sound pressure produced within the sealed cavity (or coupler) of a pistonphone, without the need for a prior measurement with another microphone. The dimensions of the cavity are constrained to allow the assumption to be made that the sound pressure is uniformly distributed within.

A sound generator consisting of a sealed cavity (or coupler) of known volume that is driven by a piston or similar mechanism capable of producing a known volume velocity (e.g. an electrodynamic loudspeaker) has the potential to generate a known sound pressure. If the piston is assumed to be rigid and of known frontal area, laser interferometry or other displacement measurement techniques can be used to determine the piston displacement and thereby derive the volume displacement.

The pressure sensitivity M_p of the microphone is then determined directly from its open-circuit output voltage $U_\text{m,0}$ and the applied sound pressure p_m.

$$M_\text{p} = \frac{U_\text{m,0}}{p_\text{m}} \quad (1)$$

Alternatively, a microphone system comprising of a microphone, a preamplifier and optionally and amplifier stage, can be calibrated by the same principle, except that the system output voltage replaces the open-circuit output voltage of the microphone in Formula (1).

5.2 Basic expressions

The generated sound pressure p_m that is applied to the diaphragm of the microphone is calculated from an evaluation of the acoustic transfer impedance Z_T of the cavity and a measurement of the piston displacement δx.

The acoustic transfer impedance is the constant of proportionality between the sound pressure at the microphone diaphragm and the volume velocity driving the cavity. In the case of a sinusoidally driven rigid piston, the volume velocity is given by the product of the piston area S_p, the piston displacement and a factor $j\omega$, where ω is the angular frequency:

$$p_\text{m} = j\omega S_\text{p} \delta x \cdot Z_\text{T} \quad (2)$$

If the piston is not rigid, calculation of the volume velocity requires the surface integral of displacement to be determined, for example with scanning interferometry.

The acoustic transfer impedance can be calculated when the cavity has a simple geometry enabling its volume, V to be determined. When the characteristic cavity dimensions are significantly smaller than the acoustic wavelength, λ (typically when $\sqrt[3]{V} \ll \lambda$), then the sound pressure can be assumed to be uniformly distributed within the cavity. Then, assuming adiabatic compression and expansion of the gas and that the cavity is perfectly sealed, the acoustic impedance of the cavity Z_c is $\kappa P_s/(j\omega V)$, where κ is the ratio of specific heats for air and P_s is the static pressure inside the cavity. From the equivalent circuit in Figure 1, Z_T is then given by:

$$\frac{1}{Z_T} = \frac{1}{Z_C} + \frac{1}{Z_m} = j\omega\left(\frac{V}{\kappa P_S} + \frac{V_{e,m}}{\kappa_r P_{S,r}}\right) \tag{3}$$

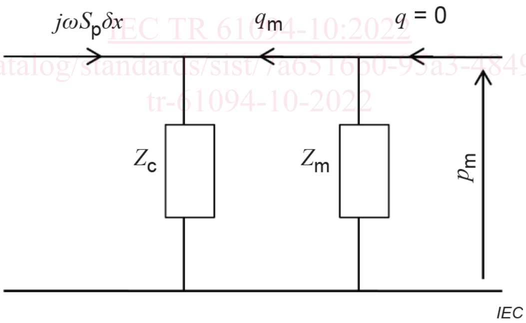
where

$V_{e,m}$ is the equivalent volume of microphone to be calibrated;

κ and κ_r are the ratio of the specific heats at measurement conditions and at reference conditions respectively;

$P_{s,r}$ is the reference static pressure.

Values for κ and κ_r in humid air can be determined from formulas given in IEC 61094-2:2009, Annex F.



Key

ω angular frequency

S_p piston surface area

δx piston displacement

q and q_m volume velocities

Z_c and Z_m acoustic impedances of the cavity and microphone respectively

p_m sound pressure acting on the microphone

Figure 1 – Equivalent circuit for evaluating the sound pressure over the exposed surface of the diaphragm of the microphone

At higher frequencies, where the wavelength can no longer be considered sufficiently large compared to the cavity dimensions, the evaluation of Z_T generally becomes more complicated and requires the specific geometry of the cavity to be accounted for. The onset of such behaviour is generally considered to be the upper frequency limit for the operation of the pistonphone within the scope of this document.

5.3 Heat conduction correction

The evaluation of Z_T in Formula (3) assumes adiabatic conditions in the cavity. However, in practice, the influence of heat conduction at the walls of the cavity causes increasing departure from purely adiabatic conditions as the frequency is reduced, especially for small cavities.

At frequencies where the sound pressure can be considered to be uniformly distributed within the cavity and under the assumption that the walls remain at a constant temperature, the influence of the heat conduction losses can be calculated and expressed in terms of a complex correction factor ΔH to the geometrical volume V in Formula (3). The formulation for the influence of the heat conduction losses and expressions for a correction factor ΔH, when the cavity shape is a perfect right circular cylinder, are given in IEC 61094-2:2009 and IEC 61094-2:2009/AMD1:2022.

5.4 Operating frequency range

The upper frequency limit of operation is likely to be determined by the onset of sound pressure non-uniformity. This is normally assessed by modelling the sound field within the pistonphone cavity. The model can be used to determine a correction to account for the non-uniform sound pressure distribution for the specific cavity geometry, but a point will be reached where the magnitude of this correction, and therefore the associated uncertainty, becomes unacceptable. Each cavity geometry will require individual treatment, but an upper frequency limit of around 200 Hz is typically possible when characteristic dimensions are no greater than 60 mm.

It is also possible that the volume velocity source determines the upper frequency of operation. As the frequency increases, a greater amount of force is necessary to drive the piston. The frequency at which this capability is exceeded could also set a practical operational limit.

The low frequency limit can be governed by the uncertainty associated with the heat conduction correction, or by pressure leakage from the cavity. The limits that can be achieved are strongly related to the specific design of the pistonphone but there are reports of devices operating at frequencies of 0,01 Hz [1] [2][1].

6 General characteristics

6.1 The pistonphone

A convenient pistonphone cavity geometry is a right circular cylinder as this allow direct application of the heat conduction model presented in IEC 61094-2:2009 and IEC 61094-2:2009/AMD1:2022.

The estimation of the sound pressure generated within the pistonphone is strongly dependent on the internal volume. When the cavity and the volume velocity source are made from a hard, dimensionally stable, non-porous materials, the influences of time, temperature, humidity and other physical parameters can be expected to have no adverse effect on performance.

Since the pistonphone is typically activated by a vibrating mechanism, care can be needed to ensure the microphone under test is not subjected to extraneous vibration signals capable of contributing to the measured output voltage.

There are no constraints on the size of the cavity, but note that the generated sound pressure is proportional to the ratio of the induced volume velocity to the overall volume of the cavity. Therefore, a larger cavity requires a more powerful volume velocity source.

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[1] Numbers in square brackets refer to the Bibliography.